EUFITMOS diagnosis report:

Adolescents' physical fitness: existing field-based tests, trends and the contribution of physical education

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EUROPEAN FITNESS MONITORING SYSTEM (EUFITMOS) ERASMUS+ SPORT PROJECT

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Adolescents' physical fitness: existing field-based tests, trends and the contribution of physical pducation

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Introduction

Physical fitness (PF) is a multi-component construct and a health biomarker (Bouchard et al., 2012; Ortega, Ruiz, et al., 2008). Assessing PF allows monitoring the biological and physiological adaptations achieved through natural development or training (Schutte et al., 2017). Health-related PF components are body composition measures (i.e. body mass index [BMI], waist circumference), cardiorespiratory fitness (CRF), muscular fitness (MF), speed, agility, balance, and coordination (Ortega et al., 2013; Tayo et al., 2020). These components have been consistently associated with indicators of cardiovascular health, metabolic health, bone health, and mental health (Ortega, Ruiz, et al., 2008).

For the assessment of the impact of genetic and environmental factors on health-related PF components and consequently on health indicators (Ortega, Artero, et al., 2008), valid, reliable and feasible PF test batteries are essential. Of special interest is how PF and the relationships with these factors change from childhood to adulthood.

In this phase, the school is an important institution for promoting physical activity (PA) and health among students. Especially in physical education classes, students engage in physical activities that have an impact on their PF level (Bocarro et al., 2012).

In the following, we summarise and describe 1) the existing fitness test batteries for children and adolescents applicable in the school setting 2) the international trends of adolescents performance in PF tests, and 3) the contribution of physical education classes for improving fitness, mainly CRF in children and adolescents.

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Field-based health-related physical fitness tests

Twenty-four different PF batteries from European, American, Asian, and Oceanian countries were identified (Marques, et al., 2021). This knowledge facilitates selecting standardised and validated PF tests and batteries, adjusting for the school setting, and considering different PF components. Simultaneously, this allows us to compare adolescents' PF levels from different geographic locations (See Appendix 1).

PF is associated with numerous health indicators among school-aged children, thus assessing PF has been suggested to be a reliable construct to monitor health in youth (Ortega, Ruiz, et al., 2008). Furthermore, PF batteries are considered a valid, simple, precise, and low-cost health monitoring tool (Pate et al., 2012). Given that, in several countries (e.g. Australia, Bahrain, Brazil, Canada, Czech Republic, China, France, Italy, Japan, Portugal, New Zealand, Russia, Singapore, Slovenia, Spain, and the USA), the military, sport, health, and education sectors have been implementing and using PF batteries.

PF is a multi-component construct. Using only one or two tests to examine PF is a misconception (Garcia-Hermoso et al., 2019; Ortega, Ruiz, et al., 2008). Hence, comprehensive PF batteries that assess each PF component are essential. These batteries facilitate creating a broad picture of PF and allow us to monitor complementing health indicators. In this review, body composition, CRF, and MF were identified as the components of PF frequently assessed in PF batteries.

Assessing body composition is usually the result of different anthropometric measures and their relation, such as height, weight, or waist circumference, and methodologies to analyse the percentage of body fat, muscle mass, and hydration (Pate et al., 2012). The measures of body composition used in PF batteries identified in this review were BMI, waist circumference, percentage of body fat (skinfolds), height to waist ratio, waist to hip ratio, wingspan, and bioelectrical impedance analysis. Requiring only height and weight, the BMI is a non-invasive, inexpensive, practical, and largely applicable anthropometric indicator of obesity (de Onis & Lobstein, 2010; Grossman et al., 2017). However, BMI does not differentiate fat mass from lean mass and is thus an insufficient indicator of body fat or abdominal adiposity (Ross et al., 2020). International experts have suggested measuring waist circumference to avoid misclassifications, which is a better indicator of central adiposity (Bovet et al., 2020; Ross et al., 2020). Precise measures of body composition, namely the percentage of body fat, were also present in some batteries, assessed by skinfolds or bioelectrical impedance analysis. Skinfolds allow calculating the percentage of fat mass and fat-free mass through specific equations. It is a low-cost methodology, but specific and intensive training must minimise potential measurement errors (Moreno et al., 2003). Bioelectrical impedance analysis is more precise and allows examining the percentage of fat mass, muscle mass or hydration status. However, it requires specific equipment, individual calibration and is more difficult to operationalise (Dehghan & Merchant, 2008).

The CRF is the most studied component of PF among school-aged children (Falk et al., 2018). Higher levels of CRF are associated with a lower risk of several health outcomes, namely obesity, cardiovascular diseases, and mental health (Ortega, Ruiz, et al., 2008). The importance of assessing CRF was also reflected in a large number of tests observed. Among these tests, the Progressive Aerobic Cardiovascular Endurance Run (PACER) and the 1-mile run/walk seemed to be present in most PF batteries. Both the PACER and 1-mile run/walk are widely validated and reliable for assessing the CRF in young populations (Castro-Piñero et al., 2009; Ortega, Artero, et al., 2008). From these tests, maximum aerobic capacity can be estimated. From all equations to estimate maximum aerobic capacity through these field-based PF tests, the equations proposed by Cureton et al. (Cureton et al., 1995) for the 1-mile run/walk test and Barnet et al. (Barnett et al., 1993) for the PACER had the strongest evidence of validity with the Léger equation (Barnett et al., 1993; Batista et al., 2017; Cureton et al., 1995; Léger et al., 1988). However, recently some issues have been raised regarding the estimation of maximum aerobic capacity considering that a multitude of factors (e.g., sex, adiposity) influence the results and emphasising that estimations should be carefully interpreted to avoid misconceptions (Armstrong & Welsman, 2019a, 2019b; Welsman & Armstrong, 2019). In addition, using the test results in the number of laps, stages or time may provide a clearer picture of the individual's CRF.

MF was also assessed in every identified PF battery. However, different components of MF (i.e. upper body strength, middle-body strength, lower body strength, agility, speed, and flexibility) were selected in each battery. Similar to CRF, MF is also associated with several health outcomes in youth (Garcia-Hermoso et al., 2019). A total of 52 different tests to assess the several components of MF were identified. Upper body strength was usually assessed by handgrip strength, push-ups, or bent arm hang test, while for lower body strength the standing broad jump and the vertical jump and for middle-body strength curl-ups and sit-ups were the most common tests. Most of these tests require minimum equipment and are applicable within a school or class setting. Agility, speed, and flexibility were present in fewer PF batteries than the other components of MF. This might be due to the fact that more evidence can be obtained observing the associations of lower, upper, and middle body strength with health indicators (Smith et al., 2014).

A total of 24 PF batteries were identified in this systematic review, and within them, 81 different PF tests for body composition, CRF, and MF. A previous systematic review focused on PF tests indicated that the PACER (or 20-meter shuttle run), the handgrip strength and standing broad jump tests, the 4×10m shuttle run test, weight, BMI, skinfolds, circumferences, and percentage of body fat estimated from skinfold thickness were the most reliable field-based PF tests for school-aged children and adolescents (Artero et al., 2011). In this review, the previous tests are among the most used in the identified PF batteries. Notwithstanding, when selecting a measurement protocol of body composition, CRF or MF to perform factors such as staff training, equipment cost, and time should be considered, as they heavily influence data collection, validity, and feasibility. In addition, to avoid data contamination and misinterpretations, all protocols should be clear and performed by trained personal, such as physical education teachers and other specialists (Pate et al., 2012). Despite being beyond the scope of this publication, it is important to acknowledge that physical education, sport, and health professionals should have a pedagogical approach in the application of PF batteries. The application of the PF batteries must be aligned with the promotion of meaningful, relevant, and positive experiences for children and adolescents (O'Brien, 2019).

Trends in physical fitness among school-aged children and adolescents

Concerning their literature review, Masanovic et al. (2020) observed a declining trend in strength, flexibility, agility, and speed (Appendix 2).

Most studies noted a declining trend regarding strength (arm and shoulder belt strength, lower limb strength, abdomen strength). Given the changing lifestyle of children and adolescents, physical inactivity, and increasing screen-time in the previous three decades, these results are not surprising. However, few studies contradict this trend and report an increase in the strength of children and adolescents (Huotari et al., 2010; Costa et al. 2017; Colley et al., 2019). It should be emphasised that in these experimental studies, additional exercise programs were conducted. In several studies, the handgrip strength test shows a growth trend in strength for girls (Dos Santos et al., 2014; Karpowicz et al., 2015; Colley et al., 2019). These results are in line with previous research. Absolute strength is proportional to the size of the cross-sectional muscle area (Singer & Breidahl, 1987) and body height, which increased over the last 40 years (NCD Risk Factor Collaboration, 2016; 2017).

In fact, most studies point to a trend of declining levels of CRF. A small number of cohorts in certain studies show no decline in CRF levels or even a growth trend. However, these are cohorts for which intervention programs mirror the longitudinal effects (Karpowicz et al., 2015; Colley et al., 2019) or studies covering insufficient periods (Moliner-Urdiales et al., 2010), or studies with non-representative populations (Andersen et al., 2010; Ao et al., 2018).

Notably, research conducted in Europe has recorded a trend of declining levels of flexibility. In other parts of the world, growth trends have been reported. For example, in Canada (Colley et al., 2019), additional exercise programs have been conducted. However, the growing trend in New Zealand (Albon et al., 2010) and Mozambique (Dos Santos et al., 2014) have not yet been explained.

Given the diversity of agility trends in the available studies, it is impossible to discuss a specific direction of movement for this motor ability in children and adolescents. Furthermore, the speed trends are challenging to interpret because the results are inconsistent. In particular, the three Chinese studies are contradictory. The increasing speed in Portugal (Costa et al., 2017) probably results from the government's policy on additional exercise. However, it is known that speed is highly genetically determined.

Generally, the decline of PF in children and adolescents around the world is caused by various factors. Several studies showed that weight gain is related to PF (Huotari et al., 2009; Johansson et al., 2020; Karpowicz et al., 2015). As body weight increased, so did BMI, which influenced this trend in China (Bi et al. 2020), Sweden (Westerstahl et al., 2003), and New Zealand (Albon et al., 2010). In addition, the increase in the thickness of the skin folds caused a decline in PF in Belgium (Matton et al., 2007). Two Chinese studies showed that the decline in PF was caused by changing lifestyles, characterised by higher media and fast-food consumption (Ao et al., 2018; Dong et al., 2019). Morales-Demori et al. (2016) linked the trend of declining CRF to a sedentary lifestyle, and Venckunas et al. (2016) with additional risk factors of smoking, alcohol consumption, non-active lifestyle, and long-term television viewing.

Studies from Finland (Huotari et al. 2010), Canada (Colley et al., 2019), and Portugal (Costa et al., 2017) show that changing policies, including the development and implementation of health-enhancing programs, can reduce the negative impact of a unhealthy lifestyle.

Contribution of physical education classes for improving fitness

Results from the contribution of PE classes to the promotion of CRF are mixed (Peralta et al., 2020) (Appendix 3). Several findings suggested that PE has a neutral effect on students' CRF, while others reinforce its importance. However, higher intensity PE classes consistently promoted students' CRF. Additionally, some other potentially relevant factors for promoting CRF in PE classes were identified, such as age and weight status. Review findings are discussed accordingly to these factors.

All studies were focused on school-aged children. However, due to the broad age range of the studies' populations, findings were organised into two age groups. Accordingly, we could identify differences between younger and older students. For older ages, PE seems to be less effective in promoting students' CRF (Andres, 2017; Beets & Pitetti, 2005; Camhi et al., 2011; Crowhurst et al., 1993; Cumming et al., 1969; Erfle & Gamble, 2015; Fairclough & Stratton, 2005, 2006; Koutedakis & Bouziotas, 2003; Mayorga-Vega et al., 2016; Mayorga-Vega & Viciana, 2015; Ramirez Lechuga et al., 2012; Reed et al., 2013; Strand & Reeder, 1993). For younger ages, almost all studies suggested that PE classes improved the students' CRF (Bendiksen et al., 2014; Jarani et al., 2016; Lucertini et al., 2013; Park et al., 2017; Reed et al., 2013). From a physiologic standpoint, CRF naturally increases as children grow up. However, this increase is relatively linear in boys until later adolescence, whereas in girls it plateaus around age 13 (Eisenmann et al., 2011; Malina et al., 2004). Furthermore, during the early stages of adolescence, participation in PA and the corresponding PF begin to show some decline (Duncan et al., 2007). Thus, increasing CRF related to body growth, occurring at younger ages and decreasing participation in PA in older students, might explain why improvements in CRF for a given period are frequently found in younger children and adolescents.

Aerobic exercise increases CRF by about 5-15% in youth (Malina et al., 2004; USDHHS, 2008). Additionally, improvements in CRF involving structural and functional adaptations and the oxidative capacity of skeletal muscle occur with regular MVPA (Malina et al., 2004). In this review, five studies reported that PE classes did not provide sufficient intensity for achieving an aerobic benefit (Crowhurst et al., 1993; Fairclough

& Stratton, 2005, 2006; Mayorga-Vega et al., 2016; Strand & Reeder, 1993) and did consistently promote students' CRF. In youth, sufficient PAs increase CRF, leading to improved maximal stroke volume, blood volume, and oxidative enzymes after exercise (Rowland, 1996). Consequently, time spent in MVPA during PE classes should be adequate to promote health. Also, findings suggesting that PE has a positive contribution in improving CRF were mainly related to the intensity level of the classes. The majority of studies examined in this review involved intervention programs built to increase PE class intensity without increasing the number of classes or curricular time dedicated to PE (Baquet et al., 2001; Baquet et al., 2002; Bendiksen et al., 2014; Mayorga-Vega et al., 2016; Mayorga-Vega & Viciana, 2015; Pelclová et al., 2008; Ramirez Lechuga et al., 2012; Rengasamy et al., 2014). Four of these studies reported that students participating in PE classes from the intervention programs increased their CRF levels, while students participating in regular PE classes decreased or maintained their CRF levels (Bendiksen et al., 2014; Mayorga-Vega et al., 2016; Mayorga-Vega & Viciana, 2015; Ramirez Lechuga et al., 2012). Considering the importance of CRF for health, the lack of intensity in PE classes is worrying (Fairclough & Stratton, 2006). From a public health perspective, PE can provide the tools to face the current youth obesity and sedentary epidemic (Sallis et al., 2012). However, to contribute to CRF and health, it is urgent to find strategies to increase the intensity of PE classes and efficiently use the allocated lesson time. These (strategies) might focus on avoiding long explanations, reducing sedentary time and promoting a motivating class atmosphere.

One study (Camhi et al., 2011), examining whether an eight-month PE program improved students' CRF when considering BMI categories, suggested that although normal-weight and overweight girls showed improvement in fitness and maintenance of these effects over the next two years, their obese peers did not. PA and BMI are inversely correlated in children and adolescents (Lohman et al., 2006). Also, studies of usual PA in children suggest that the overweight and obese are less active (Hills et al., 2007; Strong et al., 2005) and have poorer fundamental movement skills than their normal-weight counterparts (Okely et al., 2004). Mastering basic motor skills is strongly related to PA in children and adolescents. Therefore, it is crucial to foster PA since these skills are the foundation for advanced and sport-specific movement (Lubans et al., 2010).

High-quality PE, together with appropriate approaches to fitness as part of health education programs, has been shown to promote fitness and healthy lifestyles (Harris & Cale, 2019). On the contrary, when applied inappropriately and without context, fitness monitoring can have the opposite result (Cale & Harris, 2009). Therefore, mixed findings found in this systematic review may be due to the variations in PE quality.

Conclusion

Given the global decrease in CRF, a promising strategy to counteract negative health effects can be implementing high-quality PE classes. This includes, but is not limited to, a high activity intensity in PE, which evidentially contributes to promoting students' PF, i.e. CRF. To improve and maintain CRF levels in these ages, PE teachers should be keen on providing frequent and regular opportunities for students to engage in intensive PAs.

The advances in the field-based PF assessment on school settings increased the number of existing batteries. The variety of tests allows the choice of the battery that most fits the purpose and set of the assessment. Still, it limits the comparability of data from different studies and/or countries. This calls for a standardised PF test battery, facilitating comparisons between European children and adolescents. The results from the EUFITMOS project may inform the development and improvement of education and public health policies in the European Union.

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Appendix 1

Batteries (country); author (year)	Setting; age range	Physical fitness measurements / tests							
		Body composition	Cardiorespiratory fitness	Upper body strength	Middle-body strength	Lower body strength	Speed	Agility	Flexibility
AAHPER (USA) (Hunsicker et al., 1976; Klesius, 1968)	School and health; 5 to 18 years	None	Half-mile run/walk	Softball throw; bent arm hang; pull-ups	Sit-ups	Standing broad jump	50-yard dash	4x30ft shuttle run	None
AAUTB (USA) (Franks, 1899)	School and sports; 6 to 17 years	None	Shuttle run test (Hoosier-60ft)	Modified push-ups; isometric push-ups; bent arm hang	Sit-ups	Standing broad jump; phantom chair	50m dash; 100m dash	4x10m shuttle run	Sit and reach
ACHPER (Australia) (Walkley et al., 1988)	School and health; 9 to 18 years	Height; weight; BMI	PACER	Basketball throw	Sit-ups	None	None	None	Sit and reach
ALPHA (Spain) (Montosa et al., 2018; Ortega, Artero, et al., 2008; Ruiz, Castro-Piñero, et al., 2011; Ruiz, España Romero, et al., 2011)	School, sports and health; 6 to 18 years	Height; weight; BMI; WC; %BF (skinfolds)	PACER	Handgrip	None	Standing broad jump	None	4x10m shuttle run	None
ASSO-FTB (Italy) (Bianco et al., 2016)	School and health; 13 to 17 years	Height; weight; BMI; WC	PACER; 1-mile run/walk	Handgrip	Sit-ups (exhaustion)	Standing broad jump	None	4x10m shuttle run	None
Bouge (France) (Vanhelst et al., 2014; Vanhelst, Beghin, Drumez, et al., 2016; Vanhelst, Beghin, Fardy, et al., 2016)	School and health; 6 to 18 years	Height; weight; BMI	Half-mile run/walk; Navette test (20m)	Basketball throw	Curls-ups (cadence)	Standing broad jump	50m dash	10x5m shuttle run	Sit and reach; shoulder stretch
CAHPER-FPT (Canada) (CAHPER, 1966)	School; 7 to 17 years	None	Half-, 1- and 1.5-mile run/walk; 1000m run	Bent harm hang	Sit-ups (1 minute)	Standing broad jump	50m dash; 100m dash	4x10m shuttle run	None
CPAFLA (Canada) (Physiology, 2003)	School and health; 15 to 69 years	Height; weight; BMI; WC; HC; waist to hip ratio; %BF (skinfolds)	Step test	Handgrip; push-ups	Modified curl-ups; trunk-lift	Vertical jump	None	None	Sit and reach
EUROFIT (Europe) (Lovecchio et al., 2009)	School and health; 6 to 18 years	Height; weight and %BF (skinfolds)	PACER; 6 minute run test.	Handgrip; bent arm hang	Sit-ups; trunk-lift	Standing broad jump	Plate tapping	10x5m shuttle run	Sit and reach
FITescola (Portugal) (Henriques-Neto et al., 2020)	School, sports, and health; 10 to 18 years	Height; weight; BMI; WC; %BF (skinfolds); BIA	PACER; 1-mile run/walk	Push-ups	Sit-ups (cadence)	Standing broad jump; vertical jump	Speed to 20m and 40m	4x10m shuttle run	Sit and reach test; shoulder stretch
FitnessGram (USA) (Laurson et al., 2015)	School, sports, and health; 5 to 17 years	Height; weight; BMI; %BF (skinfolds); BIA	PACER; 1-mile run	Push-ups; bent arm hang; pull-ups; modified pull-ups	Curl-ups	None	None	None	Sit and reach; shoulder stretch
IPFT (Bahrain) (B, 2008)	School and health; 9 to 19 years	Height; weight; %BF (skinfolds)	1-mile run/walk test	Handgrip; back throw	None	None	None	4x10m shuttle run	None
INDARES (Czech Republic)(Chmelík et al., 2013; Kultury, 2020)	School and health; 7 to 18 years	Height; weight; %BF (skinfolds); BIA	PACER; 1500m run/walk	Push-ups; cricket ball throw	Modified curl-ups	Chair squats	60m dash	4x10m shuttle run	V sit and reach; shoulder stretch

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Batteries (country); author (year) (cont.)	Setting; age range (cont.)	Physical fitness measurements / tests (cont.)							
		Body composition	Cardiorespiratory fitness	Upper body strength	Middle-body strength	Lower body strength	Speed	Agility	Flexibility
NAPFA (Singapore) (Keong, 1981)	School and military; 12 to 24 years	None	1.5-mile run/walk	Pull-ups; flexed-arm hang (30 seconds)	Sit-ups with twist (1 minute)	Standing broad jump	None	4x10m shuttle run	Sit and reach
NFTP-PRC (China) (Zhu et al., 2017)	School and health; 9 to 19 years	None	Shuttle run (50x8m); 4-, 3- and 2-minutes shuttle run (25m); Quarter-, half- and 1-mile run/walk; 1-minute jump rope	Bent arm hang; pull-ups; modified pull-ups; parallel-bars dips	Sit-ups	Standing broad jump	50m dash; 100m dash	4x10m shuttle run	None
NYPFP (USA) (Department of the Navy, 2002)	School, health and military; 5 to 17 years	None	1-mile run/walk	Push-ups; modified push-ups; bent arm hang; pull-ups; modified pull-ups; parallel-bars dips	Sit-ups	Standing broad jump	None	None	None
NZFT (New Zealand) (Russell DG, 1989)	School and health; 6 to 12 years	Height; weight; %BF (skinfolds)	Cooper test (9 minutes)	Medicine ball throw; shot put (1 to 5kg); sand ball throw	Curl-ups	Standing broad jump	None	None	Sit and reach
PCPF (USA) (Sport, 2020)	School and health; 6 to 17 years	Height; weight; BMI; %BF (skinfolds)	PACER (20m and 15m), TAMT (aerobic behaviour, level 1); 1-mile run/walk	Push-ups 90º; flexed bent arm hang; pull-ups	Curl-ups; trunk lift	None	None	None	Sit and reach; shoulder stretch
PFAAT (Japan) (Shingo & Takeo, 2002)	School, sports and health; 6 to 17 years	Height; weight; BMI	PACER	Handgrip; pull-ups; softball / handball throw	Back strength test	Vertical jump; standing broad jump	50m dash	Side-to-side steps	Sit and reach; stand and reach
PROESP (Brazil) (Lima et al., 2018)	School, sports, and health; 6 to 17 years	Height; weight; BMI; WC; height to waist ratio; wingspan	6-minutes run/walk	Medicine ball throw (2kg)	Sit-ups (1 minute)	Standing broad jump	20m dash	Square test (4x4m)	Sit and reach
Ready for Labour and Defence - GTO (Russia) (Howell, 1976)	School and military; 10 to 60 years	None	Running test (1 or 2 km); cycling (5km); cross-country running (0.5 to 1km)	Push-ups; pull-ups; rope climbing with legs; tennis ball throw	None	Vertical jump; standing broad jump	30m, 50m, 60m, 80m or 100m dash	None	None
SLOfit (Slovenia) (Jurak et al., 2019)	Scholl and health; 6 to 19 years	Height; weight; %BF (skinfolds).	Half-mile run	Bent arm hang	Sit-ups (1 min)	Standing broad jump	60m dash; 20-seconds plate tapping	Polygon backward	Stand and reach
UNIFITTEST (Czech Republic) (Kopecky et al., 2013)	School, sports and health; 6 to 60 years	None	12-minutes run/walk	Medicine ball throw	Sit-ups (1 minute)	Standing broad jump	None	4x10m shuttle run	None
YMCA-YFT (USA) (Don, 1989)	School and health; 6 to 17 years	Height; weight; %BF (skinfolds)	1-mile run/walk	Modified pull-ups	Curls-ups	None	None	None	None

Abbreviations: AAHPER, American Association for Health, Physical Education, and Recreation; AAUTB, Amateur Athletic Union Test Battery; ALPHA, Assessing Levels of Physical Activity and Fitness; ASSO-FTB, Adolescents and Surveillance System for the Obesity prevention – Fitness Test Battery; ACHPER, Australian Council for Health, Education and Recreation; CAHPER-FPT, Canadian Association for Health, Physical Education and Recreation-Fitness Performance Test II; CPAFLA, Canadian Physical Activity, Fitness & Lifestyle Approach; IPFT, International Physical Fitness Test; INDARES, International Database for Research and Educational Support; NAPFA, Singapore National Physical Fitness Award/Assessment; NFTP-PRC, National Fitness Test Program in the Popular Republic China; NYPFP, National Youth Physical Program ; NZFT, New Zealand Fitness Test; PCPF, President's Challenge: Physical Fitness; PFAAT, Physical Fitness and Athletic Ability Test; PROESP, Projeto Esporte Brasil; USA, United States of America; YMCA-YFT, Young Men's Christian Association Youth Fitness Test.

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Appendix 2

Author, Year	Study Design	Country	Sample Characteristics (number of participants, gender, age)	The Instrument/Battery for Assessing Physical Fitness	Main Results
Westerstahl, et al., 2003	Retrospective Cross Sectional	Sweden	n=855: 417 girls, 426 boys; mean age 16.4	Sit-ups (number), Bench-press (number), Sargent jump (cm), Two-hand lift (N), Run-walk (m/9 min).	Both girls and boys performed less well in bench-press, sit-ups, and run-walk tests in 1995 compared to 1974. Boys performed better in the Sargent jump in 1995 than in 1974, but there was no difference among the girls for this test. Both girls and boys performed better in the two-hand lift in 1995 than in 1974. There were decreased aerobic fitness and an increased maximal static strength among adolescents in Sweden between 1974 and 1995.
Matton et al., 2007	Cross-sectional, Parent-offspring	Belgium	n=19999: 11899 boys (in 1969–1974), 4899 girls (in 1979–1980), 1429 boys (in 2005), 1772 girls (in 2005) aged 12–18 years.	Cross Sectional: Bent-arm hang (s), Sit-and-reach (cm), Flamingo balance (n/min), 10x5 m shuttle run (s); Parent offspring study: Plate tapping (n/20s), Vertical jump (cm), Arm pull (kg), Leg lifts (n/20s).	Boys tested in 2005 perform significantly better on the 10×5 m shuttle run test, but they perform significantly worse on sit-and-reach and bent-arm hang in cohort 12- to 14-year-olds compared to 1969–1974. Girls tested in 2005 perform significantly worse on bent-arm hang, flamingo balance, 10××5 m shuttle run test, and sit-and-reach for cohort 14 year-olds compared to 1969–1974. Boys (2002–2004) perform significantly worse on sit-and-reach plate tapping, and arm pulls (1969–1974). Girls (2002–2004) perform significantly worse on bent-arm hang, sit-and-reach, 10×5m shuttle run, plate tapping, vertical jump, and arm pull compared to their mothers (1979–1980).
Huotari, et al., 2009	Cross-sectional Population-Based study	Finland	n=1275: 717 adolescents (384 boys, 333 girls) took part in the 1976 study, 558 (305 boys, 253 girls) took part in the 2001 study; aged 13–18 years.	2000 m running (s) for boys and a 1500m running (s) for girls.	The mean 2000 m running test time was longer in 2001 compared to 1976 in boys. The mean 1500 m running test time was longer in 2001 compared to 1976 in girls, which indicates that on average, a boy in 2001 would finish about 180 m behind the average 1976 boy over the 2000 m distance. In girls, the corresponding difference in the 1500 m run was 83 m.
Albon, et al., 2010	Retrospective Cross-Sectional	New Zealand	n=3306: 1456 girls, 1850 boys aged 10–14 years.	Sit-and-reach (cm), 4x9 m run (s), Abdominal curl ups (n), Standing broad jump (cm), 550 m run (s); AAHPER battery.	Results on the 550-m run test decreased for boys (1.5%) and girls (1.7%), respectively. Results on the 4×9 m agility run test decreased for boys (0.2%) and girls (0.4%), respectively. Standing broad jump results for boys and girls in 2003 was less than their 1991 counterparts (0.3% and 0.2% per year for boys and girls, respectively). In contrast, for boys, performance in the curl-up test improvement is 1.5% per year, whereas improvement was of 2.1% per year for girls. Similarly, boys and girls were more flexible in 2003 compared to 1991; the improvement is 2.8% and 1.8% per year for boys and girls, respectively.
Andersen et al., 2010	Retrospective Cross-sectional	Denmark	n=1050: 466 boys, 584 girls; aged 15–19 years.	The VO2 max was estimated from maximal power output in a cycle test with the progressively increasing workload on a mechanically braked cycle ergometer (Monark 839, Varberg, Sweden).	No change in cardiorespiratory fitness over time (1983, 1997, 2003), and quite high levels were found in these representative cohorts. It founded substantial differences in maximal power output, but no differences when VO2 max was estimated from the equations derived in the validation studies.
Moliner-Urdiales et al., 2010	Retrospective Cross-sectional	Spain	n=731: 339 adolescents (155 boys, 184 girls) obtained between 2001 and 2002, 392 adolescents (206 boys, 186 girls) obtained between 2006 and 2007; aged 12.5–17.5 years.	Handgrip strength (kg), bent-arm hang (s), Standing broad jump (cm), 4×10 m shuttle run (s), 20 m shuttle run (stages).	Performance in 4×10 m shuttle run and 20 m shuttle run tests was higher in 2006–2007 compared with 2001–2002. Performance in handgrip strength and standing broad jump tests was lower in 2006–2007 compared with 2001–2002. The bent-arm hang test was not significantly different. Levels of both speed/agility and cardiorespiratory fitness were higher in 2006–2007 than in 2001–2002. Upper body muscular strength is on the same level.
Huotari, et al., 2010	Retrospective Cross-sectional	Finland	n=1222: 643 adolescents (312 boys, 331 girls) took part in the 1976 study, 579 adolescents (308 boys, 271 girls) in the 2001 study; aged 13–16 years.	Standing broad jump (cm), Sit-ups (n/30 s), 4×10 m shuttle run (s) for both sexes. Besides, Flexed-arm hang (n/s) was measured in girls and Pull-ups (repetition max) in boys.	No statistically significant changes in the standing broad jump results among boys from 1976 to 2001, in girls a mild tendency towards higher scores (1.9%). Upper body muscular fitness in boys decreases by 21.2% (averaged pull-ups number had fallen). The results of the girls' flexed-arm hang test showed no difference. Sit-ups improved significantly over time in both sexes, in boys (13.6%), in girls (9.1%). The results for the agility 4×10 m shuttle run had also improved over time, 4.7% in boys, and by 2.3% in girls.

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Author, Year (cont.)	Study Design (cont.)	Country (cont.)	Sample Characteristics (number of participants, gender, age) (cont.)	The Instrument/Battery for Assessing Physical Fitness (cont.)	Main Results (cont.)
Dyrstad, et al., 2011	Retrospective Cross-sectional	Norway	n=4006 pupils: 2384 boys, 1622 girls; age 16–18.	3000 m running (s)	The 3000 m running time decreases from the 1969 s to the 1979 s for boys. The distribution showed an increase in aerobic fitness in this decade. The running times have increased from the 1980 s to the 2000 s for boys and girls, respectively. The distribution showed a decline in aerobic fitness by 10% and 6%. The cohort of 16- to 18-year-old boys and girls in the decade 2000–2009 had a poorer aerobic fitness performance in the 3000 m running test compared with earlier decades.
Dos Santos et al., 2014	Retrospective Cross-sectional	Mozambique	n=3851: 591 subjects in 1992 (276 boys, 315 girls), 1840 subjects in 1999 (854 boys, 986 girls), 1420 subjects in 2012 (661 boys, 759 girls); aged 8–15 years.	Handgrip strength (kg), 10x5 m shuttle run (s) from EUROFIT battery; Sit-and-reach (cm), 1-mile run-walk (s) from AAHPERD and FITNESSGRAM batteries, respectively.	Children in 1992 were more flexible than those from 2012. Boys' handgrip strength increased from 1992 to 2012, while girls decreased their handgrip strength. Youth in 1992 were faster and more agile than their 2012 peers. A decrease was observed in cardiorespiratory fitness between 1992 and 1999 and between 1992 and 2012 for both sexes.
Karpowicz, et al., 2015	Retrospective Cross-sectional	Poland	n=169: 21 girls (measured in the 2006), 21 (2007), 20 (2008), 21 (2009), 21 (2010), 21 (2011), 22 (2012), 22 (2013); mean age 15.5±0.5	50 m sprint (s), 800 m endurance running (s), 4×10 m shuttle run (s), Standing long jump (cm), sit-ups (n/30 s), Handgrip strength (kg), Flexed-arm hang (n), Standing trunk flexion (cm); International Physical Fitness Test (IPFT) battery.	The overall physical fitness of young women basketball players has been declining year by year. Girls obtained lower results in 6 of 8 tests (50 m run, Long jump, Flexed-arm hang, 4×10 m run, Sit-ups, Standing forward bend), compared with members of the Teams in 2006, with the differences for long jump, arms hang, sit-ups, and trunk flexion tests being statistically insignificant. A slight improvement was observed only in the 800 m run and hand strength.
Morales-Demori, et al., 2016	Retrospective Cross-sectional	USA	n=435: 249 (male), 186 (female) healthy children and adolescents, aged 4-18 years, mean age 12.6±3.2 years.	Bruce protocol treadmill test	There was a significant difference in the mean endurance time between children grouped in 5-year intervals (1983–1990, 1991–1995, 1996–2000, 2001–2005, 2006–2010) with a significant downward trend in endurance time over the years, especially after 2001.
Venckunas, et al., 2016	Retrospective Cross-sectional	Lithuania	n=16199 (8131 girls, 8068 boys): 5775 in 1992, 5325 in 2002, 5099 in 2012; aged 11–18 years.	Flamingo balance (n/min), Sit-and-reach (cm), Standing broad jump (cm), Sit-ups (n/30s), bent-arm hang (s), 10×5 m speed shuttle run (s), 20 m shuttle run (n stages); Eurofit test battery	The study has shown a loss of flexibility, leg muscle power, upper body strength, and cardiorespiratory fitness between 1992 and 2012, although there was an improvement in abdominal muscle strength in girls, agility in boys, and balance in both genders during the same period. Negative trends in aspects of fitness seen between 1992 and 2002 have not slowed down between 2002 and 2012. Positive trends in agility and abdominal muscle strength were seen before 2002 have regressed or were reversed between 2002 and 2012, while balance continued to improve at an increased pace.
Costa et al., 2017	Descriptive, Non-Randomised Study	Portugal	n=1819: 881 boys, 938 girls; aged 10–11 years.	Horizontal jump (without preparatory running) (cm), 40 m sprint (s) from AAHPERD test batteries; Curl-up (n), Sit-and-reach (cm) from the FITNESSGRAM test batteries.	Children from the 1993 cohort were less flexible than those from 2013. Boys in 2013 were faster than their 1993 counterparts. A similar trend was found for girls but without statistical meaning. The curl-up assessment, showed a similar pattern in both genders, with better scores reached in the most recent quinquennial. Horizontal jump performance also showed slight improvements throughout those years but without reaching the significance of cut-of value.
Ao et al., 2018	Retrospective analysis; National Survey on Students' Constitution and Health (CNSSCH)	China (Han ethnicity)	n=136539: 34,238 (in 1985); 11,664 (in 1991); 17,485 (in 1995); 18,057 (in 2000); 19,254 (in 2005); 17,962 (in 2010); and 17,906 (in 2014); aged 12 years	50 m run (s), Standing broad jump (cm), 10×50 m run (s), Pull-ups (n/min), Sit-ups (n/min); A battery test from the Chinese National Measurement Standards on People's Physical Fitness for young children.	There was a general decline in physical fitness in both urban and rural children after 2000. Some components have upward trends: running speed in boys and girls in urban areas, cardiorespiratory fitness in boys and girls in both urban and rural areas.

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Author, Year (cont.)	Study Design (cont.)	Country (cont.)	Sample Characteristics (number of participants, gender, age) (cont.)	The Instrument/Battery for Assessing Physical Fitness (cont.)	Main Results (cont.)
Huotari, et al., 2018	Retrospective Cross-sectional	Finland	n=3736: 2390 students (1207 boys, 1183 girls) in 2003, 1346 students (683 boys and 663 girls) in 2010; aged 15–16 years.	Figure 8 (n/min), Lateral jumping (n/15 s), Motor coordination track (s).	Results demonstrate that scores of the coordination track decreased slightly in both gender groups between 2003 and 2010. Scores for the figure 8 test increased slightly among girls but not in the boys' group between 2003 and 2010. There were no significant changes in the lateral jumping test scores in either gender group between 2003 and 2010.
Colley et al., 2019	Cross-sectional	Canada	n=6,284: 2,081 (2007 to 2009), 2,133 (2009 to 2011), 2,070 (2016 to 2017); aged 6-19 in 10-year period	mCAFT step, Handgrip strength (kg), Sit-and-reach (cm); CSEP-PATH Manual.	The fitness measures have changed across the three cycles (2007–2009, 2009–2011, 2016–2017), by age group and sex. Statistically significant differences between cycles are noted. Decreases in cardiorespiratory fitness were observed for 8- to 14-year-old boys. Grip strength decreased in 11- to 19-year-old boys. Flexibility was stable across time with a slight improvement observed in 6- to 10-year-old girls.
Dong et al., 2019	Retrospective analysis; National Survey on Students' Constitution and Health (CNSSCH)	China	n=1 494 485: 409 836 (in 1985), 204 763 (in 1995), 216 073 (in 2000), 234 289 (in 2005), 215 223 (in 2010), 214 301 (in 2014); aged 7-18 years	Forced vital capacity (ml), Standing long jump (cm), Sit-and-reach (cm), Oblique body pull ups (n) and pull ups (n) for boys; sit ups (n/min) for girls), 50 m dash (s), 8×50 m shuttle runs (s), 1000 m run (s) for boys, 800 m run (s) for girls.	The mean levels of the six core items of the physical fitness indicator shifted substantially over this period. The total normal physical fitness indicator increased between 1985 and 1995, reached its peak in 1995, and then decreased in 2014, with overall physical fitness 167% lower between 1995 and 2014. Except for sit-and-reach, the other components of fitness (forced vital capacity, standing long jump, body muscle strength, 50 m dash, endurance running) significantly declined over time from 1995 to 2014, particularly forced vital capacity and endurance running.
Bi, et al., 2020	Retrospective Cross-sectional	China	n=49,357 participants: 14,548 (in 1985), 7198 (in 1995), 10,255 (in 2005), 17,356 (in 2014); aged 7–18 years.	Forced vital capacity (ml), Standing long jump (cm), Sit-and-reach (cm), Oblique body pull-ups (n) and pull-ups (n) for boys; sit ups (n/min) for girls, 50-m dash (s), 8×50 m shuttle runs (s), 1000 m run (s) for boys, 800 m run (s) for girls; CNSSCH guidelines.	Comprising the six core physical fitness items (forced vital capacity, standing long jump, sit-and-reach, body muscle strength, 50-m dash, endurance running), the physical fitness indicator increased in 1995 and then fell sharply in 2005 and continued to decrease in 2014, taking the 1985 dataset as reference. The physical fitness indicator of all age groups reached a peak in 1995, followed in descending order by 1985, 2005, and 2014.
Johansson, et al., 2020	Cross-sectional	Sweden	n=705 children: 356 girls, 349 boys; aged 8-20 years.	Maximal oxygen uptake VO2 max (Astrand-Rhyming submaximal bicycle test)	There was a statistically significant negative time trend for cardiorespiratory fitness in both sexes. Absolute VO2 max (L/min) decreased in girls and in boys per year. Relative VO2 max (mL/kg/min) decreased in girls and in boys per year.

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Appendix 3

Source	Study design, sample size, age	Country	Outcome measure(s)	Method(s)	Content of PE / intervention	Main finding(s)
Cumming et al., 1969	Longitudinal, n=89 (boys only), 6th and 10th graders	Canada	VO_2max	Submaximal cycle ergometer protocol	Not specified	(±) No changes in the VO_2max from September to June of the following year (nine months)
Crowhurst et al., 1993	Cross-sectional, n=9 (girls only), M_{age}=14.6 years	USA	(1) VO_2max (2) Heart rate	(1) Incremental, maximal cycle ergometer protocol (2) Heart rate monitor during PE lessons	Basketball and floor hockey	(±) The intensity of PE classes (in minutes exercised at >50% of VO_2max) may not generally be sufficient for achieving an aerobic benefit
Strand & Reeder, 1993	Cross-sectional, n=55, age range=12 to 13 years	USA	Heart rate	Heart rate monitor during PE classes	Team games (e.g. football, dodgeball), swimming and wrestling	(±) Students spend <50% of time in their assigned training zone (>60% of heart rate reserve)
Baquet et al., 2001	Intervention, n=551 (52% boys), age range=11 to 16 years	France	Distance covered	7-minute running test	Running	(+) High intensity PE (aerobic training) classes improves CRF
Baquet et al., 2002	Intervention, n=345 (59% boys), age range=11 to 16 years	France	Heart rate	Heart rate monitor during PE classes	Running, jumping	(+) High intensity PE classes (in % time spent >50%, 60% and 75% of heart rate reserve) may improve CRF
Koutedakis & Bouziotas, 2003	Intervention, n=84 (boys only), M_{age}=13.6 years	Greece	VO_2max	Multistage 20-meter shuttle run test	Team games (e.g. football, handball), swimming, athletics, tennis	(±) Students participating only in PE classes have lower levels of VO_2max than students participating in PE classes and other extracurricular organised physical activities
Beets & Pitetti, 2005	Cross-sectional, n=187(64% boys), age range=14 to 19 years	USA	VO_2max	PACER test	Team activities	(±) Students participating in PE classes have lower levels of VO_2max than students participating in school-sponsored sports programs
Fairclough & Stratton, 2005	Cross-sectional, n=122 (50% boys), age range=11 to 14 years	England	Heart rate	Heart rate monitor during PE classes	Team games (e.g. football, softball), individual games (e.g. badminton, tennis), movement activities (e.g. dance, gymnastics) and individual activities (e.g. athletics, fitness)	(±) Students spent <50% of time in MVPA. Students participated in most MVPA during team games and the least during movement activities
Fairclough & Stratton, 2006	Cross-sectional, n=68 (49% boys), age range=11 to 14 years	England	Heart rate	Heart rate monitor during PE classes	Team games, individual games, gymnastic, dance	(±) Students spent <50% of time in MVPA
Laurson et al., 2008	Cross-sectional, n=796 (53% boys), M_{age}=16 years	USA	Heart rate	Heart rate monitor during PE classes	Team games (e.g. volleyball, ultimate frisbee), individual games (e.g. golf, dance), fitness activities (e.g. aquatics, bleachers)	(+) 71% of class time was spent in MVPA (>50% of maximum heart rate) (+) Fitness activities provided greater % of time above the lower heart rate threshold than individual and team games
Pelclová et al., 2008	Cross-sectional, n=241 (girls only), M_{age}=16.0 years	Czech Republic and Poland	Heart rate	Heart rate monitor during PE classes	Dance and aerobic dance	(+) Girls spent more than 50% of class time (aerobic dance classes) in MVPA (>60% of maximum heart rate)
Gallotta et al., 2009	Intervention, n=152, age range=11 to 12 years	Italy	Test duration	1-mile run/walk test	Pre-tumbling, rhythmic gymnastics, ball mini-games, dexterity circuits	(±) There were no significant differences in the 1-mile run/walk test results five months apart, for both control (regular PE classes) and intervention groups

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Source (cont.)	Study design, sample size, age (cont.)	Country (cont.)	Outcome measure(s) (cont.)	Method(s) (cont.)	Content of PE / intervention (cont.)	Main finding(s) (cont.)
Camhi et al., 2011	Longitudinal, n=131 (girls only), M_{age}=13.8 years	USA	Heart rate	Heart rate monitor during submaximal step test	Aerobic dance, football, walking/jogging, fitness activities (e.g. resistance training, circuit training), swimming, basketball, volleyball, recreational games	(+) Normal-weight and overweight girls enrolled in an eight months PE program showed improvement in fitness (decrease in stage 1 heart rate), as well as maintenance of these effects over the two next years (±) Obese girls showed no fitness improvements in response to the same PE program.
Ramirez Lechuga et al., 2012	Intervention, n=84 (61% boys), age range=15 to 18 years	Spain	VO_2max	Portable gas analyser during multistage 20-meter shuttle run test	Running	(+) A eight weeks high intensity aerobic training program developed in PE classes improved students' VO_2max (±) During the same 8-week period, regular PE classes did not improved students' VO_2max
Lucertini et al., 2013	Intervention, n=101, (50% boys), 3rd to 5th graders	Italy	VO_2max	Multistage 20-meter shuttle run test	Basic motor skills, rhythm, coordination, endurance, strength, flexibility	(+) Specialist led and generalist teacher led PE classes increased primary school children's VO_2max during a six months period
Reed et al., 2013	Intervention, n=470 (50% boys), 2nd to 8th graders	USA	Number of laps	PACER test	Fundamental skills, multiactivity sport theme curriculum	(+) CRF of elementary school students participating in regular PE increased in an eight months period (–) CRF of middle school students participating in regular PE decreased in an eight months period
Bendiksen et al., 2014	Intervention, n=91 (55% boys), age range=8 to 9 years	Denmark	(1) Heart rate (2) Distance covered	(1) Heart rate monitor during YYIR1C (2) YYIR1C	Team games (e.g. football, unihockey), individual games (e.g. walking, parkour), Nintendo Wii Boxing, Nintendo Wii Tennis	(±) Students participating in regular PE classes did not improve CRF (distance covered and % of maximal heart rate) in a six weeks period (+) Students participating in high intensity PE classes improved CRF (distance covered and % of maximal heart rate) in a 6 weeks period
Rengasamy et al., 2014	Intervention, n=173 (50% boys), M_{age}=16 years	Malaysia	Distance covered	12-Minute Cooper's Test	Circuit training	(+) A 10-week fitness program implemented within PE classes enhanced the students' CRF
Erfle & Gamble, 2015	Intervention, n=10206 (50% boys), 6th to 8th graders	USA	Test duration	1-mile run/walk test	Not specified	(±) Students participating in regular PE classes did not improve CRF during one school year
Mayorga-Veiga & Viciana, 2015	Intervention, n=178 (58% boys), elementary and middle school children	Spain	Test duration	Multistage 20-meter shuttle run test	Fitness activities (e.g. circuit training, multi-jumps), team games	(–) CRF of middle school students participating in regular PE decreased in eight weeks period (+) CRF of elementary and middle school students with low CRF participating in high intensity PE classes (fitness program) improved in an eight weeks period
Jarani et al., 2016	Intervention, n=767 (52% boys), 1st and 4th graders	Albania	VO_2max	Intermittent shuttle run test	Throwing/catching, rhythm activities (e.g. dance), fitness activities, tumbling / gymnastics	(+) Exercise (fitness) and game-oriented PE classes improved children's CRF and have greater effect in improving CRF than other PE classes
Mayorga-Veiga et al., 2016	Intervention, n=111 (63% boys), M_{age}=12.5 years	Spain	(1) Test duration (2) Heart rate	(1) Multistage 20-meter shuttle run test (2) Heart rate monitor during PE classes	Fitness activities (circuit training, multi-jumps), team games	(+) Students participating in high intensity PE classes (fitness program) improved CRF in a nine weeks period and maintained the improvements after four weeks detraining period (+) High intensity PE classes had >50% of time in MVPA (–) Students participating in regular PE classes decreased CRF in a nine weeks period (±) Regular PE classes had <50% of time in MVPA

Source (cont.)	Study design, sample size, age (cont.)	Country (cont.)	Outcome measure(s) (cont.)	Method(s) (cont.)	Content of PE / intervention (cont.)	Main finding(s) (cont.)
Andres, 2017	Intervention, n=100	Ukraine	Test duration	1-km run/walk test	Not specified	(±) No improvements in CRF from October to May of the following year (seven months)
Park et al., 2017	Intervention, n=48 (50% boys), M_{age}≈12 years	South Korea	Test duration	1-km run/walk test	Fitness activities (e.g. burpees, shuttle run)	(+) CRF of children participating in PE improved, while CRF of children not participating in PE decreased after an eight weeks period

CRF, cardiorespiratory fitness; PE, physical education; PACER, progressive aerobic cardiovascular endurance run; YYIR1C, Yo-Yo Intermittent Recovery Level 1 Children's test; MVPA, moderate-to-vigorous physical activity; M, age.
(+) Found a positive effect of PE on students' CRF (positive changes in CRF or ≥50% of time in MVPA) (n=16).
(±) Found a neutral effect of PE on students' CRF (no changes in CRF or <50% of time in MVPA) (n=14).
(–) Students' CRF decreased during a given time period in a PE program (n=3).