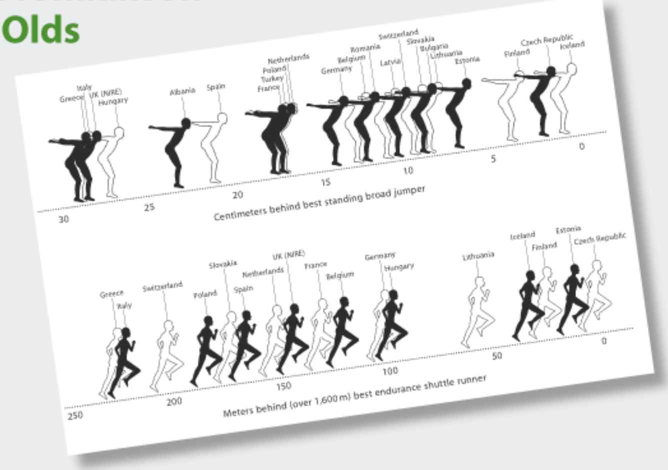
Medicine and Sport Science
Editors: J. Borms, M. Hebbelinck, A.P. Hills
Vol. 50

Pediatric Fitness

Secular Trends and Geographic Variability

Editors
G.R. Tomkinson
T.S. Olds



KARGER

Pediatric Fitness

Medicine and Sport Science

Vol. 50

Series Editors

J. Borms, Brussels
M. Hebbelinck, Brussels
A.P. Hills, Brisbane

Pediatric Fitness

Secular Trends and Geographic Variability

Volume Editors

Grant R. Tomkinson, Adelaide
Timothy S. Olds, Adelaide

49 figures, and 39 tables, 2007

KARGER

Basel · Freiburg · Paris · London · New York ·
Bangalore · Bangkok · Singapore · Tokyo · Sydney

Medicine and Sport Science
Founder and Editor from 1969 to 1984: E. Jokl†, Lexington, Ky.

Dr. Grant R. Tomkinson
Centre for Applied Anthropometry
School of Health Sciences
University of South Australia
City East Campus
GPO Box 2471
Adelaide SA 5001 (Australia)

Prof. Timothy S. Olds
Nutritional Physiology Research Centre
School of Health Science
University of South Australia
City East Campus
GPO Box 2471
Adelaide SA 5001 (Australia)

Library of Congress Cataloging-in-Publication Data

A catalog record for this title is available from the Library of Congress.

Bibliographic Indices. This publication is listed in bibliographic services, including Current Contents® and Index Medicus.

Disclaimer. The statements, options and data contained in this publication are solely those of the individual authors and contributors and not of the publisher and the editor(s). The appearance of advertisements in the book is not a warranty, endorsement, or approval of the products or services advertised or of their effectiveness, quality or safety. The publisher and the editor(s) disclaim responsibility for any injury to persons or property resulting from any ideas, methods, instructions or products referred to in the content or advertisements.

Drug Dosage. The authors and the publisher have exerted every effort to ensure that drug selection and dosage set forth in this text are in accord with current recommendations and practice at the time of publication. However, in view of ongoing research, changes in government regulations, and the constant flow of information relating to drug therapy and drug reactions, the reader is urged to check the package insert for each drug for any change in indications and dosage and for added warnings and precautions. This is particularly important when the recommended agent is a new and/or infrequently employed drug.

All rights reserved. No part of this publication may be translated into other languages, reproduced or utilized in any form or by any means electronic or mechanical, including photocopying, recording, microcopying, or by any information storage and retrieval system, without permission in writing from the publisher.

© Copyright 2007 by S. Karger AG, P.O. Box, CH–4009 Basel (Switzerland)
www.karger.com
Printed in Switzerland on acid-free paper by Reinhardt Druck, Basel
ISSN 0254–5020
ISBN 978–3–8055–8177–6

Contents

Foreword

In the conduct of scientific research, the testing of a theory often generates additional questions or identifies gaps in information that require further study. Research into the fitness of young people has been no exception. If fitness of children is declining, why is it doing so? when did it start happening? are they still fit enough? and for practical purposes, what can we do about it?

Pediatric Fitness – Secular Trends and Geographic Variability provides us with a comprehensive, worldwide overview of changes in children's fitness levels over previous decades and while the volume does not aim to provide an answer for what can be done about declining levels, it is thorough in its compilation of international data, which paints a very apparent picture.

Given the current international spotlight on overweight and obesity, this book will contribute greatly to the evidence base and the argument surrounding the impact that physical activity, or inactivity, has. Policy makers, practitioners, providers and even parents, will benefit from the information presented as it can be used as a tool for advocacy and support.

I, as President of the International Council of Sport Science and Physical Education (ICSSPE), commend the authors and editors for compiling such an extensive body of research which can support future decision-making processes. ICSSPE welcomes and encourages the sharing of research, seeing it as a vital component of development of all aspects of sport, sport science and physical education.

Gudrun Doll-Tepper
ICSSPE President

Contributors

Contributors

Neil Armstrong
University of Exeter, Exeter (UK)
N.Armstrong@exeter.ac.uk

Jan Borms
Vrije Universiteit Brussel, Brussels
(Belgium)
jborms@skynet.be

James Dollman
University of South Australia,
Adelaide (Australia)
james.dollman@unisa.edu.au

Jaak Jürimäe
University of Tartu, Tartu (Estonia)
jaakj@ut.ee

Toivo Jürimäe
University of Tartu, Tartu (Estonia)
toivoj@ut.ee

Duncan Macfarlane
University of Hong Kong,
Hong Kong (Hong Kong)
djmac@hku.hk

Robert Malina
Tarleton State University, Bay City,
Tex. (USA)
rmalina@wcnet.net

Timothy Olds
University of South Australia,
Adelaide (Australia)
tim.olds@unisa.edu.au

Kate Ridley
Flinders University, Adelaide
(Australia)
kate.ridley@flinders.edu.au

Thomas Rowland
Bay State Medical Center, Bay City,
Tex. (USA)
Thomas.Rowland@bhs.org

Jo Salmon
Deakin University, Burwood
(Australia)
jo.salmon@deakin.edu.au

Roy Shephard
University of Toronto, Toronto, Ont.
(Canada)
royjshep@shaw.ca

Anna Timperio
Deakin University, Burwood,
(Australia)
anna.timperio@deakin.edu.au

Grant Tomkinson
University of South Australia,
Adelaide (Australia)
grant.tomkinson@unisa.edu.au

Emmanuel Van Praagh
Université Blaise Pascal, Aubière
(France)
Emmanuel.VanPraagh@wanadoo.fr

Vida Volbekiene
Lithuanian Academy of Physical
Education, Kaunas (Lithuania)
v.volbekiene@lkka.lt

Joanne Welsman
University of Exeter, Exeter (UK)
J.R.Welsman@exeter.ac.uk

Referees

The chapters in this volume have undergone peer review by an international expert committee consisting of the following members:

Lars Bo Andersen, Oslo
Neil Armstrong, Exeter
Georges Baquet, Lille
Michael Beets, Corvallis, Oreg.
Cora Craig, Toronto, Ont.
David Docherty, Victoria, B.C.
James Dollman, Adelaide
Robert Duffield, Bathurst
Frank Fu, Hong Kong
Michael Hamlin, Christchurch
Beth Hands, Fremantle
Sang-Jo Kang, Seoul
Luc Léger, Montreal, Qué.
Duncan Macfarlane, Hong Kong
Robert Malina, Stephenville, Tex.
Geraldine Naughton, Sydney
Timothy Olds, Adelaide
Kate Ridley, Adelaide
Thomas Rowland, Springfield, Mass.
Ann Rowlands, Exeter
Grant Tomkinson, Adelaide
Niels Wedderkopp, Ringe

Tomkinson GR, Olds TS (eds): Pediatric Fitness. Secular Trends and Geographic Variability.
Med Sport Sci. Basel, Karger, 2007, vol 50, pp 1–4

Introduction

Grant R. Tomkinson[a], *Timothy S. Olds*[b]

[a]Centre for Applied Anthropometry and [b]Nutritional Physiology Research Centre,
School of Health Sciences, University of South Australia, Adelaide, Australia

The Impetus for This Book

There is general agreement that pediatric fatness has been increasing in most high- and middle-income countries, with a marked acceleration since the 1970s. There is less consensus on trends in children's fitness. The following quotations from the research literature illustrate the spectrum of positions:

'The results of this study do not support the current well-publicized view in the United Kingdom that children's cardiopulmonary fitness is deteriorating.' [1, p. 373]

'The existing research literature does not permit any confident conclusions to be drawn regarding temporal changes in aerobic fitness.' [2, p. 8]

'So it seems that there has been a real decline in fitness, and an increase in fatness, in Australian children since 1985.' [3, p. 119]

The polarisation of opinion around this important question provided the impetus for the present volume, which has elicited contributions from researchers from four continents.

What Are We Measuring?

Before attacking the question of secular change in children's fitness, it is important to be clear on just what we mean by 'fitness', and how it is operationalized. The evidence that children's performance on tests of aerobic fitness has been declining in recent years is stronger than that for parallel changes in maximal oxygen uptake. Indeed, Armstrong et al. [1] and Eisenmann and Malina [4] have collected data which show little secular change in peak oxygen uptake since the 1930s. In their chapter, Armstrong and Welsman [this vol., pp. 5–25] delineate the mechanisms which contribute to performance on tests of aerobic fitness. The inference is that it is quite possible that maximum oxygen uptake has remained stable while performance has declined. Changes in 'anaerobic threshold', oxygen uptake kinetics, mechanical efficiency, motivation, tactical experience and pacing skills can affect performance with no change in peak oxygen uptake.

Similar considerations are important in considering trends in performance on tests of motor skills, strength and power, which are generally less well operationalized than the gold standard $\dot{V}O_{2max}$ test. In the next chapter, van Praagh [this vol., pp. 26–45] asks what we are actually measuring in such tests, and describes how results can be affected by small variations in testing protocol. The first two chapters both caution against jumping too easily from changes in performance to changes in underlying mechanisms.

The World Picture

The next seven chapters paint a global picture of the available performance data, from North America, Europe, the Baltic states, Asia and Australasia. Tomkinson and Olds [this vol., pp. 46–66] bring together data from around the world on over 25 million children and conclude that performance on tests of aerobic fitness has been declining globally at the rate of about 5% each decade since 1970. Prior to 1970, performance was improving. This pattern of rise and fall may help explain why some researchers, who use datapoints falling on either side of the peak in 1970, have failed to find declines in fitness performance.

Malina [this vol., pp. 67–90] looks at data from the United States. In contrast to the inclusive approach of Tomkinson and Olds, Malina cautiously focuses largely on randomized national surveys, an approach which undoubtedly yields better quality data, but also leaves many gaps. A mixed picture emerges. Shephard [this vol., pp. 91–103] moves us north to Canada, describing declines in the fitness of Inuit children from extraordinarily high levels in the 1970s until today.

Europe has benefited from the introduction of the Eurofit test battery, a standardized set of simple measurement instruments used very widely throughout the continent. This allows comparison between countries. Tomkinson, Olds and Borms [this vol., pp. 104–128] ask ‘Who are the Eurofittest?’ The answer has been unchanged since the 1950s: northern European children outperform children from Southern and Western Europe, and from children around the developed Pacific Rim. The superior fitness of northern European children has been a consistent finding in the literature since the first comparisons of European and North American children in the 1950s, which galvanized the American government into corrective action. The enduring superiority of children from Scandinavia and the Baltic warrants further exploration.

The situation in the Baltic States, Eastern Europe and Russia has been complicated by the social upheavals following the break-up of the Soviet Union in 1989–91. Jürimäe and colleagues [this vol., pp. 129–142] track changes in fitness performance in Estonia and Lithuania since independence, again detecting performance declines.

Data from Asia remain hard to access. Several Asian countries – among them the Korean Republic and Singapore – routinely collect fitness data on a census-like basis, but the data are not always made available to researchers. Macfarlane and Tomkinson [this vol., pp. 143–167] collate available data from Asia, documenting not only very large fitness differentials between children from different countries (with the Japanese performing exceptionally well), but also clear secular declines in aerobic performance. Finally, Tomkinson and Olds [this vol., pp. 168–182] move to Australasia, where a substantial historical record exists. The trends in aerobic fitness performance are quite clear: consistent declines in aerobic test performance since about 1970 in both boys and girls and across most age groups.

The Causes

The last four chapters raise some considerations regarding causes. Salmon and Timperio [this vol., pp. 183–199] review the evidence around environmental influences on children's activity levels. The evidence is equivocal, with the authors concluding that the impact of the built environment (amenity, street design and land use) on activity levels may be very context-specific.

The most obvious reason why performance on tests of aerobic fitness is declining is that aerobic fitness itself – operationalized by the criterion method of gas analysis – is declining. Rowland [this vol., pp. 200–209] analyses data on trends in maximal oxygen uptake, concluding that data are too limited to unequivocally support a clear decline.

There is consensus that increases in fatness have differentially affected the right tail of the distribution: there are more fat children, and they are much fatter than their counterparts of 30 years ago. There are very few corresponding data on shifts in the distribution of scores on fitness tests. Comparing Australian data from 1985 and 1997, Dollman and Olds [this vol., pp. 210–225] found that the overall decline in boys' performances has been the result of a shift towards poorer performance in the middle of the distribution. In contrast, girls' scores have not shown distributional changes, and the overall decline in girls' performances has been the result of across-the-board declines.

Finally, Olds, Ridley and Tomkinson [this vol., pp. 226–240] ask whether increases in fatness alone can explain performance declines. Using cross-sectional data from within and between countries, and an analysis of the fitness performance of Australian children from 1985 and 1997 matched for fatness, they conclude that increases in fatness alone explain less than half the observed decline in aerobic fitness performance.

This volume covers four continents, from the Baltic to the Mediterranean, from the Arctic Circle to the Mexican border, and across the vast sweep of Asia from the Sea of Japan to the coasts of Tasmania. It covers the 50 years from the ruins of World War Two to the superabundance of postindustrial society, years which saw the integration of indigenous societies into the economic mainstream, the industrialization of Asia and the fall of the Soviet empire. In many ways the fitness of children may serve as a barometer of these changes.

References

1 Armstrong N, Williams J, Balding J, Gentle P, Kirby B: The peak oxygen uptake of British children with reference to age, sex and sexual maturity. Eur J Appl Physiol 1991;62:369–375.

2 Rowland T: Declining cardiorespiratory fitness in youth: fact or supposition? Pediatr Exerc Sci 2002;14:1–8.

3 Dollman J, Olds T, Norton K, Stuart D: The evolution of fitness and fatness in 10- to 11-year-old Australian schoolchildren: changes in distributional characteristics between 1985 and 1997. Pediatr Exerc Sci 1999;11:108–121.

4 Eisenmann JC, Malina RM: Secular trend in peak oxygen consumption among United States youth in the 20th century. Am J Hum Biol 2002;14:699–706.

Grant R. Tomkinson, PhD
Centre for Applied Anthropometry, School of Health Sciences
University of South Australia, City East Campus
GPO Box 2471
Adelaide SA 5001 (Australia)
Tel. +61 8 8302 1407, Fax +61 8 8302 2766, E-Mail grant.tomkinson@unisa.edu.au

Tomkinson GR, Olds TS (eds): Pediatric Fitness. Secular Trends and Geographic Variability.
Med Sport Sci. Basel, Karger, 2007, vol 50, pp 5–25

Aerobic Fitness: What Are We Measuring?

Neil Armstrong, Joanne R. Welsman

Children's Health and Exercise Research Centre, University of Exeter, Exeter, UK

Abstract

Aerobic fitness depends upon the components of oxygen delivery and the oxidative mechanisms of the exercising muscle. Peak oxygen uptake is recognised as the best single criterion of aerobic fitness but it is strongly correlated with body size. Methods of controlling for body size are discussed and it is demonstrated how inappropriate use of ratio scaling has clouded our understanding of aerobic fitness during growth and maturation and across time. Changes in aerobic fitness over time are reviewed but no published study of peak oxygen uptake, appropriately adjusted for body mass and maturation, has investigated secular changes in aerobic fitness. Data expressed in direct ratio with body mass provide limited insights into secular changes in aerobic fitness but aerobic performance appears to be decreasing in accord with the secular increase in body mass. Cross-sectional and longitudinal peak oxygen uptake data are analysed in relation to age, maturation and sex. Muscle lactate production and blood lactate accumulation are outlined and young people's blood lactate responses to submaximal and maximal exercise are examined. However, exercise of the intensity and duration required to monitor conventional laboratory measures of aerobic fitness are rarely experienced in young people's lives. In many situations it is the oxygen uptake kinetics of the non-steady state which best assess the integrated responses of the oxygen delivery system and the metabolic requirements of the exercising muscle. The chapter therefore concludes with a discussion of insights into aerobic fitness provided by the emerging database on young people's oxygen uptake kinetics responses to exercise of different intensities.

Aerobic fitness may be defined as the ability to deliver oxygen to the muscles and to utilise it to generate energy during exercise. Children's aerobic fitness is well documented and it is almost 70 years since Robinson [1] published the first laboratory investigation of boys' aerobic fitness and over 50 years since Astrand [2] conducted his pioneering studies of the aerobic fitness of both boys and girls. Yet, the clarification of young people's aerobic fitness is still shrouded with controversy. The literature is replete with performance tests, such as the

20 m shuttle run (20 mSRT), masquerading as accurate measures of young people's aerobic fitness and even the understanding of physiological measures of aerobic fitness during youth has been confounded by inappropriate means of controlling for body size and maturation.

Maximal oxygen uptake ($\dot{V}O_{2max}$), the highest rate at which an individual can consume oxygen during exercise, limits the rate of aerobic provision of adenosine triphosphate (ATP) and is therefore widely recognised as the best single physiological measure of aerobic fitness [3]. However, although $\dot{V}O_{2max}$ limits the performance of aerobic exercise it does not describe fully all aspects of aerobic fitness. It is well documented that exercise of the intensity and duration required to elicit $\dot{V}O_{2max}$ is rarely experienced in young people's everyday lives [4, 5]. The vast majority of bouts of physical activity are submaximal and of short duration and, under these circumstances, it is the transient kinetics of $\dot{V}O_2$ which best assess the integrated response of the oxygen delivery system and the metabolic requirements of the exercising muscle. Furthermore, $\dot{V}O_{2max}$ is neither the best measure of an individual's ability to sustain aerobic exercise at submaximal intensities nor the most sensitive means by which to detect improvements in aerobic fitness following training. Despite its origins in anaerobic metabolism, blood lactate accumulation is a valuable indicator of aerobic fitness and it can be used to detect improvements in muscle oxidative capacity with exercise training in the absence of changes in $\dot{V}O_{2max}$.

We here describe the components of young people's oxygen uptake ($\dot{V}O_2$) during exercise, examine the assessment and interpretation of aerobic fitness during youth and focus specifically on physiological measures of $\dot{V}O_{2max}$, blood lactate accumulation and $\dot{V}O_2$ kinetics in relation to age, growth, maturation and sex. We will also comment on secular trends in aerobic fitness and performance.

Components of Oxygen Uptake during Exercise

The rate at which muscles can generate energy from aerobic metabolism depends on the ability of the cardiopulmonary system to deliver oxygen from the atmosphere to the muscles and the ability of the mitochondria of the exercising muscles to utilise the oxygen. Both oxygen delivery and utilisation mature as children move through adolescence and into adult life.

Oxygen Delivery

The rise in minute ventilation ($\dot{V}_E$) during progressive exercise is similar in adults and young people. Initially $\dot{V}_E$ is closely matched to the increase in exercise intensity but as exercise intensity increases, the bicarbonate buffering of hydrogen ions accompanying lactic acid dissociation to lactate causes a rise in carbon dioxide production ($\dot{V}CO_2$) relatively faster than the rise in $\dot{V}O_2$. $\dot{V}_E$ rises proportionally with $\dot{V}CO_2$ and it is therefore possible to use various combinations of the plots of $\dot{V}_E$, ventilatory equivalents ($\dot{V}_E/\dot{V}O_2$; $\dot{V}_E/\dot{V}CO_2$), end-tidal gas concentrations and the respiratory exchange ratio (R) against time for the determination of the ventilatory threshold (T_{vent}). The T_{vent} and the related lactate threshold (T_{LAC}) are useful as indicators of aerobic fitness. These thresholds occur at a higher relative exercise intensity in children compared with adults.

During exercise children have a higher ratio of respiratory frequency to tidal volume than adults and this may reflect increased lung recoil forces in young people. During maximal exercise a respiratory frequency greater than 60 breaths per minute is not uncommon in children compared with around 30–40 breaths per minute in adults. The efficiency of pulmonary function during exercise is reflected by the ventilatory equivalent for oxygen ($\dot{V}_E/\dot{V}O_2$) and the higher the value, the less efficient the process. At the same relative exercise intensity the child has a higher $\dot{V}_E/\dot{V}O_2$ than the adult and values decline gradually with age suggesting that there is some maturation of the ventilatory control mechanisms during growth. Gas exchange in the alveoli is, however, determined by alveolar rather than pulmonary ventilation and young people's alveolar ventilation is more than adequate to optimise gas exchange. $\dot{V}_E$ during exercise seldom exceeds 70% of maximal voluntary ventilation and does not limit the aerobic fitness of healthy children and adolescents [6].

$\dot{V}O_2$ can be expressed as the product of cardiac output ($\dot{Q}$) and arteriovenous (AV) oxygen difference with $\dot{Q}$ being a function of heart rate (HR) and stroke volume (SV). Ethical and methodological issues have limited our understanding of $\dot{Q}$ and SV responses to exercise, particularly at maximal levels, but the available data are consistent. $\dot{Q}$ increases with exercise intensity and during progressive submaximal exercise it parallels the rise in $\dot{V}O_2$. At the onset of exercise in the upright position, skeletal muscle contractions in the legs mobilise the blood pooled by gravity and initiate a 30–40% rise in SV which then remains stable to the point of exhaustion. Any further increase in $\dot{Q}$ with exercise is due to HR which rises steadily with progressive exercise before tapering-off to its maximum. HR_{max} is subject to wide individual variations but during youth, it is independent of age, maturation, sex and aerobic fitness. The increase in $\dot{Q}_{max}$ with age is therefore wholly due to the increase in SV_{max} which reflects the growth in left ventricular size [4, 7].

AV oxygen difference increases with progressive exercise but as it is calculated from measurements of $\dot{V}O_2$ and estimates of the related $\dot{Q}$ at maximal exercise, few secure data are available. Evidence is equivocal with some studies reporting age-related increases in maximal AV oxygen difference and others observing no relationship with age. Although data showing an age-related increase in AV oxygen difference must be treated cautiously the lower blood haemoglobin concentration and lower blood volume in children than in adults supports the premise that adults have a greater arterial oxygen content and therefore potentially a higher maximal AV oxygen difference. However, children can at least partially compensate for their lower blood haemoglobin. Children and adolescents have been observed to have a greater facility than adults for unloading oxygen at the tissues and this may be influenced by the decline in 2,3-diphosphoglycerate with age [7, 8].

Oxygen Utilisation

During exercise muscle contraction is supported by the energy released during the hydrolysis of adenosine triphosphate (ATP) but the intramuscular stores of ATP are limited and for exercise to be sustained ATP must be rapidly regenerated. Resynthesis of ATP from phosphocreatine (PCr) occurs almost instantaneously once exercise commences but reaches its peak within 2 s and declines thereafter. The anaerobic catabolism of glycogen/glucose to pyruvate is initiated very rapidly and reaches peak production of ATP within 5 s. However, for glycolysis to be sustained pyruvate must be removed, primarily through its conversion to carbon dioxide and water by oxidative metabolism in the mitochondria or by its reduction to lactate. The rate of lactate formation during exercise is therefore dependent on the balance between aerobic and anaerobic metabolism of pyruvate. The greater the oxidation of pyruvate the less lactate produced. As relative exercise intensity increases lactate production increases and some of the lactate diffuses out of the muscle fibres and into the blood where, in relation to exercise intensity, it provides a useful indicator of aerobic fitness.

Aerobic metabolism through the tricarboxylic acid cycle is relatively slow to adapt to the demands of exercise and the time constant (τ) of the response to high intensity exercise is about 20 s in young people. The rate at which ATP can be generated is much slower than that of anaerobic ATP resynthesis but the aerobic pathway has a much greater capacity for energy generation than the anaerobic pathways. Although it makes a relatively minor contribution during short-term high-intensity exercise, the contribution to ATP resynthesis gradually increases with time and, in children, the aerobic pathway provides most of the energy during exercise of longer than 1 min duration.

Data are sparse but the balance of evidence suggests that muscle ATP stores are similar in children and adults but PCr stores increase with age. Liver and muscle glycogen stores are lower in children who appear to be less capable than adolescents and adults of resynthesizing ATP anaerobically, probably through lower activity of glycolytic enzymes. In response to high intensity exercise energy generation through anaerobic glycolysis progressively rises with age. In contrast, children and adolescents appear well-adapted to prolonged exercise with an enhanced ability to generate energy from aerobic metabolism.

Evidence is limited by ethical and methodological constraints but consistent data from several methodologies suggest that children's ratio of aerobic to anaerobic enzyme activity, percentage of type 1 fibres in exercising muscle and lipid utilisation may be higher than in adults and that they are therefore well-equipped to use aerobic pathways during exercise [9].

Maximal or Peak $\dot{V}O_2$

$\dot{V}O_{2max}$ is determined in a laboratory during an incremental exercise test to voluntary exhaustion. $\dot{V}O_2$ progressively increases with exercise intensity up to a point at which no additional increase in $\dot{V}O_2$ takes place, despite a well-motivated subject being able to increase further the intensity of exercise. Additional exercise above the intensity where $\dot{V}O_2$ reaches its maximum is assumed to be supported exclusively by anaerobic re-synthesis of ATP resulting in an intracellular accumulation of lactate, acidosis and inevitably termination of exercise. During an appropriate $\dot{V}O_{2max}$ test the sampling of blood lactate at a range of submaximal intensities can provide another physiological measure of aerobic fitness [10, 11].

The conventional criterion for the attainment of $\dot{V}O_{2max}$ in adults is a levelling-off or plateau in $\dot{V}O_2$ despite an increase in exercise intensity. Astrand [2] was the first to document that many young people complete such a test without a levelling-off in $\dot{V}O_2$ and subsequent studies with large samples of both children and adolescents have demonstrated that those who plateau do not have higher $\dot{V}O_2$, HR, R, or post-exercise blood lactate values than those not eliciting a $\dot{V}O_2$ plateau [12]. Furthermore, it has been showed in children that $\dot{V}O_2$ does not increase with supramaximal exercise above values observed in a progressive exercise test in which a plateau is not exhibited [13]. As the term $\dot{V}O_{2\,max}$ conventionally implies the existence of a $\dot{V}O_2$ plateau, it has become more common in paediatric exercise physiology to define the highest $\dot{V}O_2$ observed during an exercise test to exhaustion as peak $\dot{V}O_2$. If a child has been habituated to the laboratory environment and shows clear signs of intense effort supported by objective criteria (e.g. HR $>95\%$ of maximum, R >1.0) peak $\dot{V}O_2$ can be accepted as equal to $\dot{V}O_{2\,max}$ and a maximal index of aerobic fitness [11, 12].

Young people's peak $\dot{V}O_2$ has been determined using a wide range of ergometers but the treadmill and cycle ergometer are the ergometers of choice in most paediatric physiology laboratories. Although the correlation between cycle ergometer and treadmill values is about 0.90, as treadmill running engages a larger muscle mass than cycling, peak $\dot{V}O_2$ is more likely to be limited by central than peripheral factors and is typically 8–10% higher during treadmill running than cycle ergometry [10, 11]. Peak $\dot{V}O_2$ is, however, a robust

Fig. 1. Peak oxygen uptake by age. Redrawn from Armstrong and Welsman [11].

variable which, on a specific ergometer, is generally independent of exercise protocol with a typical error across three trials a week apart of about 4% [14].

As the determination of peak $\dot{V}O_2$ requires sophisticated apparatus and technical expertise a number of simple performance tests have been developed to estimate aerobic fitness. The 20 mSRT is currently the most popular test but although part of the variability in 20 mSRT scores can be explained by variability in peak $\dot{V}O_2$ a range of factors other than peak $\dot{V}O_2$ also contribute to children's 20 mSRT performance. With children these factors include, e.g. running efficiency, anaerobic fitness, environmental conditions, footwear, running surfaces, test familiarisation, attention spans, motor skills, motivation and, crucially, body mass and composition. The work done in each shuttle is dependent on body mass and, in particular, overweight children are disadvantaged in tests of this type. Tests such as the 20 mSRT are useful field tests of *performance* but they are no substitute for a direct laboratory assessment of peak $\dot{V}O_2$ and hypotheses based on estimated aerobic fitness data from these tests need to be interpreted cautiously.

Peak $\dot{V}O_2$ and Age

Young people's peak $\dot{V}O_2$ in relation to age has been well documented and a plethora of cross-sectional data indicates that boys' peak $\dot{V}O_2$ demonstrates a progressive increase with age. Girls' data demonstrate a similar but less consistent trend with a tendency to level-off from about 14 years of age. Figure 1 illustrates the mean values of studies involving almost 5,000 treadmill-determined peak $\dot{V}O_2$ scores from untrained 8- to 16-year-olds. The regression equations indicate that peak $\dot{V}O_2$ increases by 80% between the ages of 8 and 16 years in girls and by 150% in boys over the same age range [11].

Longitudinal studies of treadmill-determined peak $\dot{V}O_2$ provide a more secure analysis in relation to age but relatively few investigations of untrained children have included reasonable sample sizes (n >20 male or female participants). Rigorous studies of Canadian [15] and Dutch [8] children and Czech boys [16] were initiated in the 1970s and more recently data have been reported on English children [8, 17] (table 1).

The boys' data reflect the cross-sectional findings and offer a consistent picture of a gradual increase in peak $\dot{V}O_2$ from 8 to 18 years. The Canadian boys experienced a 164% increase in peak $\dot{V}O_2$ from 8 to 16 years and the peak $\dot{V}O_2$ of the European boys doubled from 11 to 17/18 years. The largest annual increases occurred between 13 and 15 years in all studies covering this age range. Girls' data are less clear. The Canadian girls experienced an annual increase in peak $\dot{V}O_2$ of 12% over the age range 8–13 years (total increase in peak $\dot{V}O_2$ of 73%) and the English girls experienced a further 12% increase from 13 to 17 years. However, the Dutch girls followed from 13 to 16 years exhibited a levelling-off with only a 2% increase in peak $\dot{V}O_2$ from age 14 to 16 years. This apparent plateauing of girls' peak $\dot{V}O_2$ from age 14 years is consistent with findings from several cross-sectional studies.

Peak $\dot{V}O_2$ and Growth

Peak $\dot{V}O_2$ is strongly correlated with body size and much of the increase in peak $\dot{V}O_2$ with age illustrated in figure 1 and table 1 reflects the overall increase in body size during the transition from childhood through adolescence and into young adulthood. Researchers have attempted to control for body size during growth by dividing peak $\dot{V}O_2$ by body mass and expressing it as the simple ratio millilitres of oxygen per kilogram body mass per minute (i.e. $ml \cdot kg^{-1} \cdot min^{-1}$). When peak $\dot{V}O_2$ is expressed in this manner, a different picture emerges from that apparent when absolute values of peak $\dot{V}O_2$ ($litres \cdot min^{-1}$) are used. Boys' mass-related peak $\dot{V}O_2$ remains remarkably stable over the age range 8–18 years whereas girls' values generally fall with increasing age. Boys demonstrate higher mass-related peak $\dot{V}O_2$ than girls throughout childhood and adolescence with the sex difference being reinforced by girls' greater accumulation of body fat during puberty [8, 11].

Although the expression of peak $\dot{V}O_2$ in ratio with body mass has been the conventional method of partitioning out the influence of body mass compelling arguments have been presented to question the validity of using ratio scaling to remove the influence of body size from size-dependent measures such as peak $\dot{V}O_2$.

Table 1. Longitudinal studies of treadmill-determined peak $\dot{V}O_2$: values are shown as mean (SD)

Study	Country	Age, years	n	Peak $\dot{V}O_2$, litres · min^{-1}
Boys				
Mirwald and Bailey [15]	Canada	8	75	1.42 (0.21)
		9	75	1.60 (0.20)
		10	75	1.77 (0.22)
		11	75	1.93 (0.25)
		12	75	2.12 (0.29)
		13	75	2.35 (0.38)
		14	75	2.66 (0.46)
		15	75	2.98 (0.48)
		16	75	3.22 (0.45)
Sprynarova et al. [16]	Czechoslovakia	11	90	1.74 (0.23)
		12	90	2.02 (0.31)
		13	90	2.20 (0.35)
		14	90	2.76 (0.45)
		15	90	3.24 (0.47)
		16	39	3.38 (0.47)
		17	39	3.38 (0.48)
		18	39	3.53 (0.48)
Amsterdam Growth and Health Study (Van Mechelen, pers. commun., in Armstrong and Welsman [8])	Netherlands	13	83	2.66 (0.39)
		14	80	3.07 (0.48)
		15	84	3.37 (0.43)
		16	79	3.68 (0.52)
Armstrong and Welsman [17]	United Kingdom	11.2	71	1.80 (0.25)
		12.1	71	2.15 (0.34)
		13.1	71	2.45 (0.47)
		17.0	37	3.55 (0.55)
Girls				
Mirwald and Bailey [15]	Canada	8	22	1.27 (0.14)
		9	22	1.39 (0.15)
		10	22	1.53 (0.20)
		11	22	1.72 (0.28)
		12	22	1.97 (0.36)
		13	22	2.20 (0.39)
Amsterdam Growth and Health Study (Van Mechelen, pers. commun., in Armstrong and Welsman [8])	Netherlands	13	97	2.45 (0.31)
		14	97	2.60 (0.35)
		15	96	2.58 (0.34)
		16	96	2.65 (0.33)
Armstrong and Welsman [17]	United Kingdom	11.2	61	1.63 (0.28)
		12.2	61	1.93 (0.28)
		13.1	61	2.14 (0.28)
		17.0	26	2.39 (0.40)

Ratio scaling assumes that peak $\dot{V}O_2$ increases in direct proportion with body mass and therefore can be described by the allometric relationship peak $\dot{V}O_2 = a \cdot mass^{1.0}$, where a is a constant multiplier and 1.0 is the mass exponent. Many studies have documented that this assumption is not valid in both children and adults. Typical of these studies are the findings presented by Welsman and Armstrong [18] for a large representative dataset of untrained 12-year-old boys and girls. This study identified a mass exponent of 0.66 with 95% confidence intervals encompassing the range 0.58–0.74 and clearly precluding the value 1.0.

It has long been recognised that traditional ratio scaling, rather than removing the influence of body size, in fact 'over-scales' and thus favours light individuals and penalises heavier ones. This effect can be demonstrated if the scaled variable (peak $\dot{V}O_2$ in $ml \cdot kg^{-1} \cdot min^{-1}$) is correlated with the original body mass variable. Theoretically, if the scaling has appropriately removed the effect of body size, the relationship between the two variables should be not significantly different from zero. Several studies have demonstrated this not to be the case and the effect was illustrated clearly in the dataset of 12-year-olds described above where relationships of $r = -0.476$ and $r = -0.640$ were identified for the boys and girls, respectively; values which demonstrate unequivocally the failure of simple ratio scaling to produce a size-free variable.

Where ratio scaling is used within a study without statistical verification, the assumption that the data conform to a directly proportional relationship should lead to the findings being viewed with caution. How inappropriate scaling using ratio standards can lead to misplaced interpretation of physiological mechanisms has been clearly demonstrated in studies which have applied both traditional ratio and appropriate allometric scaling techniques to control for body size.

For example, Welsman et al. [19] used both ratio and allometric (log-linear analysis of covariance) scaling to remove the effects of body size from peak $\dot{V}O_2$ in groups of prepubertal boys and girls, circumpubertal boys and girls, and adult men and women. In males, the conventional ratio analyses were consistent with the literature showing no significant differences between the age groups. In contrast, the allometric analyses, based upon a mass exponent common to all groups of 0.80 (95% confidence intervals 0.72–0.88), revealed significant, progressive increases in peak $\dot{V}O_2$ across groups, indicating that relative to body size, peak $\dot{V}O_2$ increases during growth rather than remaining static. Analysis of the females' data showed mass-related peak $\dot{V}O_2$ to follow the expected pattern with no change from prepuberty to circumpuberty but a significant decrease from circumpuberty to adulthood. The allometric analysis however showed that, relative to body size, females' peak $\dot{V}O_2$ significantly increases into puberty with no subsequent decline into young adulthood.

Table 2. Multilevel regression model for peak oxygen uptake in 11- to 17-year-old (adapted from Armstrong and Welsman [17])

Parameter	Estimate (SE)
Fixed:	
Constant	−1.9005 (0.1400)
$\log_e$ mass	0.8752 (0.0432)
$\log_e$ stature	n.s.
$\log_e$ skinfolds	−0.1656 (0.0174)
Age[a]	0.0470 (0.0094)
Sex	−0.1372 (0.0121)
Age * sex	−0.0214 (0.0053)
Maturity 2	0.0341 (0.0094)
Maturity 3	0.0361 (0.0102)
Maturity 4	0.0537 (0.0116)
Maturity 5	n.s.

[a] Age was centred on the group mean age of 12.9 years.

The application of allometry to longitudinal data is complex but multilevel modelling techniques represent a sensitive and flexible approach which enables, e.g. body size, age and sex effects to be partitioned concurrently within an allometric framework [18]. Armstrong and Welsman [17] applied multilevel modelling to the interpretation of peak $\dot{V}O_2$ in 11- to 17-year-old boys and girls, and founded the analysis on 388 peak $\dot{V}O_2$ determinations. The multilevel model which represented the best statistical fit for the data is presented in table 2. This model demonstrated that both body mass and fatness (as reflected by sum of two skinfolds) together were the key anthropometric determinants of peak $\dot{V}O_2$ with the positive effect for body mass combined with the negative influence of increasing skinfold thicknesses indicative of the importance of lean body mass as a determinant of growth in peak $\dot{V}O_2$.

In agreement with the cross-sectional data presented earlier [18] the data challenged the conventional view of peak $\dot{V}O_2$ during growth. The significant, positive coefficient noted for age demonstrated that there was a progressive increase in aerobic fitness in both sexes across the age range 11–17 years which was independent of and in addition to changes in peak $\dot{V}O_2$ with body mass and fatness. However, the significant coefficient for age by sex interaction, demonstrated that the magnitude of the age-related increase was smaller in the girls than the boys with the discrepancy between the sexes increasing with age (table 2).

Peak $\dot{V}O_2$ and Maturation

As young people grow they also mature and the physiological responses of adolescents must be considered in relation to biological as well as chronological age. There is evidence from longitudinal studies that an enhanced increase in peak $\dot{V}O_2$ is associated with the attainment of peak height velocity [15]. Other studies have observed skeletal age and serum testosterone concentration to make no significant contribution to the explained variance in peak $\dot{V}O_2$ beyond that accounted for by chronological age, stature and body mass [4, 8].

With maturation classified according to Tanner's indices of pubic hair, several studies have reported mass-related peak $\dot{V}O_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$) to be unrelated to maturation in both boys and girls [4]. However, a study of 176 12-year-olds demonstrated that although peak $\dot{V}O_2$ in ratio with body mass remained unchanged with stage of maturation, when body mass was appropriately accounted for using allometry there was a significant effect of maturation on peak $\dot{V}O_2$ independent of body mass [20].

Armstrong and Welsman [17] introduced stages 2–5 for pubic hair development into their multilevel regression model of 11- to 17-year-olds' aerobic fitness and showed an incremental effect of stage of maturation on peak $\dot{V}O_2$ independent of chronological age and body mass (table 2). The positive effect of maturation on aerobic fitness was consistent for both boys and girls. When skinfold thicknesses were introduced into the model the stage of maturation remained a significant covariate, in all but stage 5, but the magnitudes of the effect were markedly reduced. They concluded that fat free mass was the predominant influence in the increase in peak $\dot{V}O_2$ from 11 to 17 years but both chronological age and stage of maturation were identified as explanatory variables of peak $\dot{V}O_2$ independent of body size and fatness.

Peak $\dot{V}O_2$ and Sex

Boys' peak $\dot{V}O_2$ values both in absolute terms and adjusted allometrically for differences in body size have been showed to be consistently higher than those of girls by late childhood and the sex difference becomes more pronounced as young people progress through adolescence. Sex differences during childhood and adolescence have been attributed to a combination of factors including habitual physical activity, body composition, blood haemoglobin concentration and maximal SV.

Girls generally have lower levels of physical activity than boys but the evidence relating habitual physical activity to young people's peak $\dot{V}O_2$ is weak. Both boys' and girls' current physical activity patterns demonstrate that they rarely experience the intensity and duration of physical activity associated with increases in peak $\dot{V}O_2$ and habitual physical activity is therefore unlikely to contribute to sex differences in peak $\dot{V}O_2$ [4, 5].

Prior to puberty sex differences in body composition and blood haemoglobin concentration are minimal but boys have higher levels of aerobic fitness than girls. There are no data to support boys having a higher HR_{max} or maximal AV O_2 difference than girls but recent evidence indicates that boys have higher maximal stroke indices than girls. This probably reflects the larger values of left ventricular mass and volume and greater heart mass relative to body mass reported in boys [7, 8].

Marked sex differences in muscle mass become apparent during adolescence. Girls experience an adolescent spurt in muscle mass but it is less dramatic than that of boys. Boys' relative muscle mass increases from 42 to 54% of body mass between 5 and 16 years whereas girls' muscle mass increases from 40 to 45% of body mass between 5 and 13 years and then, in relative terms, declines due to an increase in fat mass during adolescence. Boys' greater muscle mass not only facilitates the use of oxygen during exercise but also supplements the venous return to the heart and therefore augments exercise SV [7, 8].

During puberty, boys' blood haemoglobin concentration increases whereas girls' values plateau around 13 years of age. Haemoglobin concentration is significantly correlated with peak $\dot{V}O_2$ and the boys' enhanced O_2-carrying potential is likely to be a contributory factor to the sex difference in peak $\dot{V}O_2$. By the mid to late teens boys' superior haemoglobin concentration supports their greater muscle mass and SV_{max} in attaining higher peak $\dot{V}O_2$ than girls [7, 8].

Secular Trends in Peak $\dot{V}O_2$

In previous sections we have demonstrated the importance of body size, body composition and maturation in the interpretation of young people's peak $\dot{V}O_2$. Several authors have investigated secular trends in aerobic fitness but no published study involving the direct determination of peak $\dot{V}O_2$ has appropriately controlled for body size and addressed this issue. A review of peak $\dot{V}O_2$ data from children and adolescents who have volunteered for exercise tests over the last 50 years does not indicate a secular trend in aerobic fitness (e.g. see data in table 1). Conversely, data from tests involving the transport of body mass (e.g. 20 mSRT), indicate that aerobic performance has declined over time [21]. This might be largely a reflection of the rise in body fatness over the last two decades rather than a true reduction in peak $\dot{V}O_2$.

A study of Wedderkop et al. [22] provides some insights into potential secular trends. They analysed data from two cross-sectional studies of 9-year-old Danish children performed 12 years apart. On both occasions fitness was estimated from a maximal work test (watt-max test) which involved the children exercising to exhaustion on a cycle ergometer. Unfortunately, respiratory gases were not analysed so peak $\dot{V}O_2$ was predicted in $ml \cdot kg^{-1} \cdot min^{-1}$ from the watt-max data. The boys tested in 1997–1998 were less fit but fatter than those in 1985–1986, whereas no overall differences in fitness or fatness were found between the girls tested 12 years apart. When the sample was split into deciles according to fitness levels it was noted that the fitness of the fittest boys had not changed over 12 years but the fittest girls had a higher level of fitness recorded on the first test occasion. Both the boys and girls in the lowest fitness decile were less fit in 1997–1998 than in 1985–1986. The difference between the most fit and the least fit deciles increased over time in both sexes. However, the decrease in predicted peak $\dot{V}O_2$ (in $ml \cdot kg^{-1} \cdot min^{-1}$) of the least fit groups was partly explained by a higher body mass.

Secular trends in peak $\dot{V}O_2$ data expressed in ratio with body mass need to be interpreted cautiously and a decrease in young people's aerobic fitness over time remains to be proven. However, it appears that the well-documented secular increase in body mass is not being accompanied by a corresponding increase in aerobic fitness, with the inevitable result that in activities which involve moving body mass young people's aerobic performance is declining.

Blood Lactate

Lactate is continuously produced in skeletal muscles and exercise-driven increases in the anaerobic resynthesis of ATP result in a correspondingly greater production of lactate. As described earlier, during progressive exercise the amount of lactate production is a function of the balance between the anaerobic and aerobic metabolism of pyruvate. The greater the aerobic contribution the lower the lactate production.

For ethical reasons, blood rather than muscle lactate is sampled to obtain information about muscle lactate production and changes in blood lactate accumulation are assumed to reflect changes in muscle lactate formation. Blood lactate levels cannot be assumed to have a consistent quantitative relationship with muscle lactate production. Lactate may be produced in some fibres whilst being simultaneously consumed in others, therefore the net lactate output of muscle does not directly reflect muscle production. Furthermore, once lactate diffuses into the blood it is removed by oxidation in the heart or skeletal muscles, or is converted to glucose through gluconeogenesis in the liver. The lactate concentration of sampled blood is therefore a function of several processes including muscle production, muscle consumption, rate of diffusion into the blood and rate of removal from the blood. However, during progressive exercise blood lactate accumulation in relation to exercise intensity provides a useful indicator of aerobic fitness.

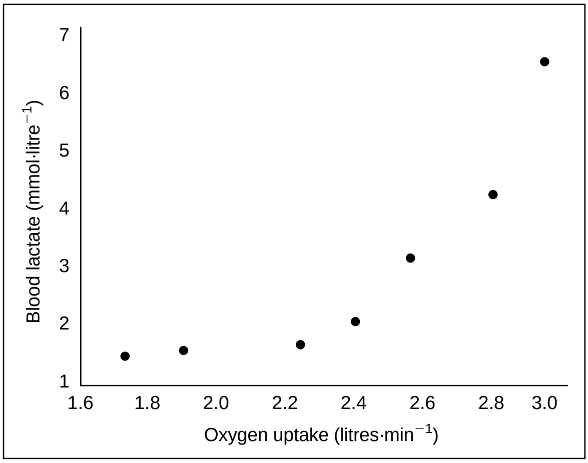


Fig. 2. Blood lactate response to exercise in relation to oxygen uptake.

Blood Lactate Responses to Exercise

In response to incremental exercise blood lactate accumulation typically increases as shown in figure 2. At the onset of moderate exercise, there are minimal changes in blood lactate with rate of diffusion into the blood being matched by rate of removal from the blood. As the exercise intensity progressively increases a point is reached where blood lactate levels begin to rise rapidly with a subsequent steep rise until exhaustion. The point at which blood lactate increases non-linearly is referred to as the T_{LAC} [4, 10].

T_{LAC} can be determined from visual inspection of the inflection in blood lactate responses, mathematical interpolation, or by defining the point of inflection as a 1 mM increase over baseline levels. A clear inflection point is not always observable and fixed blood lactate reference points have been used in some studies. Various thresholds have been proposed for use with young people but supporting evidence for specific blood lactate concentrations such as 2.0, 2.5 or 4.0 mM is sparse and conflicting. For example, during an incremental test to peak $\dot{V}O_2$ the peak blood lactate level of some children may be less than 4.0 mM. The maximal lactate steady state (MLSS) defines the highest exercise intensity which can be maintained without incurring a progressive accumulation of blood lactate and it therefore represents the highest point where blood lactate diffusion and removal are in equilibrium. Exercise can continue for prolonged periods at the MLSS and it provides a sensitive measure of submaximal aerobic fitness and a valuable marker of the transition from heavy to very heavy exercise. Exercise above the MLSS results in a steady increase in both blood lactate and $\dot{V}O_2$ until terminated by exhaustion [4, 23].

Blood Lactate in Children

The literature describing young people's blood lactate responses to submaximal exercise is confounded by methodological issues such as mode of exercise (e.g. cycling or running), site of sampling (e.g. artery, vein, capillary), timing of measurement (to allow diffusion from muscle to blood), blood preparation (e.g. serum, plasma, whole or lysed blood) and assay techniques (enzymatic-electrochemical, enzymatic-spectrophotometric). Nevertheless, regardless of methodology a consistent finding is that children accumulate less blood lactate than adults during both submaximal and maximal exercise. There is a negative correlation between T_{LAC} as a percentage of peak $\dot{V}O_2$ and age and, in most studies, the MLSS occurs at a lower absolute level of blood lactate but at a higher relative exercise intensity in young people than in adults. Studies examining specific relationships between measures of maturity (e.g. blood or salivary testosterone concentration or stages of sexual maturity) have been unable to substantiate an independent effect of maturity on blood lactate. Few studies have included both boys and girls and sex differences in blood lactate accumulation remain to be established [4, 10].

$\dot{V}O_2$ Kinetics

The $\dot{V}O_2$ kinetic response can be defined in relation to a number of identifiable exercise intensity domains, namely moderate, heavy, very heavy and severe. Moderate exercise encompasses all exercise intensities below T_{LAC} (or T_{vent}) and is characterised by three phases (fig. 3). At the onset of constant intensity exercise there is an almost immediate increase in $\dot{V}O_2$ measured at the mouth. This cardiodynamic phase is closely associated with the increase in $\dot{Q}$ which occurs prior to the arrival at the lungs of venous blood from the exercising muscles. The cardiodynamic phase (phase I) is therefore independent of oxygen consumption at the muscles and is predominantly a reflection of the increase in pulmonary blood flow with exercise. Phase I is followed by a rapid exponential increase in $\dot{V}O_2$ (phase II) that drives $\dot{V}O_2$ to the steady state value (phase III). Phase II (referred to as the primary component) develops as a result of an additional effect of the increased oxygen extraction in the blood perfusing the exercising muscles and reflects within about 10% the kinetics of oxygen consumption at the muscles, although there is a time delay between events at the muscles and those recorded at the lungs. The speed of the phase II $\dot{V}O_2$ kinetics is invariant in the moderate domain and is described by the time constant which represents the time taken to achieve 63% of the change in $\dot{V}O_2$. During phases I and II, ATP re-synthesis cannot be met fully by the $\dot{V}O_2$ and the additional energy requirements of the exercise are met primarily by the

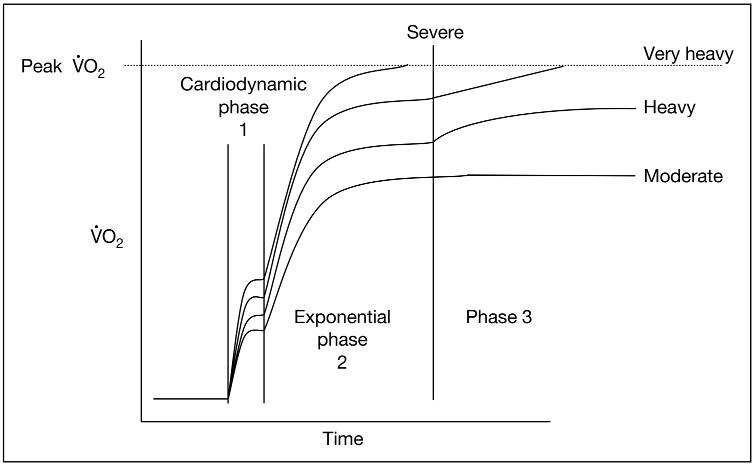


Fig. 3. The three phases of the kinetic rise in oxygen uptake in response to a step change in exercise in four different exercise intensity domains. Redrawn from Fawkner and Armstrong [27].

breakdown of PCr with minor contributions from oxygen stores and anaerobic glycolysis, but blood lactate is not significantly elevated above pre-exercise values (fig. 2). The oxygen equivalent of these energy sources is referred to as the oxygen deficit which indicates the intracellular perturbation caused by the exercise. The faster the τ, the smaller the oxygen deficit. Phase III occurs within about 2 min (or 4τ) and is the point where venous oxygen content reaches its nadir and $\dot{Q}$ plateaus. Within the moderate exercise domain $\dot{V}O_2$ increases to the steady state (phase III) with a gain of about $10\,\mathrm{ml} \cdot \mathrm{min}^{-1} \cdot \mathrm{W}^{-1}$ above that found during unloaded pedalling (fig. 3).

The heavy exercise domain is defined by exercise of intensity falling between T_{LAC} and MLSS. Some researchers prefer to use critical power as the upper marker of the heavy domain [24]. During heavy exercise, anaerobic glycolysis makes a larger contribution to the oxygen deficit than during moderate exercise but over time blood lactate accumulation is stable reflecting a balance between the rate of appearance and rate of removal. The phase II gain is similar to that observed during moderate exercise but within 2–3 min of the onset of exercise a slow component of $\dot{V}O_2$ kinetics is superimposed upon the primary $\dot{V}O_2$ response and the achievement of a steady-state may be delayed by 10–15 min (fig. 3). The gain of the steady state in adults may be as high as $13\,\mathrm{ml} \cdot \mathrm{min}^{-1} \cdot \mathrm{W}^{-1}$. Possible contributors to the slow component include the effects of lactate, catecholamines, temperature, cardiac and ventilatory work, potassium, less efficient phosphate-oxygen coupling, reduced chemical-mechanical coupling efficiency, and recruitment of lower-efficiency fast twitch motor units. The mechanisms underlying the slow component remain speculative but it appears that over 80% of the additional $\dot{V}O_2$ originates from the exercising muscle [25].

Very heavy exercise comprises exercise intensities lying between MLSS (or critical power) and peak $\dot{V}O_2$ as assessed during an incremental exercise test. In the very heavy domain, a steady state is not achieved, the slow component causes $\dot{V}O_2$ to rise to its peak level (fig. 3) and lactate increases until the exercise is terminated by exhaustion. Exercise in the very heavy domain therefore presents a range of intensities at which it is possible to reach peak $\dot{V}O_2$ and clearly illustrates the futility of using % peak $\dot{V}O_2$ (or % $\dot{V}O_{2max}$) to define exercise intensity or relative stress. During severe exercise, where the projected $\dot{V}O_2$ is greater than peak $\dot{V}O_2$, the response is truncated with the rapid attainment of peak $\dot{V}O_2$ (fig. 3) [26, 27].

$\dot{V}O_2$ Kinetics in Children

A high degree of rigour is required to elucidate $\dot{V}O_2$ kinetics in children. Small $\dot{V}O_2$ amplitudes and large breath-to-breath variations are inherent to children's response profiles and reduce the confidence with which kinetic parameters can be estimated. Consequently, confidence intervals may be beyond accepted limits unless sufficient identical transitions are aligned and averaged to improve the signal-to-noise ratio. Data from young people are sparse and the literature has been clouded by studies incorporating an inadequate number of exercise transitions, inappropriate modelling techniques, poor adherence to specific exercise domains and/or small numbers of participants. Few studies have reported the 95% confidence intervals with which they are able to estimate the model parameters. However, recent well-designed studies have provided valuable insights into children's responses to transient exercise [27, 28].

Exercise below T_{LAC}

It has been demonstrated that during exercise below T_{LAC} the $\dot{V}O_2$ dynamic response to exercise is significantly faster in children compared with adults, resulting in a smaller absolute and relative oxygen deficit. There are no sex differences in children's $\dot{V}O_2$ kinetic responses to moderate exercise but the issue of a potential independent effect of maturation on $\dot{V}O_2$ kinetics has not been addressed. Regardless of whether it is expressed in absolute terms (litres $\cdot$ min^{-1}) or with body mass appropriately controlled, peak $\dot{V}O_2$ is not related to the τ of $\dot{V}O_2$ during moderate exercise in children. Age effects on the below T_{LAC} phase II gain are less clear but the balance of evidence suggests that a greater oxygen cost of exercise is found in children than in adults [27, 28].

Children's faster increase in $\dot{V}O_2$ to a new steady state and therefore lower contribution to ATP resynthesis from anaerobic sources during the non-steady state, may be considered to be due to a more efficient oxygen delivery system, a greater relative capacity for oxygen utilisation or both. There is no strong evidence to suggest that delivery of oxygen to the mitochondria is enhanced in children compared with adults or indeed that increased availability of oxygen to the working muscles speeds $\dot{V}O_2$ kinetics during moderate exercise. The faster τ and smaller relative oxygen deficit are therefore likely to be indicative of children's better mitochondrial capacity for oxidative phosphorylation.

Exercise above T_{LAC}

Elucidating $\dot{V}O_2$ kinetic responses above T_{LAC} requires precisely relating the response to a specific exercise domain and as the absolute work rate equivalents of the exercise domains are smaller in children than adults this sets a formidable challenge. Several studies have not discriminated between the heavy and very heavy exercise domains and used an arbitrary point between T_{LAC} and peak $\dot{V}O_2$ to set the exercise intensity. Nevertheless, consistent findings across the heavy and very heavy exercise domains have included children's faster phase II τ, smaller oxygen deficit and greater gain of the primary component $\dot{V}O_2$ response. Some studies have indicated the absence of a slow component of $\dot{V}O_2$ during heavy exercise but more rigorous investigations have established that children do exhibit a slow component response which increases with age [29].

The only longitudinal study to be published to date clearly identified the presence of a slow component of $\dot{V}O_2$ in both prepubertal boys and girls [29]. The magnitude of the slow component increased over a 2-year period and was associated with a reduction in the relative amplitude of the primary phase and a slowing of the primary kinetics. In contrast to exercise below T_{LAC}, boys appear to have a faster τ than girls during heavy exercise and the slow component contribution to the total change in $\dot{V}O_2$ amplitude during exercise is greater in girls [30]. Neither the primary τ nor the magnitude of the slow component are related to peak $\dot{V}O_2$ in either boys or girls [26–30].

The analysis of exercise in the severe domain is fraught with complexities regarding the assumptions of the analytical model and the few data available are contradictory. Early studies suggested that $\dot{V}O_2$ kinetics were age-dependent but more recent investigations have found no differences between children and adults. The end-exercise oxygen cost, however, has been reported to be greater in children than adults in accord with findings in other exercise domains [27, 28].

The greater oxygen cost of the primary component ($ml \cdot min^{-1} \cdot W^{-1}$) and faster primary τ of children during exercise both above and below T_{LAC} suggest the presence of a developmental influence on the mitochondrial oxygen utilisation potential that supports an enhanced oxidative function during childhood.

These responses are also characteristic of subjects with a high ratio of types I:II muscle fibres and, although the evidence supporting age-dependent changes in the proportion of fibre types is equivocal, they may be indicative of a higher population of type I fibres in children [31]. Preferential recruitment of type I fibres by young people would also help to explain the increase in the amplitude of the slow component with age.

Why there are sex differences in $\dot{V}O_2$ kinetics above but not below T_{LAC} is not readily apparent. Studies with adults have reported negative relationships between % type I fibres and the primary τ and slow component in heavy exercise but no relationship between τ and % type I fibres in moderate exercise. So, if, as some studies have suggested, boys have a greater % of type I fibres than girls [30] this would be consistent with the extant literature. Alternatively, at exercise intensities above T_{LAC} oxygen delivery may play a more prominent role in limiting $\dot{V}O_2$ kinetics and boys may have a faster $\dot{Q}$ response than girls at the onset of heavy exercise. This would promote perfusion of blood to the active muscles and better match oxygen delivery to oxygen requirement [30].

Conclusions

Aerobic fitness depends upon the cardiopulmonary components of oxygen delivery and the oxidative mechanisms of the exercising muscles. The rigorous measurement and interpretation of aerobic fitness should therefore focus on these physiological and biochemical variables. The direct determination of peak $\dot{V}O_2$ is widely recognised as the criterion measure of aerobic fitness but no single measure encompasses all aspects of aerobic fitness. Blood lactate accumulation during submaximal exercise reveals improvements in muscle oxidative capacity with training in the absence of changes in peak $\dot{V}O_2$. $\dot{V}O_2$ kinetic responses to exercise provide insights into the kinetics of muscle $\dot{V}O_2$ during changes in exercise intensity in various domains. The primary time constant is not related to peak $\dot{V}O_2$.

The interpretation of the aerobic fitness of children and adolescents is confounded without consideration of age, maturation and sex. To make measures of aerobic fitness meaningful it is imperative to appropriately control for changes in body size. The use of ratio scaling to accommodate differences in body mass to make comparisons of peak $\dot{V}O_2$ within studies or between studies is widespread but data expressed in this manner should be treated with caution as the assumption that peak $\dot{V}O_2$ increases in direct proportion with body mass is not valid. Inappropriate methods of controlling for body size have therefore clouded our understanding of aerobic fitness not only during growth and maturation but also across time. Aerobic performance appears to be declining in accord with the secular increase in body mass but no published study has appropriately controlled for body mass and maturation and investigated secular changes in young people's peak $\dot{V}O_2$. The question of whether aerobic fitness is declining over time therefore remains to be answered.

References

1 Robinson S: Experimental studies of physical fitness in relation to age. Arbeitsphysiologie 1938;10:251–323.

2 Åstrand PO: Experimental Studies of Physical Working Capacity in Relation to Sex and Age. Copenhagen, Munksgaard, 1952.

3 American College of Sports Medicine: ACSM's Guidelines for Exercise Testing and Prescription. Baltimore, Williams & Wilkins, 1995.

4 Armstrong N, Welsman JR: Young People and Physical Activity. Oxford, Oxford University Press, 1997.

5 Armstrong N: Physical fitness and physical activity during childhood and adolescence; in Chan KM, Micheli LJ (eds): Sports and Children. Hong Kong, Williams & Wilkins, 1998, pp 50–75.

6 Rowland TW: Pulmonary function; in Armstrong N, Van Mechelen W (eds): Pediatric Exercise Science and Medicine. Oxford, Oxford University Press, 2000, pp 153–161.

7 Rowland TW: Cardiovascular function; in Armstrong N, Van Mechelen W (eds): Pediatric Exercise Science and Medicine. Oxford, Oxford University Press, 2000, pp 163–172.

8 Armstrong N, Welsman JR: Development of aerobic fitness during childhood and adolescence. Pediatr Exerc Sci 2000;12:128–149.

9 Armstrong N, Welsman JR: Exercise metabolism; in Armstrong N (ed): Pediatric Exercise Physiology. London, Elsevier, 2006, pp 71–98.

10 Armstrong N, Welsman J: Aerobic fitness; in Armstrong N, Van Mechelen W (eds): Pediatric Exercise Science and Medicine. Oxford, Oxford University Press, 2000, pp 65–76.

11 Armstrong N, Welsman J: Assessment and interpretation of aerobic fitness in children and adolescents. Exerc Sports Sci Rev 1994;22:435–476.

12 Armstrong N, Welsman J: The assessment and interpretation of aerobic fitness in children and adolescents: an update; in Froberg K, Lammert O, St. Hansen H, Blimkie CJR (eds): Exercise and Fitness – Benefits and Limitations. Odense, University Press, 1997, pp 173–180.

13 Armstrong N, Welsman J, Winsley R: Is peak $\dot{V}O_2$ a maximal index of children's aerobic fitness? Int J Sports Med 1996;17:356–359.

14 Welsman JR, Bywater K, Farr C, Welford D, Armstrong N: Reliability of peak $\dot{V}O_2$ and maximal cardiac output assessed using thoracic bioimpedance in children. Eur J Appl Physiol 2005;94: 228–234.

15 Mirwald RL, Bailey DA: Maximal Aerobic Power. London, Ont, Sports Dynamics, 1986.

16 Sprynarova S, Parizkova J, Bunc V: Relationships between body dimensions and resting and working oxygen consumption in boys aged 11 to 18 years. Eur J Appl Physiol 1987;56:725–736.

17 Armstrong N, Welsman JR: Peak oxygen uptake in relation to growth and maturation in 11–17 year old humans. Eur J Appl Physiol 2001;85:546–551.

18 Welsman JR, Armstrong N: Statistical techniques for interpreting body size-related exercise performance during growth. Pediatr Exerc Sci 2000;12:112–127.

19 Welsman JR, Armstrong N, Kirby BJ, Nevill AM, Winter EM: Scaling peak $\dot{V}O_2$ for differences in body size. Med Sci Sports Exerc 1996;28:259–265.

20 Armstrong N, Welsman JR, Kirby B: Peak oxygen uptake and maturation in 12-year-olds. Med Sci Sports Exerc 1998;30:165–169.

21 Tomkinson GR, Léger LA, Olds TS, Cazorla G: Secular trends in the performance of children and adolescents (1980–2000): an analysis of 55 studies of the 20 m Shuttle Run test in 11 countries. Sports Med 2003;33:285–300.

22 Wedderkopp N, Froberg K, Hansen HS, Andersen LB: Secular trends in physical fitness and obesity in Danish 9-year-old girls and boys: Odense schoolchild study and Danish substudy of the European youth heart study. Scans J Med Sci Sports 2004;14:1–6.
23 Pfitzinger P, Freedson P: Blood lactate responses to exercise in children. 2. Lactate threshold. Pediatr Exerc Sci 1997;9:299–307.
24 Fawkner SG, Armstrong N: Assessment of critical power with children. Pediatr Exerc Sci 2002;14:259–268.
25 Gaesser GA, Poole DC: The slow component of oxygen uptake kinetics in humans. Exerc Sports Sci Rev 1996;24:35–71.
26 Neder J, Whipp BJ: Kinetics of pulmonary oxygen uptake; in Armstrong N, Van Mechelen V (eds): Pediatric Exercise Science and Medicine. Oxford, Oxford University Press, 2000, pp 191–200.
27 Fawkner SG, Armstrong N: Oxygen uptake kinetic response to exercise in children. Sports Med 2003;33:651–669.
28 Barstow TJ, Schuermann B: $\dot{V}O_2$ kinetics: effects of maturation and aging; in Jones AM, Poole DC (eds): Oxygen Uptake Kinetics in Sport, Exercise and Medicine. London, Routledge, 2004, pp 331–352.
29 Fawkner SG, Armstrong N: Longitudinal changes in the kinetic response to heavy intensity exercise. J Appl Physiol 2004;97:460–466.
30 Fawkner SG, Armstrong N: Sex differences in the oxygen uptake kinetic response to heavy intensity exercise in prepubertal children. Eur J Appl Physiol 2004;93:210–216.
31 Jansson E: Age-related fiber type changes in human skeletal muscle; in Maughan RJ, Shirreffs S (eds): Biochemistry of Exercise XI. Champaign, Human Kinetics, 1996, pp 297–307.

Prof. Neil Armstrong
Children's Health and Exercise Research Centre, University of Exeter
Heavitree Road
Exeter EX1 2LU (UK)
Tel. +44 0 1392 264 106, Fax +44 0 1392 263 008, E-Mail N.Armstrong@exeter.ac.uk

Tomkinson GR, Olds TS (eds): Pediatric Fitness. Secular Trends and Geographic Variability.
Med Sport Sci. Basel, Karger, 2007, vol 50, pp 26–45

Anaerobic Fitness Tests: What Are We Measuring?

Emmanuel Van Praagh

Université Blaise Pascal, Aubière, France

Abstract

Anaerobic fitness, during growth and development, has not received the same attention from researchers as aerobic fitness. This is surprising given the level of anaerobic energy used daily during childhood and adolescence. During physical activity and sport, the child is spontaneously more attracted to short-burst movements than to long-term activities. It is, however, well known that in anaerobic activities such as sprint cycling, sprint running or sprint swimming, the child's performance is distinctly poorer than that of the adult. This partly reflects the child's lesser ability to generate mechanical energy from chemical energy sources during short-term high-intensity work or exercise. Direct measurements of the rate or capacity of anaerobic pathways for energy turnover presents several ethical and methodological difficulties. Therefore, rather than measure energy supply, pediatric exercise scientists have concentrated on measuring short-term power output by means of standardized protocol tests such as short-term cycling power tests, running tests or vertical jump tests. There is, however, no perfect test and, therefore, it is important to acknowledge the benefits and limitations of each testing method. Mass-related short-term power output was shown to increase dramatically during growth and development, whereas the corresponding increase in peak blood lactate was considerably lower. This suggests that the observed difference between children and adolescents during short-term power output testing may be related to neuromuscular factors, hormonal factors and improved motor coordination.

'The children spontaneously choose varied exercises, they readily strain themselves maximally for some seconds but heartily dislike monotonous, heavy work. Their way of living is rather of an "anaerobic character" [1].'

Scientists and practitioners in pediatrics are always struck by the impressive accumulation of results relating to aerobic fitness and prolonged maximal power output [2]. In contrast, anaerobic fitness has received much less attention. This is surprising, considering that short-term high-intensity exercise (HIE) lasting only a few seconds is a more natural pattern during childhood than prolonged low-intensity exercise [3] with children's activities being highly transitory and intermittent. In anaerobic tasks or sport events such as sprint swimming, sprint running, jumping, sprint cycling and throwing, a child's performance is distinctly poorer than that of an adult. This partly reflects the child's lesser ability to generate mechanical energy from chemical energy sources during short-term HIE. Anaerobic fitness is a quantitative trait influenced by several determinants such as genetic factors, age and gender, muscle fiber characteristics, hormonal and training factors. This chapter will focus on the What, Why and How of HIE during childhood, rather than during adulthood.

When examining secular trends in anaerobic fitness and the process of measuring such an outcome, it is essential to define the key terms for clearer understanding. The term 'anaerobic function' has been defined in many different ways and the term remains ambiguous and indiscriminately used. The subcomponents of anaerobic fitness can be broken down into power, adenosine triphosphate (ATP) production and power output. 'Power' refers to the ability of the neuromuscular system to produce the greatest possible impulse in a given time period. The time period depends on the resistance or the load against which the individual has to work and the acceleration pattern. In some physical activities, such as sprinting, jumping and throwing, it is necessary to overcome resistance with the greatest possible muscle contraction velocity at the beginning of the movement while in others, the maximal acceleration should be delayed to reach a maximal velocity for the body or parts of the body. Power production is, therefore, limited by the rate at which energy is supplied, as well as the rate of limiting glycolytic enzymes (ATP production) for the muscle contraction (ATP utilization) or in other words the rate at which the myofilaments can convert chemical energy into mechanical work.

'Anaerobic power' is the maximal anaerobic ATP per second yield by the whole organism, during short duration, maximal exercise [4]. Since the substrate utilisation cannot accurately be measured during whole-body ultra-short-term exercise (100–200 ms), it is more appropriate to measure the mechanical energy yield. Anaerobic power is characterized by the generation of very high power outputs. Compared with adults, children are not always able to put themselves under stress, particularly under laboratory conditions. Meanwhile the 'anaerobic capacity' is the maximal amount of ATP resynthesized via anaerobic metabolism (by the whole organism) during a specific type of short duration, maximal exercise [4].

Using work output to estimate or to reflect anaerobic capacity is less difficult than attempting to quantify the ATP yield using 'direct methods' (e.g. needle biopsy, nuclear magnetic resonance spectroscopy) or indirect methods such as accumulated oxygen deficit. However, interpreting the physiological implications of work outputs is more difficult. This is especially true as the mechanical work estimates not only reflect anaerobic ATP supply, but also reflect the contribution of oxidative sources of ATP, as well as the various factors involved in the transduction of chemical-to mechanical energy, also known as work done. Thus, factors which influence work estimates of anaerobic fitness are rarely completely anaerobic in nature [5–7]. 'Peak power' or 'maximal short-term power' is defined here as the highest mechanical power that can be delivered during high-intensity exercises of up to 30 s duration.

For the purpose of this review, short term HIE will be used when referring to the 'maximal' outcome performed during short-burst activities. Bailey et al. [8] showed that the median duration of prepubescent children's activity was around 6 s for low-to-medium-intensity activities and 3 s for high-intensity activities. Moreover, although it has been recently suggested that short-term spontaneous physical activity has an important effect on growth and development during childhood by modulating anabolic agents at the cellular level [9], most pediatric exercise scientists consider that anaerobic function is more performance-related and less health-related than aerobic function. However, the irony of this is that one of the most developmentally appropriate and natural ways for children to improve cardiorespiratory fitness is to employ 'above threshold' opportunities for short bursts of energy. This has been proven in popular childhood sports such as basketball, soccer, hockey and rugby. Furthermore, highly invasive techniques and painful stress in the study of healthy children cannot be justified ethically. Finally, one of the difficulties in the assessment of short-term power output in a growing child is to analyze the participation and influence of the different energy pathways. To quote Wilkie [10], 'In children, exercise scientists instead of attempting to quantify anaerobic energy yield by ATP or glycolysis, are more inspired to measure the resulting mechanical output during short-term exercise, which is the truly useful product.' This statement makes the assessment of anaerobic performance more 'powerful', since only the subject's maximal performance will be considered as the criterion. Therefore, during growth, the measurement of mechanical output during short-term high-intensity exercise is a reasonable and useful alternative for elaborating innovative techniques and procedures [11].

When dividing anaerobic fitness into its subcomponents, there is an obvious need to investigate the impact of growth on the various testing protocols used to measure anaerobic fitness and which are appropriate to use in the pediatric population. To do this, the methods of measuring anaerobic energy supply will be highlighted and the problems associated with each measure explained. Based on the methodological problems evident, the common measures that have been used to allow comparisons of the effect of time periods, gender and culture on anaerobic performance in children will be investigated.

Table 1. Muscle metabolism at rest (child/adult values for glycogen): adapted from Van Praagh [14]

Authors	Methods	Age years	Sex	ATP $\text{mM} \cdot \text{kg}^{-1}$	PCr $\text{mM} \cdot \text{kg}^{-1}$	Glycogen $\text{mM} \cdot \text{kg}^{-1}$
Eriksson [13, 15]	biopsy	12–16	male	5	20	55/80
Ferretti et al. [16]	31PNMRS	8–13	male and female	C 13.6 AU A 11.9 AU $p > 0.05$	C 47.1 AU A 44.7 AU $p > 0.05$	

A = Adult; AU = arbitrary units; C = child.

What? Developmental Muscle Energetics

Estimation of Muscle Metabolism

There are a number of methods used for measuring the anaerobic energy supply in the estimation of muscle metabolism. These include the 'direct' muscle biopsy technique, nuclear magnetic resonance spectroscopy, lactate [La^-] blood concentration and acid base balance. Each methodology is suited to different exercise environments such as when an individual is at rest or postexercise, during exercise and recovery, and when in a state of fatigue. It is important to understand the benefits and associated problems for each measure, especially when using a test on a child.

Muscle Metabolism at Rest and Postexercise

During short-term HIE, decreases in muscle ATP and in phosphocreatine (PCr) are observed along with an increase in lactate. The understanding of muscle energetics in children has improved with studies involving muscle biopsy. The first studies using the needle biopsy technique in the pediatric population were done in the US [12] and in Sweden [13]. In most reviewed studies from the needle biopsy period (1970–1985), muscle tissue was obtained during surgical intervention (trauma or orthopedic operations). Few studies on muscle storage of phosphagens have shown that the content of the peripheral energy-delivering substrates is the same for both children and adults (table 1). A limited number of reports have found low glycolytic ability in prepubescent children when compared with adults. However, the exact underlying mechanism for relatively low anaerobic function during childhood is still unclear. In several textbooks and scientific reports, it is still assumed that the rate of anaerobic glycolysis is limited in children because of their lower phospho-fructokinase (PFK) activity. However, this assumption is only discussed on the basis of the results of PFK at

Table 2. Muscle metabolism during exercise: adapted from Van Praagh [14]

Authors	Methods	Age years	Sex	PCr:(PCr + P_i)	Intracellular pH
Zanconato et al. [21]	^{31}PNMRS (calf muscles)	7–10	male	higher*	higher*
Kuno et al. [22]	^{31}PNMRS (thigh muscles)	12–15 (T and UT)	male	higher*	higher*

T = Trained; UT = untrained; *Child-adult comparison.

rest [13]. A 30% lower resting PFK activity in pubertal boys compared with adults was reported. Studies carried out in prepubertal children by Berg et al. [17] and Haralambie [18] showed a lower activity of various glycolytic enzymes, but in subsequent studies in adolescent subjects [19] no differences from adults was observed. It is interesting that during some 30 years, it was speculated that the lower glycolytic ability during short-term HIE of the child (e.g. lower lactate values, lower short-term power outputs) was due to lower glycogen content and glycolytic enzyme activities at rest. Within the limited available evidence from muscle biopsy studies, it seems necessary to consider other metabolic factors than only the muscle enzyme activities at rest or postexercise.

Muscle Metabolism during Exercise and Recovery

Differences in the adaptive response to short-term HIE might be related to growth and maturation of muscle metabolic pathways and training, but because of methodological and ethical constraints little is known about the underlying mechanisms. In the past, one problem was the lack of noninvasive methods to study muscle metabolism. The use of nuclear magnetic resonance spectroscopy (NMRS) now provides a safe and non-invasive means of monitoring intracellular inorganic phosphate (P_i), PCr, ATP and pH at rest, during exercise and recovery [20]. Zanconato et al. [21] addressed the issue of the changes in the intramuscular determinants during progressive incremental exercise (to 125% $\dot{V}O_{2max}$). They established the profiles of P_i/PCr and pH in the calf muscle of children and adults performing, at the same intensity, a progressive (plantar flexion) exercise. The minimal drop in pH seen in children and the fact that they achieved an end-exercise P_i/PCr value of only 27% of adult values, are consistent with several reports of the relatively low muscle and blood lactate responses to short-term HIE in children [9]. Kuno et al. [22] also presented evidence of a reduced muscle glycolytic ability during exhaustive exercise in children compared with adults (table 2). Taylor et al. [23] showed that 6- to 12-year-old children had higher pH levels with exercise than 20- to 29-year-old adults. With respect to the effect of training, when compared with controls, trained boys were found to have no significant difference in terms of P_i/PCr and pH at exhaustion [24].

In summary, resting values for muscle ATP and PCr have been shown to be similar for both children and adults. A limited number of reports have found a low resting glycolytic ability in prepubescents when compared to adults. During short-term HIE and recovery, intramuscular high-energy phosphate kinetics is attenuated in children compared with adults. Although NMRS has proved to be a unique tool for investigating muscle metabolism during exercise, ‘progressive plantar flexion’ may be a poor representation of whole body anaerobic responses that are routinely presented under laboratory conditions. Therefore, further research is required to establish whole body representation of anaerobic responses and in different activities using NMRS protocol.

Fatigue Induced by Short-Term HIE

Muscular fatigue appears consecutively with a short-term high-intensity task such as ‘all-out’ cycling or running sprints, but is even more evident during multiple sprint activities such as racquet sports, team sports (football, basketball, rugby) and other popular participation sports. This can be investigated by using post-exercise blood lactate or acid-base balance tests.

It is well accepted that the lower glycolytic response to maximal and supramaximal exercise during childhood compared with young adulthood is manifested by a lower post-exercise blood [La$^-$] concentration [5, 25, 26]. For instance, Hebestreit et al. [26] showed that after a 30-second Wingate leg cycling test, postexercise blood [La$^-$] was 5.7 and 14.2 mmol · l^{-1} in prepubertal boys and men, respectively. Similarly, during 10 repeated 10-second leg cycling sprints separated by 30-second recovery intervals, Ratel et al. [27] reported a 4-fold postexercise [La$^-$] increase (8.5 mmol · l^{-1}) in prepubertal boys compared with an 11-fold increase (15.4 mmol · l^{-1}) in 20-year-old men. One must keep in mind, however, that blood [La$^-$] reflects all those processes by which lactate is produced and removed [28]. Therefore, postexercise blood [La$^-$] provides only a qualitative indication of the degree of stress placed on anaerobic metabolism by particular bout of exercise, rather than a quantitative measure of glycolysis. It cannot be assumed, therefore, that children’s postexercise blood [La$^-$] is simply the result of a lower intramuscular lactate production. [La$^-$] can also be expressed relative to muscle mass and changes in fiber-type distribution. Therefore, the lower [La$^-$] may be, at least partially, attributed to lower muscle mass in children compared with adults. Cumming et al. [29] showed that when children were strongly encouraged to produce

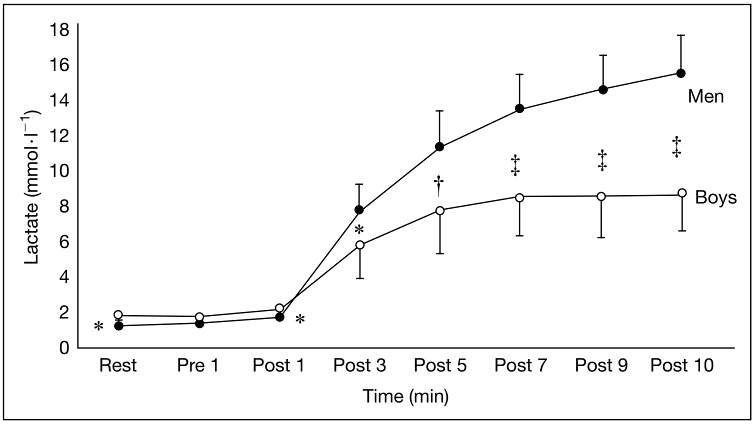


Fig. 1. Time course of blood [La] over the 10 sprint exercises, both in boys and the men. Reprinted with permission from Ratel et al. [27].

'maximal' efforts, postexercise [La^-] could be higher than previously reported. Opinion on the validity of maximal blood [La^-] as an estimate of anaerobic capacity is still under debate [30]. Moreover, a number of methodological issues with respect to lactate determination can significantly influence blood levels. In pediatric exercise research, these problems were reviewed by Welsman and Armstrong [31].

In the 1980s some authors suggested that the lower anaerobic performance in children was due to their lower ability to reach a maximal acidosis level [32]. Hebestreit et al. [26] reported that after a 30-second leg cycling test, venous blood pH only reached 7.32 in prepubescent boys compared with 7.18 in 25-year-old men. Despite a lesser reliance on glycolytic energy pathways in children, these studies showed that blood pH was slightly modified, whereas [La^-] increased. According to these data, the relationship between [La^-] and pH might be different between children and adults. Ratel et al. [27] investigated the acid-base balance during 10 repeated 10-second cycling sprints separated by 30-second recovery intervals. Results showed that although blood [La^-] was lower and blood pH higher in boys, for the same blood [La^-], blood [H^+] was significantly lower in prepubescent boys compared with young men. They concluded that children regulated their blood [H^+] better than adults do, probably because of a more efficient ventilatory regulation, especially during the initial rest intervals (figs. 1, 2). In summary, during repetitive bouts of sprints separated by short recovery intervals, prepubescent children compared with adults are more able to maintain their power output (performance) without substantial fatigue.

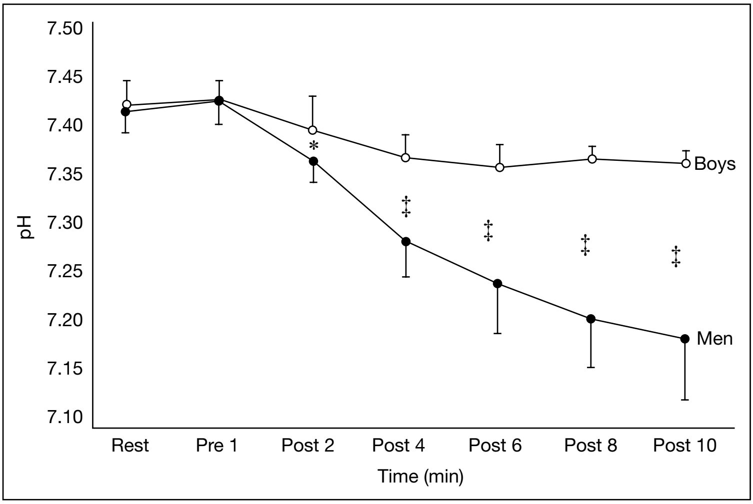


Fig. 2. Time course of blood pH over the 10 sprint exercises, both in boys and the men. Reprinted with permission from Ratel et al. [27].

How? Short-Term Power Output during Growth

Historical Background (table 3)

There are very few studies related to secular trends in children's anaerobic fitness. In contrast to the first study investigating aerobic fitness in children which was reported just before World War II [41], the first study measuring anaerobic performance (first quantitative power test in children) was only published in 1966. Margaria et al. [33] assessed short-term power during upstairs running in untrained girls and boys aged 10–15 years. The authors measured the vertical component of the maximum average speed by having subjects run up a staircase for 4–5 s, in which the body mass of the individual represented the external force. To measure the power output, the time recorded was around 400–500 ms. Significant sex differences were found in absolute maximal anaerobic performance between girls and boys at ages 11 and 15 years. No significant gender differences were observed when maximal anaerobic performance was expressed relative to body mass. It was concluded that psychomotor, biomechanical, and biochemical changes that occur in children of these ages contribute to fairly linear increases in absolute maximal anaerobic performance up to approximately 13 years of age. After that age the values for boys continue to increase, while those for girls level off [42]. For additional information, see reviews of Bar-Or [43], Van Praagh [44], and Van Praagh and França [11].

Table 3. Children's laboratory-based anaerobic performance tests

Test	Performance index	Advantages	Limitations
Sprinting upstairs [33]	peak leg power	inexpensive equipment	some skill required
Vertical jump – sargent [34]	impulse	easy to administer	some skill required
Wingate anaerobic test [35]	mean leg power	can measure arm or leg power; suitable for fatigue research	considerable aerobic component
Vertical jump – force platform [36]	instantaneous leg power	measures actual force, velocity and power	some skill required; expensive equipment
Isokinetic cycling [36]	peak leg power	suitable for muscle research	expensive ergometer
Sprint – motorized treadmill [37]	maximal anaerobic capacity	mode of exercise reflects many sports activities	expensive ergometer
Force-velocity test – frictional (Van Praagh [5])	peak leg power	highly reliable; elicits peak cycling power	time consuming
Accumulated oxygen deficit [38]	maximal anaerobic capacity	less sensitive to motivational factors than other tests of anaerobic capacity	not well validated with children
Sprint – nonmotorized treadmill [39]	peak leg power	mode of exercise reflects many sports activities	some skill required
Force-velocity test – inertial adjusted [40]	instantaneous leg power	elicit the highest value possible for cycling peak power	not specific to many sporting activities

Despite the statements made by Margaria et al. [33], the test's results are influenced by factors such as the skill of climbing at maximal velocity, leg length, stride pattern, and body mass. In young children, because of the risk of injury in taking two steps at a time, the administrator might consider the 30 m dash as an alternative. Considering the above-mentioned methodological drawbacks, the test was progressively abandoned in the eighties and replaced, in the laboratory, by more consistent and reproducible cycle ergometer tests (Wingate test: Bar-Or et al. [35]; Force-velocity test: Van Praagh et al. [5]).

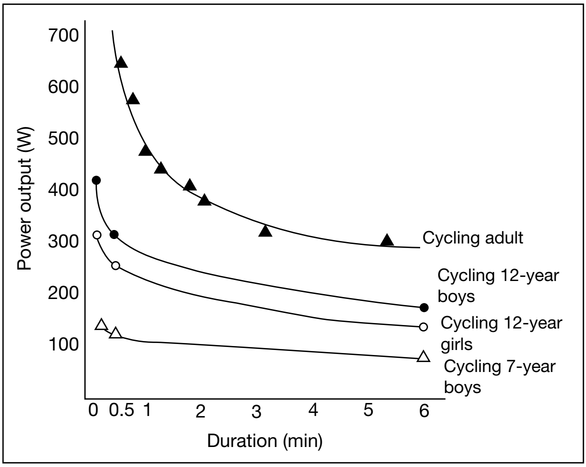


Fig. 3. Power-duration curves for adults [45] and children [14].

Fundamental Considerations

The assessment of anaerobic performance raises some methodological problems.

As power is the product of force and velocity, the external load must closely match the capability of the active muscles so that they operate at their optimal velocity [45]. Clearly, this is difficult to meet in some short-term high-intensity activities such as sprint running or vertical jumping. A second problem is that power output decreases rapidly as a function of time. This can be illustrated through the power-duration curves for adults and children shown in figure 3 [14, 45]. Thus, if maximal anaerobic power is to be measured, the duration of the test must be as short as possible. This has been shown to range from milliseconds in vertical jumping [16] to 3 s in sprint cycling [46, 47]. A methodological issue arises from the fact that assessment of 'true' peak power requires measurements of instantaneous values of force and velocity. This condition is only satisfied in tests that use a force platform for jumping protocols [48], cycling protocols using the inertial-load method [47] or methods that measure power due to both frictional resistance and flywheel inertia [46, 49]. In other power tests such as staircase running [33], 30-second Wingate test [50], cycling on friction-loaded ergometers [5] or monoarticular dynamometry [51], the forces and velocities are averaged instead of being instantaneous values [52]. Anaerobic glycolysis and aerobic contribution are limited during instantaneous power exercises or tests. However, when using a 30-second Wingate test in prepubescent and adolescent boys, Hebestreit et al. [26] and Van Praagh et al. [53] suggested that the aerobic fraction was high when compared to young men.

Another issue with anaerobic testing is that lactate production and removal starts during the first seconds of a supramaximal exercise. In adults, it has been reported that glycolysis is already involved in exercise lasting less than 10 s [54]. Therefore, only exercises lasting a few milliseconds can be considered as an estimate of the maximal ATP in vivo splitting rate [48]. Moreover, the measurement of short-term high-intensity performance is protocol-dependent (in contrast with maximal aerobic power measurement, which is to some extent protocol-independent). As aforementioned, both the sensitivity and integrity of short-term power tests have been improved in recent years. However, presently no objective criteria that confirm maximality are available and thus the researcher or the coach must rely on the willing cooperation of the individual. For further information concerning anaerobic performance testing during growth, the reader is referred to Van Praagh and Doré [55].

Procedures for Assessing Anaerobic Fitness

Sprint Cycling

Wingate Anaerobic Test (WAnt). This test has been examined more extensively than any other ‘anaerobic’ performance test, and found to be highly reliable and valid in both normal and disabled populations. However, as was pointed out by Bar-Or [43], one disadvantage of this popular test is that a 30-s cycling exercise is too short to sufficiently exhaust the organism and thus to extract all anaerobic work. Furthermore, the 30-second cycling test needs strong motivation from the child, which is far from reality. This method appears to be more useful in establishing fatigue profiles.

Age- and Sex-Associated Variation. Boys do not demonstrate consistently higher values for absolute peak and mean anaerobic performance than girls throughout early childhood. Sex differences are minimal until the onset of the accelerated growth of anaerobic performance indices in boys. Absolute peak power increases during childhood in boys and girls, with an acceleration at puberty in boys. Between the ages of 12 and 17 years, peak power during the WAnt increases by around 120% in males and 66% in females [56]. Most data adjusted for body mass or free-fat mass indicate that the anaerobic performance during the WAnt also increases during childhood and adolescence. However, Van Praagh et al. [57] and Sargeant [58] reported that ‘correction procedures’ may be useful in activities that require a movement of the whole body mass (e.g. running or jumping), but in activities such as cycling or rowing it seems inappropriate to standardize leg muscle power for body mass. During puberty, hormonal and neuromuscular factors are most often associated with the dramatic increase in muscle tissue and may partly explain the gender difference in anaerobic performance. In Western countries (including Europe, USA, Canada) both cross-sectional and longitudinal studies have consistently confirmed, an

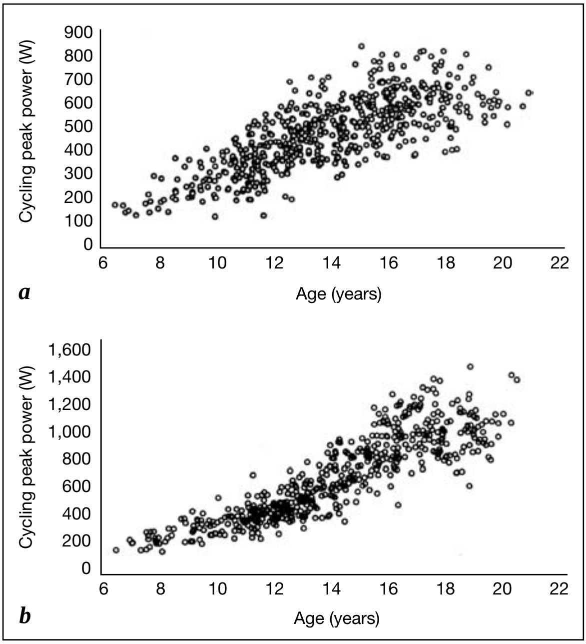


Fig. 4. ***a*** Relationship between cycling peak power (CPP) and age in females (cross-sectional data from Doré et al. [40]). Reprinted with permission from Van Praagh [14]. ***b*** Relationship between cycling peak power (CPP) and age in males (cross-sectional data from Doré et al. [40]). Reprinted with permission from Van Praagh [14].

increase in anaerobic performance between the ages of 8–16 years using the WAnt testing method [5, 25, 50, 59, 60]. Although the WAnt is a worldwide and popular test, it presents some fundamental drawbacks [55]. In particular, the fixed external resistance force used during the WAnt does not satisfy muscle force-velocity relationships [61] and thus short-term anaerobic performances may be adversely affected [62].

Growth and Anaerobic Performance. Several studies have described the effect of growth on anaerobic performance. Most of them were cross-sectional studies [11, 43, 44, 63], with a smaller number of longitudinal studies reported [64–66]. All investigations reported a significant increase of anaerobic performance (absolute or relative values) with chronological age [40, 67] or maturity status [11] (fig. 4a, b). Figure 5 [66] illustrates that between 7 and 17 years absolute cycling peak power increased by 295% in girls whereas it increased by 375% in boys. However, when corrected for lean leg volume, relative cycling peak power increased by 40% in girls and 102% in boys. This, therefore, suggests

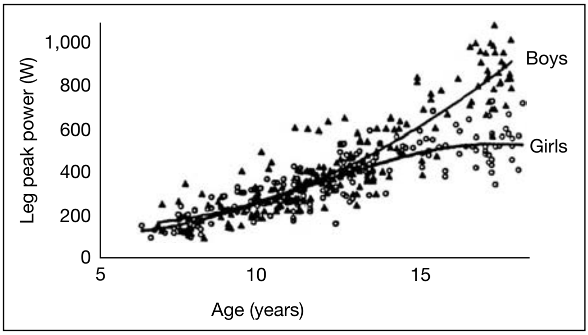


Fig. 5. Relationship between short-term leg peak power and age in girls and boys (longitudinal data). Reprinted with permission from Martin et al. [66].

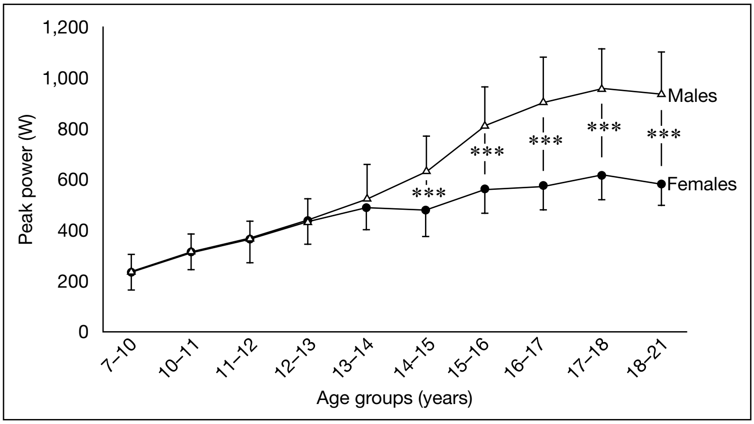


Fig. 6. Absolute cycling peak power (W) in females and males during growth (cross-sectional data from Doré et al. [40]). Reprinted with permission from Van Praagh [14].

that not only does growth affect anaerobic performance, but gender also affects the resulting anaerobic measures.

Sex-Associated Variation. Boys have consistently higher average absolute cycling peak power (W) than girls between 13 and 21 years of age. Any gender differences were observed prior to the male pubertal growth spurt (fig. 6). However, gender-related differences in relative cycling peak power (W · kg^{-1}) occurred as early as 10–11 years of age. As shown in figure 7, cycling peak power continues to increase up to puberty and then plateaus in females, even after normalizing for body mass, fat-free mass and lean leg volume [40, 68].

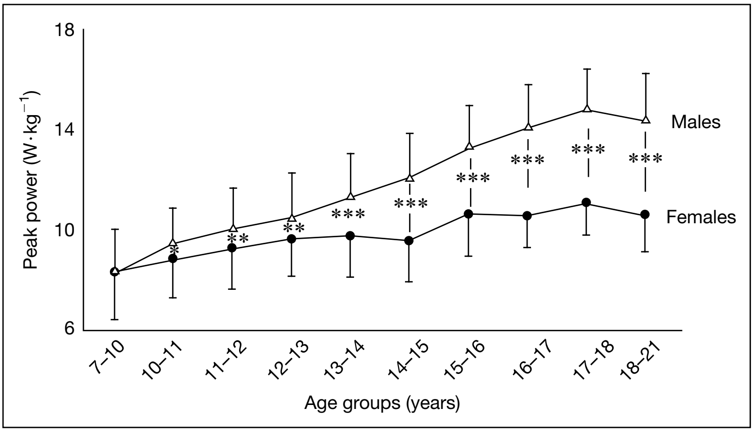


Fig. 7. Relative cycling peak power ($W \cdot kg^{-1}$ BM) in females and males during growth (cross-sectional data from Doré et al. [40]). Reprinted with permission from Van Praagh [14].

Conversely in boys, absolute and relative cycling power plateaued around 18 years in untrained individuals. The difference between sexes during puberty is due to a proportionately greater increase in muscle mass in males.

Sprint Running

Historically, physical educators and coaches have used a 30–50 m dash as a measure of running velocity. The test is easy to administer and can be done indoors or outdoors, and pediatric populations can be assessed in a short time. This simple test enables one to categorize subjects as ‘slow’, ‘medium slow’, or ‘rapid’. However, it cannot be considered a ‘real’ power test, according to Wilkie [61], as the force component is not measured. Sprint speed over a given distance progressively improves during childhood. However, multiple factors such as stride length, force production, muscle fiber types, neural influences, contribute to this improved performance. In some studies the improvement in sprint performance with growth was found to be similar in boys and girls. Between the ages of 7 and 17 years, average 50-yard sprint velocity improved by about 50% in boys and 23% in girls [69]. Among the very few reports with respect to secular trends of anaerobic performance it is worthwhile to mention that American boys and girls ran faster during a 50-yard dash in 1958 than in 1975 (fig. 8). However, the differences in performances during field tests [69] could be due to e.g. environmental conditions such as the use of synthetic tracks instead of clay tracks. In spite of an ever-increasing number of published reports in this area, in the last 25 years, it appears that, for the moment, we are unable to detect any consistent secular trends in sprint running performances,

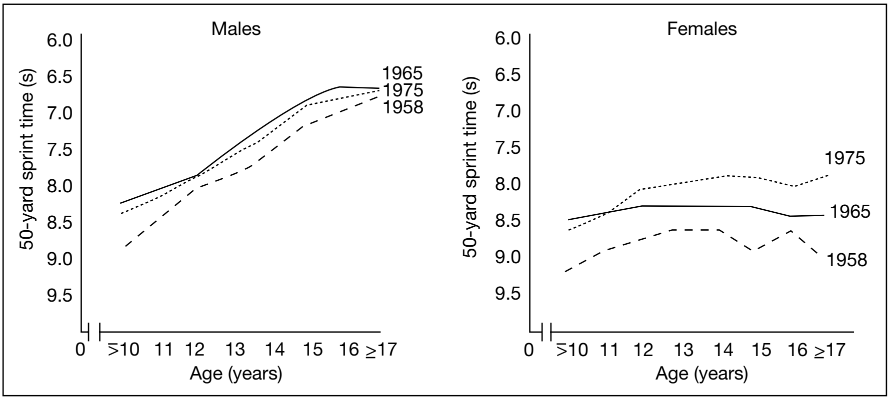


Fig. 8. Sprint performance in boys (***a***) and girls (***b***) with increasing age. Reprinted with permission from AAHPERD [70].

meaning that the child in the 1980s presented with similar outcomes when compared to 2005.

Vertical Jumping

The vertical height performed during a maximal jump has been interpreted to indicate explosive muscle power [71]. In the laboratory, force-platform tests [16, 36], which give reliable information about instantaneous muscle leg power, have been used to measure leg short-term power output (W). In contrast to the force platform methodology, field tests measure maximum standing vertical jump (VJ) by assessing jump displacement (m). Although VJ height performance has the dimension of work (J), the VJ test is considered as a criterion of leg muscular power [62, 72]. Most of the studies included a small sample. However, in large-scale population surveys, the testing procedures involved in the assessment of muscle performance have not only to be valid and reliable, but also simple to administer and be of suitable difficulty. For instance, in motor performance test batteries or assessment of leg muscle performance, standing long or vertical jumps (m) are the most commonly used field tests because of their ease of application, especially in school settings, for resistance training improvements, elite performance sports, talent detection, multiple-sprint activities (football, rugby, track and field etc.). In females, it was shown that VJ performance increased linearly until 15 years, then plateaued with a maximal value (determined from the age-performance relationship) between 17 and 18 years. In males, the same changes in performance were observed until approximately 13 years of age. Thereafter, there was a dramatic increase until 19 years with a

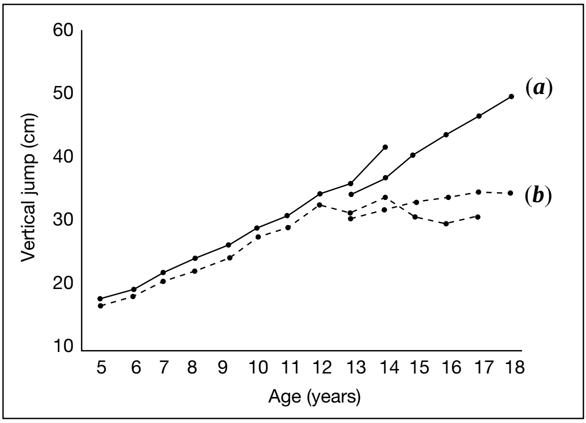


Fig. 9. Increase in vertical jump height between ages 5 and 18 years. Data from multiple sources compiled by Malina and Bouchard. Reprinted with permission from Malina and Bouchard [73].

prospective maximal value at about 21 years. Malina and Bouchard [73] combined the findings of several cross-sectional studies to describe age- and sex-related changes in VJ (fig. 9). Klausen et al. [74] reported longitudinal changes in VJ height in two groups of girls and boys studied between the ages of 10–12 years and between 13 and 15 years. Average jump height increased in the 10- to 12-year-old group from 15 to 19 cm, with no gender difference. Meanwhile in the 13- to 15-year-old group average VJ performance increased from 18 to 24 cm in boys, but no significant change was observed in girls over the 3 years. However, it has clearly been demonstrated that body dimensions have to be considered when studying age and/or gender differences [16]. When their VJ performances were corrected for body mass, no significant changes was observed over time in the 10- to 12-year-old group (0.45 cm $\cdot$ kg^{-1} BM initially and 0.43 cm $\cdot$ kg^{-1} BM at follow-up). In the 13- to 15-year-old group, the VJ height corrected for BM did not change in boys over the 3 years of testing (from 0.43 to 0.40 cm $\cdot$ kg^{-1} BM), but VJ performances declined in girls (from 0.42 to 0.34 cm $\cdot$ kg^{-1} BM) at final testing. A major weakness of the VJ test is the lack of standardization in test administration and its high reliance on jumping skills. The latter is also the case for squat jumps or countermovement jumps; however, the use of the force platform technique is considered to be representative of the capacity to generate power and improves, therefore, the validity of the test.

Trainability of Anaerobic Fitness

The reduced anaerobic fitness of the child athlete compared with the adult athlete has been attributed to the intrinsic properties of the muscle that are not actually fully understood [75]. Katch [76] suggested that there is one critical period in a child's life ('trigger point') that coincides with puberty in most children (but may occur earlier in some), below which the effects of physical conditioning will be minimal, or will not occur at all. Strength and anaerobic performance trainability increases markedly during puberty (for review, see [77]).

Conclusion

During development, short-term power output can now be quantified and underlying metabolic processes demonstrated. However, and especially in children and adolescents, quantification of this underlying metabolism is still a considerable challenge. Although in almost daily tasks, games or sports events, the child is primarily involved in short-term HIE, most of the scientific literature is devoted to the study of maximal aerobic power. This paradoxical situation is mainly due to the absence of an anaerobic 'gold standard' comparable to the universally adopted $\dot{V}O_{2max}$ criterion, the difficulty in measuring accurately non-steady state physiological responses or the prohibition against highly invasive techniques and painful stress in the study of healthy children. However, it has been proven that anaerobic testing reflects developmentally appropriate experiences for children and, therefore, changes in anaerobic fitness can strongly reflect growth, gender and maturation. Advances in technology have provided ethically acceptable means to research anaerobic performances in health populations, but surprisingly few studies have addressed the gaps in the literature.

References

1 Åstrand PO: Experimental Studies of the Physical Working Capacity in Relation to Sex and Age. Copenhagen, Munksgaard, 1952.

2 Baquet G, Van Praagh E, Berthoin S: Endurance training and aerobic fitness in young people. Sports Med 2003;33:1127–1143.

3 Williams C: Short term activity; in Macleod D, Maughan R, Nimmo M, Reilly T, Williams C (eds): Exercise Benefits, Limits and Adaptations. London, E&FN Spon, 1987, pp 59–62.

4 Green S: A definition and systems view of anaerobic capacity. Eur J Appl Physiol Occup Physiol 1994;69:168–173.

5 Van Praagh E, Falgairette G, Bedu M, Fellmann N, Coudert J: Laboratory and field tests in 7-year-old boys; in Oseid S, Carlsen KH (eds): Children and Exercise. Champaign, Human Kinetics, 1989, vol XIII, pp 11–17.

6 Hebestreit H, Meyer E, Htay H, Heigenhauser GJ, Bar-Or O: Plasma metabolites, volume and electrolytes following 30-s high-intensity exercise in boys and men. Eur J Appl Physiol 1996;72: 563–569.

7 Beneke R, Pollmann C, Bleir I, Leithäuser RM, Hütler M: How anaerobic is the Wingate Anaerobic Test for humans? Eur J Appl Physiol 2002;87:388–392.

8 Bailey RC, Olson J, Pepper SJ, Porszasz J, Barstow TJ, Cooper DM: The level and tempo of children's physical activities: an observational study. Med Sci Sports Exerc 1995;27:1033–1041.

9 Cooper DM: New horizons in pediatric exercise research; in Blimkie CJR, Bar-Or O (eds): New Horizons in Pediatric Exercise Science. Champaign, Human Kinetics, 1995, pp 1–24.

10 Wilkie DR: Equations Describing Power Input by Humans as a Function of Duration of Exercise. Exercise Bioenergetics and Gas Exchange. Amsterdam, Elsevier/North Holland Biomedical Press, 1980, pp 25–35.

11 Van Praagh E, França NM: Measuring maximal short-term power output during growth; in Van Praagh E (ed): Pediatric Anaerobic Performance. Champaign, Human Kinetics, 1998, pp 155–189.

12 Brooke MH, Engel WK: The histographic analysis of human muscle biopsies with regard to fibre types: children's biopsies. Neurology 1969;19:591–605.

13 Eriksson BO, Karlsson J, Saltin B: Muscle metabolites during exercise in pubertal boys. Acta Paediatr Scand 1971;217(suppl):154–157.

14 Van Praagh E: Development of anaerobic function during childhood and adolescence. Pediatr Exerc Sci 2000;12:150–173.

15 Eriksson BO, Gollnick PB, Saltin B: Muscle metabolism and enzyme activity after training in boys 11–13 years old. Acta Physiol Scand 1973;87:485–487.

16 Ferretti G, Narici MV, Binzoni T, Gariod L, Le Bas JF, Reutenauer H, Cerretelli P: Determinants of peak muscle power: effects of age and physical conditioning. Eur J Appl Physiol 1994;68: 111–115.

17 Berg A, Kim SS, Keul J: Skeletal muscle enzyme activities in healthy young subjects. Int J Sports Med 1986;7:236–239.

18 Haralambie G: Activités enzymatiques dans le muscle squelettique des enfants de divers âges [Enzymatic activity in the skeletal muscle of children of various ages]; in: Le Sport et l'Enfant. Montpellier, Euromed, 1980, pp 243–258.

19 Haralambie G: Enzyme activities in skeletal muscle of 13- to 15-year-old adolescents. Bul Eur Physiopathol Respir 1982;18:65–74.

20 Cooper DM, Barstow TJ: Magnetic resonance imaging and spectroscopy in studying exercise in children; in Holloszy JO (ed): Exercise and Sports Science Reviews. Baltimore, Williams & Wilkins, 1996, pp 475–499.

21 Zanconato S, Buchtal S, Barstow TJ, Cooper DM: ^{31}P-magnetic resonance spectroscopy of leg muscle metabolism during exercise in children and adults. J Appl Physiol 1993;74:2214–2218.

22 Kuno S, Takahashi H, Fujimoto K, Akima H, Miyamaru M, Nemoto I, Itai Y, Katsuta S: Muscle metabolism during exercise using phosphorus-31 nuclear magnetic resonance spectroscopy in adolescents. Eur J Appl Physiol 1995;70:301–304.

23 Taylor DJ, Kemp GJ, Thompson CH, Radda GK: Ageing: effects on oxidative function of skeletal muscle in vivo. Mol Cell Biochem 1997;174:321–324.

24 Kuno S, Miyamaru M, Itai Y: Muscle energetics during exercise of elite children sprinters by 31P NMR (abstract). Med Sci Sports Exerc 1993;25:S175.

25 Falgairette G, Bedu M, Fellmann N, Van Praagh E, Coudert J: Bioenergetic profile in 144 boys age from 6 to 15 years with special reference to sexual maturation. Eur J Appl Physiol 1991;62: 151–156.

26 Hebestreit H, Mimura KI, Bar-Or O: Recovery of muscle power after high-intensity short-term exercise: comparing boys and men. J Appl Physiol 1993;74:2875–2880.

27 Ratel S, Duché P, Hennegrave A, Van Praagh E, Bedu M: Acid-base balance during repeated cycling sprints in boys and men. J Appl Physiol 2002;92:479–485.

28 Stanley WC, Gertz EW, Wisneski JA, Morris DL, Neese RA, Brooks GA: Systematic lactate turnover during graded exercise in man. Am J Physiol 1985;249:E595–E602.

29 Cumming GR, Hastman L, McCort J, McCullough S: High serum lactates do occur in children after maximal work. Int J Sports Med 1980;1:66–69.

30 Green S, Dawson B: Measurement of anaerobic capacities in humans: definitions, limitations and unsolved problems. Sports Med 1993;15:312–327.

31 Welsman JR, Armstrong N: Assessing post-exercise lactates in children and adolescents; in Van Praagh E (ed): Pediatric Anaerobic Performance. Champaign, Human Kinetics, 1998, pp 137–153.

32 Matejkova J, Koprivova Z, Placheta Z: Changes in acid-base balance after maximal exercise; in Placheta Z, Brno JE (eds): Youth and Physical Activity. Usti nad Labem, Purkyne University, 1980, pp 191–200.
33 Margaria R, Aghemo P, Rovelli E: Measurement of muscular power (anaerobic) in man. J Appl Physiol 1966;21:1662–1664.
34 Glencross DJ: The nature of the vertical jump test and the standing broad jump. Res Q 1966;37:353–359.
35 Bar-Or O, Dotan R, Inbar O: A 30-second all-out ergometric test: its reliability and validity for anaerobic capacity. Isr J Med Sci 1977;13:326.
36 Davies CTM, Young K: Effects of external loading on short-term power output in children and young male adults. Eur J Appl Physiol 1984;52:351–354.
37 Paterson DH, Cunningham DA: Development of anaerobic capacity in early and late maturing boys; in Binkhorst RA, Kemper HCG, Saris WH (eds): Children and Exercise. Champaign, Human Kinetics, 1985, vol XI, pp 119–128.
38 Carlson JS, Naughton GA: Determination of the maximal accumulated oxygen deficit. in Coudert J, Van Praagh E (eds): Children and Exercise, Pediatric Work Physiology. Paris, Masson, 1993, vol XVI, pp 23–25.
39 Fargeas MA, Lauron B, Léger L, Van Praagh E: A computerized treadmill ergometer to measure short-term power output. Int Congress of Biomechanics, Paris, 1993, pp 394–395.
40 Doré E, Bedu M, França NM, Diallo O, Duché P, Van Praagh E: Testing peak cycling performance: effects of braking force during growth. Med Sci Sports Exerc 2000;32:493–498.
41 Robinson S: Experimental studies of physical fitness in relation to age. Arbeitsphysiologie 1938;10:251–323.
42 Davies CTM, Barnes C, Godfrey S: Body composition and maximal exercise performance in children. Hum Biol 1972;44:195–214.
43 Bar-Or O: Anaerobic performance; in Docherty D (ed): Measurement in Pediatric Exercise Science. Champaign, Human Kinetics, 1996, pp 161–182.
44 Van Praagh E: Testing of anaerobic performance; in Bar-Or O (ed): The Encyclopaedia of Sports Medicine: The Child and Adolescent Athlete (IOC). London, Blackwell Science, 1996, pp 602–616.
45 Wilkie DR: Man as a source of mechanical power. Ergonomics 1960;3:1–8.
46 Doré E, França NM, Bedu M, Van Praagh E: The effect of flywheel inertia on short-term cycling power output in children. Med Sci Sports Med 1997;29:S170.
47 Martin JC, Wagner BM, Coyle EF: Inertial-load method determined maximal cycling power in a single exercise bout. Med Sci Sports Exerc 1997;29:1505–1512.
48 Ferreti G, Gussoni M, di Prampero PE, Cerretelli P: Effects of exercise on maximal instantaneous muscular power of humans. Eur J Appl Physiol 1987;62:2288–2294.
49 Lakomy HKA: Measurement of work and power output using friction-loaded cycle ergometers. Ergonomics 1986;29:509–517.
50 Bar-Or O: The Wingate Anaerobic Test, an update on methodology, reliability and validity. Sports Med 1987;4:381–394.
51 Saavreda C, Lagassé P, Bouchard C, Simoneau J: Maximal anaerobic performance of the knee extensor muscles during growth. Med Sci Sports Exerc 1991;23:1083–1089.
52 Vandewalle H, Peres G, Heller J, Panel J, Monod H: Force-velocity relationship and maximal power on a cycle ergometer: correlation with the height of vertical jump. Eur J Appl Physiol 1987;56: 650–656.
53 Van Praagh E, Bedu M, Falgairette G, Fellmann N, Coudert J: Oxygen uptake during a 30-s supramaximal exercise in 7- to-15-year-old boys; in Frenkl R, Smodis I (eds): Children and Exercise: Pediatric Work Physiology. Budapest, National Institute for Health Promotion, 1991, pp 281–287.
54 Mercier B, Granier P, Mercier J, Foucat L, Bielicki G, Pradere J, Renou JP, Préfaut C: Noninvasive skeletal muscle lactate detection between periods of intense exercise in humans. Eur J Appl Physiol 1998;78:20–27.
55 Van Praagh E, Doré E: Short-term muscle power during growth and maturation. Sports Med 2002;32:701–728.

56 Inbar O, Bar-Or O, Skinner JS: The Wingate Anaerobic Test: Development, Characteristics, and Application. Champaign, Human Kinetics, 1999.
57 Van Praagh E, Fellmann N, Bedu M, Falgairette G, Coudert J: Gender difference in the relationship of anaerobic power output to body composition in children. Pediatr Exerc Sci 1990;2: 336–348.
58 Sargeant AJ: Problems in, and approaches to, the measurement of short-term power output in children and adolescents; in Coudert J, Van Praagh E (eds): Children and Exercise. XVI. Pediatric Work Physiology. Paris, Masson, 1992, pp 11–17.
59 Gaul CA, Docherty D, Cicchini R: Differences in anaerobic performance between boys and men. Int J Sports Med 1995;16:451–455.
60 Armstrong N, Welsman JR, Kirby BJ: Performance on the Wingate anaerobic test and maturation. Pediatr Exerc Sci 1997;9:253–261.
61 Wilkie DR: The relation between force and velocity in human muscle. J Physiol 1950;110: 249–280.
62 Winter E, MacLaren DP: Assessment of maximal-intensity exercise; in Eston RG, Reilly T (eds): Kinanthropometry and Exercise Physiology Laboratory Manual: Tests Procedures and Data. Exercise Physiology. London, Routledge, 2001, vol 2, pp 264–289.
63 Van Praagh E: Pediatric Anaerobic Performance. Champaign, Human Kinetics, 1998.
64 Falk B, Bar-Or O: Longitudinal changes in peak aerobic and anaerobic mechanical power of circumpubertal boys. Pediatr Exerc Sci 1993;5:318–331.
65 Armstrong N, Welsman JR, Chia MYH: Short term power output in relation to growth and maturation. Br J Sports Med 2001;35:118–124.
66 Martin RJF, Doré O, Twisk J, Van Praagh E, Hautier CA, Bedu M: Longitudinal changes of maximal short-term peak power in girls and boys during growth. Med Sci Sports Exerc 2004;36: 498–503.
67 Martin RJF, Doré O, Hautier O, Van Praagh E, Bedu M: Peak power changes in adolescents groups of similar anthropometric characteristics. Med Sci Sports Exerc 2003;35:1436–1440.
68 Doré E, Martin R, Ratel S, Duché P, Bedu M, Van Praagh E: Gender differences in peak muscle performance during growth. Int J Sports Med 2005;26:274–280.
69 American Alliance for Health, Physical Education, Recreation and Dance: Youth Fitness Testing Manual. Reston, American Alliance of Health, Physical Education, Recreation & Dance, 1980.
70 American Alliance for Health, Physical Education, Recreation and Dance (AAHPERD): AAHPERD Youth Fitness Test Manual (revised 1976 edition). Reston, American Alliance of Health, Physical Education, Recreation & Dance, 1976.
71 Sargent DA: The physical test of a man. Am Phys Ed Rev 1921;26:188–194.
72 Rowland TW: Children's Exercise Physiology, ed 2, revised. Champaign, Human Kinetics, 2005.
73 Malina RM, Bouchard C: Growth, Maturation, and Physical Activity. Champaign, Human Kinetics, 1991.
74 Klausen K, Schibye B, Rasmussen B: A longitudinal study of changes in physical performance of 10- to 15-year-old girls and boys; in Oseid S, Carlsen KH (eds): Children and Exercise. Champaign, Human Kinetics, 1989, vol XIII, pp 113–122.
75 Sargeant AJ: The determinants of anaerobic muscle function during growth; in Van Praagh E (ed): Pediatric Anaerobic Performance. Champaign, Human Kinetics, 1998, pp 97–117.
76 Katch VL: Physical conditioning of children. J Adolesc Health Care 1983;3:241–246.
77 Naughton G, Farpour-Lambert NJ, Carlson J, Bradney M, Van Praagh E: Physiological issues surrounding the performance of adolescent athletes. Sports Med 2000;30:309–325.

Prof. Emmanuel Van Praagh
Laboratory of Exercise Biology (UFRSTAPS), Université Blaise Pascal
BP 104
FR–63170 Aubière (France)
Tel. +33 473 407 535, Fax +33 473 407 446, E-Mail emmanuel.vanpraagh@wanadoo.fr

Tomkinson GR, Olds TS (eds): Pediatric Fitness. Secular Trends and Geographic Variability.
Med Sport Sci. Basel, Karger, 2007, vol 50, pp 46–66

……

Secular Changes in Pediatric Aerobic Fitness Test Performance: The Global Picture

Grant R. Tomkinson[a], *Timothy S. Olds*[b]

[a]Centre for Applied Anthropometry and [b]Nutritional Physiology Research Centre,
School of Health Sciences, University of South Australia, Adelaide, Australia

Abstract

Introduction: Current attitudes towards secular changes in pediatric aerobic fitness are highly polarized, both in the popular and scientific literature. Few studies have actually quantified secular changes in pediatric aerobic fitness, with most making only informal comparisons. The aim of this study therefore, was to quantify the global change in pediatric aerobic fitness test performance. **Methods:** Following an extensive review of the literature, 33 pediatric studies examining secular changes in maximal field running tests of aerobic performance were analyzed. Secular changes were calculated at the country × study × age × sex × test level using least squares linear regression weighted by the square root of sample size. All secular changes were expressed as a percentage of the weighted mean value for all data points in the regression. Negative values indicated performance declines, and positive values improvements. **Results:** Secular changes in aerobic performance were calculated for 25,455,527 6- to 19-year-old from 27 countries (representing five geographical regions) between 1958 and 2003. Over the 45-year period, there has been a global decline in aerobic performance of −0.36% per annum. Secular changes have been very consistent across age, sex, and geographical groups. The pattern of change however, was not consistent over time, with improvements from the late 1950s until about 1970, and declines of increasing magnitude every decade thereafter. **Discussion/Conclusion:** This study provides the most comprehensive picture to date, of the global change in pediatric aerobic performance. It shows that there has been a precipitous decline in pediatric aerobic performance since 1970, a pattern which is not observed in pediatric anaerobic performance. This secular decline may result from a network of social, behavioral, physical, psychosocial and physiological factors.

‘Our year eight physical education students do a mixture of fitness and skill learning. It is very evident to us that the fitness level of the “new” year eight students each year is declining. We do cardiovascular fitness tests on these students, and on average there has been a decline in standard over the last five years.' [1, p. 63]

'There is no scientific evidence to suggest that young people's aerobic fitness has declined over the last 50 years.' [2, p. 71]

'Multiple sources tell us that in our apparent physical fitness and health boom, children are not as physically fit as they were in past decades.' [3, p. 1698]

'This study shows little, if any, evidence that indicates that children and youth are less fit than they were in previous decades.' [4, p. 104]

'America's youth are in worse shape than ever...' [5, p. 58]

'The existing research literature does not permit any confident conclusions to be drawn regarding temporal changes in aerobic fitness.' [6, p. 8]

There has been considerable interest in both the popular and scientific literature regarding whether today's children and adolescents are fitter than their peers from the past. Some believe that pediatric fitness has declined in recent decades, while others doubt that it has changed at all or suggest that we do not know. Few, it seems, are willing to argue that it has improved.

So how can such a diversity of opinion have arisen? It could be because of an apparent lack of scientific evidence. Over the past half a century, there have been fewer than three studies published every 2 years which have commented on secular changes in pediatric fitness [7]. Most of these have made only informal secular comparisons, with very occasional rigorous statistical treatment. This means that little is known about the actual magnitude and direction of the secular changes. Compounding the problem further, is that these studies often provide only local snapshots, which are temporally limited, and restricted to narrow age bands and a single fitness component (typically aerobic fitness). In addition, secular data for criterion measures of fitness are few, with the vast majority available for fitness test performances. The aim of this study, therefore, was to conduct an extensive review of the literature to systematically quantify the global change in pediatric aerobic fitness test performance.

Methods

Data Sources

An extensive review of the literature was undertaken to locate studies which explicitly reported on secular changes in aerobic fitness test performance of normal children and adolescents, or studies that have published data from which secular changes can be estimated. The method used to locate studies is described in detail in the chapter by Tomkinson and Olds [this vol., pp. 168–182]. Briefly, studies were located via a computer search of online bibliographic databases and the University of South Australia's library catalogue; a manual search of all hard copy scientific journals, books, and bibliographic indexes held at the University of South Australia Library; examining and cross-referencing the reference lists of all located studies, and personal communication with the authors of each located study.

Study Selection

Fifty-eight candidate studies were located, of which 33 were retained for analysis. Twenty-five studies were excluded because secular changes were reported for: (1) large, undifferentiated age ranges spanning three or more years (e.g. 10- to 12-year-olds); (2) a sample not distinguished by sex; (3) samples previously reported in other located studies; (4) samples not spanning at least two time points across a minimum of three years, or (5) individuals not tested on maximal field running tests of aerobic performance (e.g. timed runs, distance runs and endurance shuttle runs).

Study Characteristics

The majority of the retained studies were peer-reviewed scientific journal articles or books (58% or 19 of 33), with the remainder being published book chapters (12% or 4 of 33), published conference articles (9% or 3 of 33), postgraduate theses (6% or 2 of 33), or commissioned reports (15% or 5 of 33). These studies analyzed secular changes in randomized-stratified samples, stratified-uniform samples, stratified-proportional samples, and convenience samples, collected at the country (59%), state/province (18%), or city (23%) level. Table 1 summarizes the studies used in this analysis.

Data Treatment and Statistical Analysis

Many of the retained studies made only informal secular comparisons, with few quantifying these comparisons, or making them a focus of discussion. Only 42% (14 of 33) of studies used hypothesis testing to confirm the statistical significance of secular comparisons, with half of these (7 of 14) actually quantifying secular changes.

To compare studies reporting secular changes, all secular changes were expressed as relative changes – i.e. absolute changes in performance expressed as a percentage of mean values per annum (% p.a.). For each study, all relative changes were calculated at the country × age × sex × test level. Figure 1 shows the systematic procedure used to express (or calculate) secular changes as relative changes. The procedure comprised five main steps.

In the first step, studies were separated into those which quantified secular changes (21% or 7 of 33), and those which did not (79% or 26 of 33). Of the studies quantifying secular changes, five reported relative changes and two absolute changes. All relative changes were left untreated, and all absolute changes were converted to relative changes, by expressing the absolute changes as a percentage of $\sqrt{n}$-weighted mean values per annum.

In step two, studies not quantifying secular changes were searched for descriptive summary data (sample sizes, means, standard deviations, etc.), with those reporting such data progressing to step three (96% or 25 of 26), and those not, progressing to step four (4% or 1 of 26). Of the studies at step three, 64% (16 of 25) numerically summarized data in tables, and progressed to step five, while 36% (9 of 25) graphically summarized data in figures, and progressed to step four.

The reference lists of the ten studies at step four were searched for references which may have contained relevant descriptive summary data needed to quantify relative changes. All relevant references were followed up, and if located, then the study moved back to step three,

Table 1. Summary of the studies used in this analysis

References	Country	Years	Sex	Age range, years	Sample No.	Test(s)
Commonwealth of Australia [1]	Australia	1988–1992	M, F	G8	50–100	1,600 m
Tomkinson [7]	Australia	1976–2000	M, F	8–11, 13	55–297	12 min, 600 m
Tomkinson and Olds [this vol.]	Australia	1960–2002	M, F	6–17	22–13, 325	10 min, 550 m, 1,600 m, 20 m SRT
Wilson [8]	Australia	1979–1988	M	8–12	199–1,080	550 m
Tomkinson et al. [9]	Belgium	1985–1997	M, F	6–19	20–1,200	20 m SRT
Tomkinson [7]	Bulgaria	1970–1982	M, F	11–19	673–856	300 m, 600 m
Tomkinson et al. [9]	Canada	1981–1990	M, F	6–17	215–738	20 m SRT
Macfarlane and Tomkinson [this vol.]	China	1979–2000	M, F	7–19	10,904–23,963	400 m, 800 m, 1,000 m
Bunc et al. [10]	Czech Republic	1976–2001	M	12, 15, 18	ND	12 min
Jürimäe et al. [this vol.]	Estonia	1992–2002	M, F	11–17	241–502	20 m SRT
Nupponen, pers. commun. (2002)	Finland	1976–2001	M, F	14, 16, 17	117–250	1,500 m, 2,000 m
Tomkinson et al. [9]	France	1986–2000	M, F	7–16	128–816	20 m SRT
Bös [11]	Germany	1984–1995	M	6–10	ND	6 min
Kretschmer [12]	Germany	1984–1999	M, F	7–10	287–640	6 min
Hong Kong Government [13]	Hong Kong	1998–2003	M, F	12–19	381–694	9 min
Mészáros et al. [14]	Hungary	1975–2000	M	10–13	346–356	1,200 m
Ben-Sira [15]	Israel	1970–1984	M, F	16–18	267–458	800 m, 1,000 m
Buonaccorsi, pers. commun. (2001)	Italy	1981–2000	M, F	11–14	126–541	1,200 m
Tomkinson et al. [9]	Italy	1986–1997	M, F	12–18	220–820	20 m SRT
Ikai and Fukunaga [16]	Japan	1917–1969	M, F	9–11	ND	5 min
Noi and Masaki [17]	Japan	1964–1997	M, F	14, 17	7,926–11,575	1,000 m, 1,500 m
Tomkinson [7]	Japan	1964–1997	M, F	12–13, 15–16, 18	7,553–25,245	1,000 m, 1,500 m
Watanabe et al. [18]	Japan	1968–1994	M, F	12, 18	512–516	1,000 m, 1,500 m
Tomkinson et al. [19]	Korean Republic	1968–2000	M, F	6–18	377–2,746,884	600 m, 800 m, 1,000 m, 1,200 m
Jürimäe et al. [this vol.]	Lithuania	1992–2002	M, F	11–17	280–557	20 m SRT
Saranga et al. [20]	Mozambique	1992–1999	M, F	8–12	49–108	1,600 m
Tomkinson et al. [9]	Netherlands	1983–1987	M, F	12	164–174	20 m SRT

Table 1. (continued)

References	Country	Years	Sex	Age range, years	Sample No.	Test(s)
Tomkinson and Olds [this vol.]	New Zealand	1961–2002	M, F	9–17	180–2,684	12 min, 550 m
Tomkinson et al. [9]	Northern Ireland	1986–1992	M, F	12, 15	666–794	20 m SRT
Przewęda and Trzesniowski [21]	Poland	1979–1989	M, F	7–19	2,697–21,697	600 m, 800 m, 1,000 m
Przewęda and Dobosz [22]	Poland	1989–1999	M, F	7–19	1,515–13,320	600 m, 800 m, 1,000 m
Przeweda [23]	Poland	1989–1999	M, F	7–19	1,239–9,183	12 min
Tomkinson et al. [9]	Poland	1992–1999	M, F	15–19	853–2,995	20 m SRT
Lyach et al. [24]	Russia	1979–1990	M, F	G2–G11	ND	6 min
Quek et al. [25]	Singapore	1980–1991	M, F	12–19	132–393	2,400 m
Tomkinson et al. [9]	Spain	1985–1999	M, F	9–18	204–1,385	20 m SRT
Westerstahl et al. [26]	Sweden	1974–1995	M, F	16	379–413	9 min
California State Dept. of Ed. [27, 28]	USA	1970–1979	M, F	10–18	6,060–6,277	6 min
Davis et al. [29]	USA	1984–1992	M, F	6–16	585*	805 m, 1,609 m
Hunsicker and Reiff [30]	USA	1958–1965	M, F	10–17	1,233*	550 m
Hunsicker and Reiff [31]	USA	1965–1975	M, F	10–17	1,177*	550 m
Morrow et al. [32]	USA	1973–1984	M, F	10–16	333–3,096*	1,609 m, 2,414 m
Pate et al. [33]	USA	1979–1984	M, F	10–17	970*	1,609 m
Updyke and Willett [34]	USA	1980–1989	M, F	6–17	10,000–20,000*	402 m, 805 m, 1,207 m, 1,609 m

Shown are the country and span of measurement years, the sex and age range of the children and adolescents tested, the range of sample sizes for each age × sex × test group, and the test(s) for which secular changes were reported.

G = Grade (see column 'Age range'); ND = not determined.

5 min = 5 min run; 6 min = 6 min run; 9 min = 9 min run; 10 min = 10 min run; 12 min = 12 min run; 20 m SRT = 20 m shuttle run test; 300 m = 300 m run; 400 m = 400 m run; 402 m = 402 m (¼ mile) run; 550 m = 550 m (600 yards) run; 600 m = 600 m run; 800 m = 800 m run; 805 m = 805 m (½ mile) run; 1,000 m = 1,000 m run; 1,200 m = 1,200 m run; 1,207 m = 1,207 m (¾ mile) run; 1,500 m = 1,500 m run; 1,600 m = 1,600 m run; 1,609 m = 1,609 m (1 mile) run; 2,000 m = 2,000 m run; 2,400 m = 2,400 m run; 2,414 m = 2,414 m (1½ mile) run.

*Values derived from reported descriptive summary data.

[#] The manuscript was received by 'Facta Universitatis: Physical Education' on January 15, 2002, but was backdated and published as volume 1, 1999.

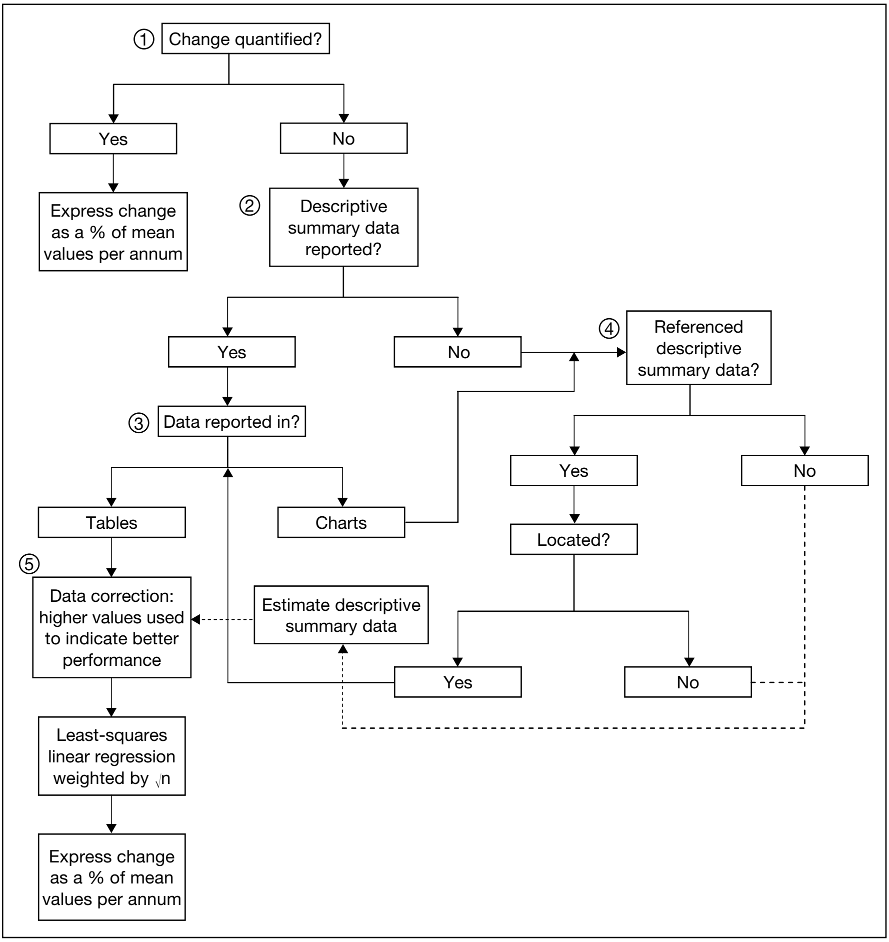


Fig. 1. Flowchart showing the steps (1–5) taken to express (or calculate) secular changes as relative changes (% p.a.).

where the located references were searched for descriptive summary data. If necessary, this process was repeated until all studies progressed to step five. On the other hand, studies at step four not citing relevant references, or those which did but could not be located, were eligible for exclusion (50% or 5 of 10). However, since the studies eligible for exclusion entered step four because descriptive data were summarized graphically, all reported descriptive data were estimated from the graphical displays, with the studies progressed to step five rather than excluded.

In step five, the reported means were adjusted such that higher scores indicated better performance. Secular changes were then calculated at the country × study × age × sex × test level using least squares linear regression weighted by the square root of sample size

($\sqrt{n}$), with year of test as the predictor variable and mean test performance as the response variable. The square root of sample size was chosen as the weighting method because our confidence in the estimation of each group mean (i.e. the standard error) is proportional to the square root of the sample size. Relative changes were calculated by expressing the weighted regression coefficient (the absolute change) as a percentage of the $\sqrt{n}$-weighted mean value for all data points in the regression. The standard error of a relative change was estimated using procedures described in Tomkinson [7]. Negative values indicated performance declines, and positive values improvements.

Mean secular changes and their corresponding 95% confidence intervals (CI) were calculated to estimate the likelihood of a 'real' change. CIs were calculated as the range spanning 1.96 standard errors either side of the mean change. The standard error of a mean change was estimated using procedures described in Tomkinson [7]. A mean change was considered significantly different from zero when the CI did not include zero. The time-related patterns of change and the time-related patterns of performance were summarized using the following procedure. Starting with the earliest year, Y_1, covered by any country × study × age × sex × test group, each group including Y_1 in its span of measurement years was located, with the performance change dx_1 (% p.a.) noted. This process was repeated until all the groups including Y_1 were located. The mean of all the listed performance changes was calculated, and taken as the mean change for year Y_1. This process was then repeated for $Y_2, Y_3, Y_4\ldots$ until the last year covered by any study, Y_n. This process yielded a series of mean annual performance changes ($dx_1\ldots dx_n$) which describe the time-related patterns of change.

The time-related patterns of performance (as opposed to changes in performance) were described using an iterative procedure. Starting with an initial value of 100 for the mean performance value at the end of the year before Y_1 (Y_0), the value at the end of Y_1 was calculated given that it would be subject to a mean annual performance change of dx_1. That is:

initialize: $X_0 = 100$,

then $X_1 = X_0 + X_0\, dx_1/100$.

This process was then applied iteratively to construct a series of annual performance ratings ($X_1\ldots X_n$). In general,

$X_{i+1} = X_i + X_i\, dx_i/100$.

Results

Secular changes in aerobic performance were calculated in 737 country × study × age × sex × test groups on 25,455,527 children and adolescents (6–19 years) from 27 countries (high, middle and low income economies) and five geographical regions (fig. 2), between 1958 and 2003. Note, because data prior to 1958 were limited to only six age × sex × test groups from a single country, only post-1957 data were analyzed. The country × study × age × sex × test changes consisted of a median of 1,113 individuals (range 20–2,746,884) and spanned an average of 11 years (range 4–41 years). Despite great lability in country × study × age × sex × test changes when sample sizes and the span of measurement years were small, changes stabilised near the global mean as both increased.

Fig. 2. World map showing the countries for which secular changes in pediatric aerobic performance have been reported. The shaded areas indicate the countries where previous studies examining secular changes are available (n = 27). The countries come from five geographical regions – Africa and the Middle-East, Asia, Australasia, Europe and North America. The arrows point to three countries (Hong Kong, Israel and Singapore) which are geographically small and hard to spot on the map.

Between 1958 and 2003, aerobic performances declined globally at an average of −0.36% p.a. (CI −0.36 to −0.36% p.a.) (note, due to very large sample sizes, the estimated standard errors, and hence the confidence intervals, are extremely small), with 75% (551 of 737) of country × study × age × sex × test changes negative (declines in performance) (table 2). Across the decades, mean changes for boys and girls, and for children (<13 years) and adolescents (≥13 years), were remarkably similar (table 2). The only exception was the 1970s, where the mean decline for boys was nearly double that for girls, and the mean decline for children was more than double that for adolescents. All groups showed improvements in the 1960s, and declines of increasing magnitude every decade thereafter.

Mean changes were also similar among geographical regions (table 3). Over the period 1970–2000 (data prior to 1970 were not available for all geographical regions), mean declines ranged from −0.74% p.a. (CI −0.76 to

Table 2. Mean changes (Δ % p.a.) in aerobic performance per decade

	Δ % p.a. (CI)				
	1960s	1970s	1980s	1990s	1958–2003
Boys	+0.59 (+0.57 to +0.61)	−0.33 (−0.33 to −0.33)	−0.46 (−0.47 to −0.45)	−0.58 (−0.59 to −0.57)	−0.40 (−0.40 to −0.40)
Girls	+0.63 (+0.61 to +0.65)	−0.17 (−0.17 to −0.17)	−0.38 (−0.39 to −0.37)	−0.49 (−0.50 to −0.48)	−0.31 (−0.31 to −0.31)
Children	+0.63 (+0.58 to +0.68)	−0.41 (−0.41 to −0.41)	−0.47 (−0.48 to −0.46)	−0.63 (−0.64 to −0.62)	−0.47 (−0.47 to −0.47)
Adolescents	+0.60 (+0.58 to +0.62)	−0.18 (−0.18 to −0.18)	−0.36 (−0.37 to −0.35)	−0.46 (−0.47 to −0.45)	−0.27 (−0.27 to −0.27)
All	+0.61 (+0.59 to +0.63)	−0.25 (−0.25 to −0.25)	−0.42 (−0.43 to −0.41)	−0.54 (−0.55 to −0.53)	−0.36 (−0.36 to −0.36)
n	267,333	22,099,107	796,628	2,292,459	25,455,527
k	69	95	224	349	737

Secular changes were classified based on the decade in which the mid-year of the measurement periods over which changes were calculated fell. Shown are the sample sizes (n), the number of country × study × age × sex × test groups (k), and the 95% confidence intervals about the mean changes (CI).

Note, data from the Hong Kong Government [13] study were included in the calculation of the '1990s' values, despite having a mid-year measurement period of 2001. Furthermore, because sample size data were not available for four studies, the reported 1960s, 1980s, 1990s and 1958–2003 sample sizes are somewhat underestimated.

Note also, due to very large sample sizes, the estimated standard errors, and hence the confidence intervals, are extremely small.

Table 3. Mean changes (Δ % p.a.) in aerobic performance for five geographical regions and the World (1970–2000)

	n	k	Δ % p.a. (CI)
Africa/Middle-East	2,542	15	−0.67 (−0.89 to −0.45)
Asia	23,741,524	188	−0.44 (−0.44 to −0.44)
Australasia	144,110	84	−0.56 (−0.58 to −0.54)
Europe	995,950	275	−0.31 (−0.32 to −0.30)
North America	304,068	106	−0.74 (−0.76 to −0.72)
World	25,188,194	668	−0.46 (−0.46 to −0.46)

Shown are the sample sizes (n), the number of country × study × age × sex × test groups (k), and the 95% confidence intervals about the mean changes (CI).

Note, because sample size data were not available for one Asian study and three European studies, the reported Asian, European and World sample sizes are somewhat underestimated.

−0.72% p.a.) for North America to −0.31% p.a. (CI −0.32 to −0.30% p.a.) for Europe. The global change for this period was −0.46% p.a. (CI −0.46 to −0.46% p.a.). Note, estimates of mean changes calculated over a 30-year period within a geographical region were subject to the availability of data (e.g. 275 country × study × age × sex × test changes were available since 1970 on 995,950 Europeans from 16 countries, compared to only 15 on 2,542 Africans and Middle-Easterners from two countries).

Sixty-seven percent (18 of 27) of the countries were classified as high-income economies [35], with high income economies representing 67% of the country × study × age × sex × test groups. Mean changes for high vs. middle and low income economies were also strikingly similar between 1970 and 2000. On average, the rate of decline for high income economies was −0.49 p.a. (CI −0.49 to −0.49% p.a.), marginally higher than the decline of −0.39% p.a. (CI −0.40 to −0.38% p.a.) for middle and low income economies.

Both the time-related patterns of change and the time-related patterns of performance are shown in figure 3. From the late 1950s and throughout the 1960s, there were improvements in aerobic tests, with a cross-over point from improvements to declines at about 1970, and declines of increasing magnitude every subsequent decade (fig. 3a). The results presented in table 2 support these time-related patterns of change. As for the time-related patterns of performance, figure 3b shows that aerobic performances improved sharply from the late 1950s until about 1965, where there was a performance shoulder between 1965 and 1975, followed by a 25-year decline.

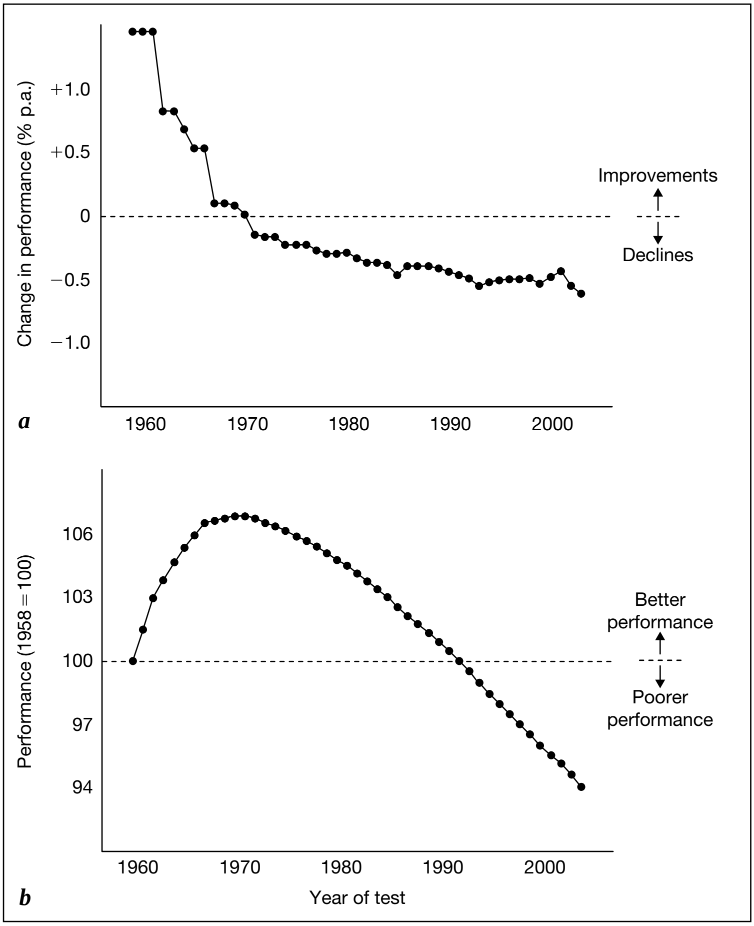


Fig. 3. Global time-related patterns of (***a***) change and (***b***) performance in pediatric aerobic performance between 1958 and 2002. In (***a***), higher values (i.e. those greater than zero) indicate improvements in performance, while in (***b***), higher values (i.e. those greater than 100) indicate better performance.

Discussion

Using data on over 25 million 6- to 19-year-olds from 27 countries tested between 1958 and 2003, this study showed that aerobic performances have declined precipitously over the past three decades. Secular changes were remarkably similar for boys and girls, for children and adolescents, and for countries of different economic status, and reasonably similar for different geographical regions.

This is the first study to have comprehensively quantified the global change in pediatric aerobic performance. A major strength of this study is that it systematically analyzed all previous reports, explicitly commenting on secular changes in pediatric aerobic performance, and by doing so, pieced together numerous, and geographically and temporally limited snapshots, to paint the global picture over the last half a century. In addition, it used a novel statistical approach to estimate the time-related patterns of change and the time-related patterns of performance. By describing the global time-related patterns of change, this study provides a global context for the secular changes for individual countries.

However, this study is limited by the fact that it only considered reports which explicitly commented on secular changes in pediatric aerobic performance. This may have resulted in a possible selection bias, as studies showing increases in performance may not have been reported (e.g. treated as anomalies). By considering every suitable report, even if measured at a single point in time (as opposed to a minimum of two points in time), the scope of the global picture would have been wider. Also, studies included in this analysis, examined secular changes across groups which were sampled using different protocols (from convenience samples to randomized national surveys), and conceivably tested using different protocols (e.g. different running surfaces, practice runs). Though these factors were rarely reported and could not be controlled for, without any evidence of systematic time-related changes in sampling or testing protocols, estimates of mean changes should not be biased. Finally, the use of linear models (which may not have always been the best-fitting models) may not have been ideal. However, given that each country × study × age × sex × test change consisted of between two and twenty-three country × study × age × sex × test × year of test reports, and spanned 4–41 years, a consistent method of analysis was needed.

Effect of Maturation on Secular Changes in Aerobic Fitness Test Performance

Children have been maturing earlier since at least the end of the 19th century, with advances in the age of menarche of 3–4 months and the age at which boys' voices break of 2 months per decade [36]. In some countries, however, maturational advances appeared to have slowed or stopped in the recent decades [37]. Assuming the trend towards earlier maturation is continuing, over a 40-year period, maturational advances of over a year for girls and 8 months for boys would be expected. Since performances on aerobic fitness tests generally improve with age, an age-related improvement in performance would be expected between 1960 and 2000 based on maturational advances alone. Using data from several large Australian and New Zealand health and fitness surveys of children and adolescents [38–41], performances on maximal field running tests improve by 0.6–2.9% for each year of age between 9 and 15 years (note, these age-related changes in aerobic fitness test performance do not necessarily reflect age-related changes in aerobic fitness, i.e. peak oxygen uptake). Therefore, to estimate 'real' biological-based changes, the magnitude of chronological age-based changes should be added to the expected improvements based on maturational advances. For example, between 1961 and 2002 there was a decline of −12.3% (or −0.30% p.a.) for 11-year-old New Zealand girls tested on the 550-meter run. Over this period, a maturational advance of at least 1 year would be expected. Using cross-sectional data, girls improve their 550-meter run performance between the ages of 12 and 13 by +1.5%. The underlying change is therefore −13.8%, or about −0.34% p.a. While the effect of maturational change will be quantitatively small for secular changes in aerobic performance, especially given that country × study × age × sex × test changes spanned an average of only 11 years, it does at least highlight that the reported declines are likely to be underestimated.

Secular Changes in Field Tests vs. Criterion Laboratory Tests of Aerobic Fitness

There have been few reports on secular changes in criterion measures of aerobic fitness in children and adolescents. Armstrong et al. [42] and Eisenmann and Malina [43] reported that directly measured peak/maximum oxygen uptake values ($ml \cdot kg^{-1} \cdot min^{-1}$) have remained relatively stable over time in children and adolescents from the United Kingdom and the United States, respectively. Further examination of Eisenmann and Malina's [43] data suggest that peak/maximum oxygen uptake values improved in the late 1960s and throughout the 1970s, and declined thereafter [see chapter by Malina, this vol., pp. 67–90]. These secular changes are consistent with the secular changes in aerobic performance reported in the present study. In addition, Fredriksen et al. [44] found declines of about −0.12% p.a. in the peak oxygen uptake values ($ml \cdot kg^{-1} \cdot min^{-1}$) of 8- to 16-year-old Norwegians between 1952 and 1997. Miyashita and Sadamoto [45] reported that the maximal oxygen uptake ($ml \cdot kg^{-1} \cdot min^{-1}$) of 10- to 12-year-old Japanese children declined at about −1.24% p.a. between 1969 and 1978–1979. Note, these secular changes are confounded by the use of the ratio standard to express peak/maximal oxygen uptake [46]. For example, given secular increases in pediatric body mass [47], secular declines in peak/maximal oxygen uptake expressed in $ml \cdot kg^{-1} \cdot min^{-1}$ may be observed despite secular stability in peak/maximal oxygen uptake in $liters \cdot min^{-1}$.

While these studies report secular changes in criterion measures of aerobic fitness, they have been criticized for using small samples (typically comprising only volunteers who are willing to exercise to exhaustion), undifferentiated age ranges and mixing data from different ergometers (cycle and treadmill) [see

Table 4. Validity coefficients for ten maximal field running tests of aerobic fitness in children and adolescents

Test	Number of studies	n	r^2
Timed runs			
6 min	2	151	0.33 (0.25–0.40)
9 min	2	103	0.50 (0.38–0.67)
12 min	7	175	0.52 (0.19–0.81)
Distance runs			
550 m	6	508	0.33 (0.05–0.51)
800 m	3	366	0.39 (0.05–0.58)
1,200–1,207 m	2	121	0.24 (0.19–0.32)
1,600–1,609 m	8	644	0.54 (0.36–0.77)
2,000 m	1	58	0.53
2,400 m	1	195	0.56 (0.52–0.59)
Endurance shuttle runs			
20 m SRT	15	795	0.51 (0.21–0.77)

Shown are the number of validity studies, the sample sizes (n), and the $\sqrt{n}$-weighted mean coefficients of determination (r^2) and the associated range. Note, only one validity coefficient was available for the 2,000 m run, hence, no range was reported.

chapters by Malina, this vol., pp. 67–90, and Rowland, this vol., pp. 200–209]. Nonetheless, collectively, they do at least suggest that peak/maximum oxygen uptake has been reasonably stable over time in children and adolescents, with small declines in some groups more recently.

But what evidence is there that secular changes in aerobic performance represent secular changes in underlying physiological components (e.g. peak/maximal oxygen uptake)? Table 4 shows the validity coefficients ($\sqrt{n}$-weighted mean coefficients of determination) for ten of the 22 maximal field running tests for which secular changes could be calculated. Data were compiled from a review of 34 pediatric validity studies [7], which quantified the strength of the relationship between maximal field running tests of aerobic fitness and directly measured peak/maximal oxygen uptake ($ml \cdot kg^{-1} \cdot min^{-1}$). Table 4 shows that these tests are reasonable estimators of peak/maximal oxygen uptake, as a moderate to large part of the variability in aerobic fitness test performance can be explained by the variability in peak/maximal oxygen uptake. It also shows that tests which require running over long distances, or running for long periods of time, are more valid estimators of peak/maximal oxygen uptake. It is notable that validity coefficients typically increased with age.

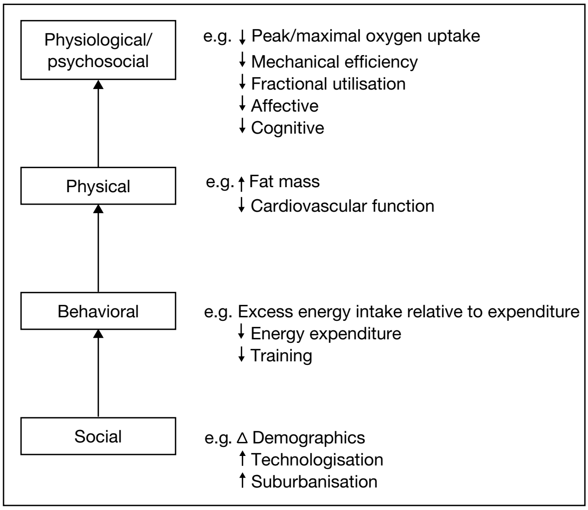


Fig. 4. Flowchart showing potential factors causing the decline in aerobic performance.

However, it is important to remember that factors other than peak/maximal oxygen uptake also contribute to aerobic fitness test performance, particularly in younger children where motor skills and cognitive ability are likely to play a major role [46], including mechanical efficiency, the sustainable fraction of peak/maximal oxygen uptake, anaerobic capacity, oxygen uptake kinetics and psychosocial factors (e.g. pacing skills, motivation and self-efficacy). Furthermore, given that aerobic performances have been assessed using a wide range of aerobic fitness tests, each of which impose different physiological and psychosocial demands, it could be argued that secular changes (% p.a.) in one test do not equate to secular changes in another. For example, factors such as oxygen uptake kinetics and anaerobic capacity will be relatively more important for performances over short distances – though the effect will be very small over distances of more than several hundred meters [48] – and peak/maximal oxygen uptake relatively more important for performances over long distances.

What Is Causing the Recent Secular Declines in Aerobic Performance?

Figure 4 shows a model which suggests that secular declines in maximal field tests of aerobic performance are caused by a network of social, behavioral, physical, psychosocial and physiological factors (for more details, see [7]). First, proximate causes of declines in running performance are, assuming maximal effort, necessarily changes in peak/maximal oxygen uptake, mechanical efficiency and the sustainable fraction of peak/maximal oxygen uptake [49]. For example, a decrease in mass-specific peak/maximal oxygen uptake will impair running performance, and a reduction in mechanical efficiency will change the running speed-oxygen uptake relationship and increase the oxygen cost at any given running speed. Furthermore, a reduction in sustainable fraction of peak/maximal oxygen uptake will mean that only a lower exercise intensity can be maintained. Second, psychosocial aspects of maximal performance, both affective (e.g. motivation) and cognitive (e.g. pacing), may also be important. Third, physiological changes are in turn affected by physical changes such as increased fat mass and reduced cardiovascular function [18, 26]. While there are no secular data for cardiovascular function, there is overwhelming evidence of global increases in pediatric fatness [50], and strong mechanistic, causal and temporal links between increases in fatness and declines in aerobic performance [for more details, see chapter by Olds et al., this vol., pp. 226–240]. Fourth, increases in fatness are ultimately the result of behavioral changes such as excessive energy intake relative to expenditure, reduced energy expenditure, and reduced vigorous physical activity. With plausible causal mechanisms [7], and in light of recent evidence showing relative stability in pediatric energy intake over time [51], it is likely that increases in pediatric fatness are due principally to declines in energy expenditure. Though there are few reliable secular data on pediatric energy expenditure, largely due to variability in sampling and methodology, a series of snapshots suggest that vigorous physical activity is declining [52]. Finally, these behavioral changes, in turn, are likely mediated by a changing social and built environment (e.g. a changing family profile, a breakdown of local communities, the increased use of sedentary technologies, and a shift towards suburbanization), which is becoming 'toxic for exercise' [7].

Though this model describes plausible underlying causal mechanisms, it is the changes in aerobic performances which are of primary interest in this study. It is the ability to run fast, play harder and keep moving longer which is important for children's physical activity levels, irrespective of the underlying mechanisms responsible for the changes.

Secular Comparisons of Aerobic and Anaerobic Performances

The vast majority of available scientific evidence examining secular changes in pediatric fitness has focused on secular changes in aerobic fitness rather than anaerobic fitness. This is not surprising given the relationship between aerobic fitness and health. Of the available evidence, Tomkinson's study [53] of over 49 million children and adolescents between 1958 and 2003, provides the most complete commentary on secular changes in pediatric anaerobic fitness. In contrast to the results of this study, Tomkinson [53] reports that pediatric anaerobic fitness test performance has been relatively stable since the

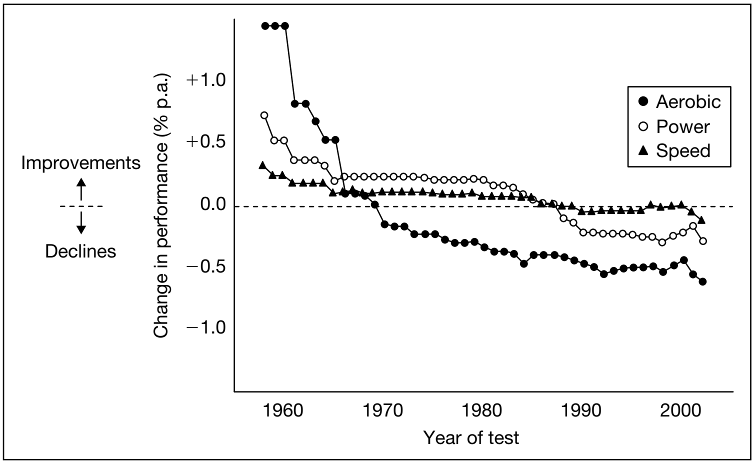


Fig. 5. Global time-related patterns of change for aerobic fitness tests (closed circles) and anaerobic fitness tests of power (open circles) and speed (closed triangles) for the period 1958–2002. The power and speed test data are from Tomkinson [53]. Higher values (i.e. those greater than zero) indicate improvements in performance.

late 1950s, with an overall improvement equivalent to about +0.04% p.a. Figure 5 illustrates these secular differences, by showing the time-related patterns of change for power, speed and aerobic test performance over the period 1958–2002. Examination of figure 5 shows that the decline is steepest and occurs earliest for aerobic tests, with a cross-over point from improvements to declines at about 1970. The decline is smaller for power tests, and the crossover occurs much later, at about 1985. On speed tests, almost all changes are improvements, but these dropped to close to zero by 1985.

So why have aerobic performances declined, and power and speed performances remained relatively stable? First, Tomkinson et al. [54] suggested that the secular differences may be due to the differential effects of fat mass and fat-free mass on aerobic and anaerobic performances [see also chapter by Tomkinson and Olds, this vol., pp. 168–182]. Second, another answer may rest with maturational advances. Analysis of data from several large health and fitness surveys of Australian children and adolescents [39–41], reveals that age-related improvements in power and speed test performances (3.4–8.5 and 1.1–3.8% for each year of age between 9 and 15 years respectively), are larger than the age-related improvements in aerobic test performances (0.6–2.9%) [54]. The effect of maturational change will therefore be relatively larger for secular changes in anaerobic performances, and the apparent stability in anaerobic performances might actually reflect an 'underlying' decline. Third, it is also possible that skill contributes more to power and speed performance in children and adolescents, and without evidence of a secular change in motor skills, anaerobic performances could be less susceptible to secular change. Though not complete, these are at least three reasons for the secular differences in aerobic and anaerobic performances.

Conclusion

Though opinion is divided on whether today's children and adolescents are fitter than their peers from the past, this study, presenting secular data on over 25 million 6- to 19-year-olds from 27 countries between 1958 and 2003, shows that aerobic performances have declined globally at a rate of −0.46% p.a. since 1970. These changes are in stark contrast to those reported for children's anaerobic fitness test performance [53]. Despite its limitations, this study paints a very consistent picture. There have been systematic changes in aerobic performance across age, sex, and geographical groups over the past half century.

Acknowledgements

We would like to thank all of the study authors for clarifying the details of their own study and for providing information on other studies.

References

1 Commonwealth of Australia: Physical and Sport Education: a Report by the Senate Standing Committee on Environment, Recreation and the Arts. Canberra, Senate Printing Unit, 1992.
2 Armstrong N, van Mechelen W: Are young people fit and active?; in Biddle S, Sallis J, Cavill N (eds): Young and Active? Young People and Health-Enhancing Physical Activity – Evidence and Implications. London, Health Education Authority, 1998, pp 69–97.
3 Strong WB: Physical activity and children. Circulation 1990;81:1697–1701.
4 Corbin CB, Pangrazi RP: Are American children and youth fit? Res Q Exerc Sport 1992;63:96–106.
5 Lemonick MD, Masters C: Rediscovering playtime. Time Mag 2005;165:56–58.
6 Rowland T: Declining cardiorespiratory fitness in youth: fact or supposition? Pediatr Exerc Sci 2002;14:1–8.
7 Tomkinson GR: Secular changes in fitness performance of Australasian children and adolescents; diss. University of South Australia, Adelaide, 2004.
8 Wilson T: The evolution of fitness and fatness in boys of high socio-economic status; diss. University of South Australia, Adelaide, 2002.

9 Tomkinson GR, Léger LA, Olds TS, Cazorla G: Secular trends in the performance of children and adolescents (1980–2000): an analysis of 55 studies of the 20 m shuttle run in 11 countries. Sports Med 2003;33:285–300.

10 Bunc V, Jansa P, Kluka D: Prognosis of boys' physical fitness development in the Czech Republic to 2001. ICHPER-SD J 1997;33:51–54.

11 Bös K: Kinder und jugendliche brauchen sport (Children and young people need sport). Fachtagung Sport des Kultusministeriums Baden-Württemberg und Kongress der Turnbünde, Baden-Württemberg und Rheinland-Pfalz, 1998.

12 Kretschmer J: Changes in childhood and children's motor development. Int J Phys Educ 2001;38:114–126.

13 The Government of the Hong Kong Special Administrative Region: Physical education – surveys on physical fitness status of Hong Kong school pupils. accessed 23 February 2005, at http://www.emb.gov.hk.

14 Mészáros J, Mahmoud O, Szabó T: Secular trend and motor performance scores in Hungarian school-boys. Facta Universitatis Phys Educ 1999;1:43–49.

15 Ben-Sira D: A survey of the level of physical fitness of Israeli high school students; in Ruskin H, Simkin A (eds): Physical Fitness and the Ages of Man: Proceedings of the Symposium of the International Council for Physical Fitness Research, Jerusalem, 1986. Jerusalem, Academon Press, 1987, pp 164–177.

16 Ikai M, Fukunaga T: Imbalance between growth and physical fitness; in Asahina K, Shigiya R (eds): Physiological Adaptability and Nutritional Status of the Japanese. B. Growth, Work Capacity and Nutrition of Japanese. Tokyo, University of Tokyo Press, 1975, pp 26–30.

17 Noi S, Masaki T: The educational experiments of school health promotion for the youth in Japan: analysis of the 'sport test' over the past 34 years. Health Promot Int 2002;17:147–160.

18 Watanabe T, Yamamoto Y, Miyashita M, Mutoh Y: Secular change in running performance of Japanese adolescents: a longitudinal developmental study. Am J Hum Biol 1998;10:765–779.

19 Tomkinson GR, Olds TS, Kang SJ, Kim DY: Secular trends in the aerobic fitness test performance and Body Mass Index of Korean children and adolescents (1968–2000). Int J Sports Med 2007;28: 314–320.

20 Saranga S, Prista A, Maia J: Mudança nos níveis de aptidão física em função de alterações políticas e sócio-económicas de 1992–1999 (Changes in Physical fitness levels as a function of political and socio-economic alterations between 1992 and 1999); in Prista A, Maia J, Saranga S, Marques A (eds): Saúde, crescimento e desenvolvimento: Um estudo epidemiológico em crianças e jovens de Moçambique (Health, Growth and Development: An Epidemiological Study in Boys and Girls from Mozambique). Porto, FCDEF – Universidade do Porto/FCEFD – Universidade Pedagógica, 2002, pp 71–87.

21 Przeweda R, Trzesniowski R: Sprawnosc fizyczna Polskiej mlodziezy w swietle badan z roku 1989 (Physical Fitness of Polish Youth in the Light of Studies in 1989). Warsaw, Akademia Wychowania Fizycznego, 1996.

22 Przewęda R, Dobosz J: Growth and Physical Fitness of Polish Youths. Warsaw, Akademia Wychowania Fizycznego, 2005.

23 Przewęda R: Generation changes of physical fitness in Polish children and youth during the last two decades. Scripta Periodica 2000;3:99–108.

24 Lyach V, Bogdanov GP, Polyanskaya NV, Meikson GB: Physical development and motor performance of schoolchildren in the Russian Federation; in Lidor R, Ben-Sira D, Artzi Z (eds): Physical Activity in the Lifecycle: Proceedings of the 1993 FIEP World Congress. Netanya, Israel, The Zinman College of Physical Education at the Wingate Institute, 1994, pp 143–149.

25 Quek JJ, Menon J, Tan S, Wang B: Review of National Physical Fitness Award (NAPFA) norms; in: Optimising performance: Proceedings of the International Sports Science Conference 93, Singapore, 1993. Singapore, Singapore Sports Council, 1993, pp 161–212.

26 Westerstahl M, Barnekow-Bergkvist M, Hedberg G, Jansson E: Secular trends in body dimensions and physical fitness among adolescents in Sweden from 1974 to 1995. Scand J Med Sci Sports 2003;13:128–137.

27 California State Department of Education: The physical performance test for California (revised). Sacramento, California State Department of Education, 1971.
28 California State Department of Education: The physical performance test for California (revised). Sacramento CA, California State Department of Education, 1981.
29 Davis KL, Roberts TC, Smith RR, Ormond F, Pfohl SY, Bowling M: North Carolina children and youth fitness survey. J Phys Educ Rec Dance 1994;65:65–72.
30 Hunsicker PA, Reiff GG: A survey and comparison of youth fitness 1958–1965. J Health Phys Educ Rec 1966;37:23–25.
31 Hunsicker PA, Reiff GG: Youth fitness report: 1958–1965–1975. J Phys Educ Rec 1977;48:31–33.
32 Morrow JR, Crowhurst ME, Monaghen SD, Morava LB, Pyfer J: A summary of the Texas Youth Fitness Study 1984. Texas Assoc Health Phys Educ Rec Dance J 1986;54:11–14, 56–57.
33 Pate RR, Ross JG, Dotson CO, Gilbert GG: The new norms: a comparison with the 1980 AAHPERD norms. J Phys Educ Rec Dance 1985;56:70–72.
34 Updyke WF, Willett MS: Physical Fitness Trends in American Youth 1980–1989: Report Summary. Bloomington, Chrysler Fund-AAU Physical Fitness Program, 1989.
35 World Bank: Data and statistics: country groups. Accessed December 14, 2005 at http://web.worldbank.org/WBSITE/EXTERNAL/DATASTATISTICS/0,,contentMDK:20421402~menuPK:64133156~pagePK:64133150~piPK:64133175~theSitePK:239419,00.html.
36 Himes JH: Secular changes in body proportions and composition; in Roche AF (ed): Secular Trends in Human Growth, Maturation and Development. Chicago, Society for Research in Child Development, 1979, pp 28–58.
37 Malina RM, Bouchard C, Bar-Or O: Growth, Maturation and Physical Activity. Champaign, Human Kinetics, 2004.
38 Dawson K, Hamlin M, Ross J, Duffy D: Trends in the health-related physical fitness of 10–14 year old New Zealand children. J Phys Educ NZ 2001;34:26–39.
39 Dollman J, Olds T, Norton K, Stuart D: The evolution of fitness and fatness in 10–11-year-old Australian schoolchildren: changes in distributional characteristics between 1985 and 1997. Pediatr Exerc Sci 1999;11:108–121.
40 Pyke JE: Australian Health and Fitness Survey 1985. Adelaide, Australian Council for Health, Physical Education and Recreation, 1987.
41 Tomkinson GR, Olds TS, Gulbin J: Secular trends in physical performance of Australian children: evidence from the Talent Search program. J Sports Med Phys Fitness 2003;43:90–98.
42 Armstrong N, Williams J, Balding J, Gentle P, Kirby B: The peak oxygen uptake of British children with reference to age, sex and sexual maturity. Eur J Appl Physiol 1991;62:369–375.
43 Eisenmann JC, Malina RM: Secular change in peak oxygen consumption among United States youth in the 20th century. Am J Hum Biol 2002;14:699–706.
44 Fredriksen PM, Thaulow E, Nystad W, Ingjer F: Aerob kapasitet hos barn og unge – Nordiske resultater gjennom 45 år (Aerobic capacity among children and adolescents – Nordic results over the past 45 years). Tidsskr Nor Lœgeforen 1998;118:3106–3110.
45 Miyashita M, Sadamoto T: The current problems of physical fitness in Japanese children: in comparison with European and North American children. J Sports Med 1987;27:217–222.
46 Armstrong N, Welsman JR: Assessment and interpretation of aerobic fitness in children and adolescents. Exerc Sport Sci Rev 1994;22:435–476.
47 Olds TS, Harten NR: One hundred years of growth: the evolution of height, mass, and body composition in Australian children, 1899–1999. Hum Biol 2001;73:727–738.
48 Péronnet F, Thibault G: Mathematical analysis of running performance and world records. J Appl Physiol 1989;67:453–465.
49 Olds TS, Dollman J: Are changes in distance-run performance of Australian children between 1985 and 1997 explained by changes in fatness? Pediatr Exerc Sci 2004;16:201–209.
50 World Health Organization: Obesity: Preventing and Managing the Global Epidemic. Geneva, World Health Organization, 1998.
51 Livingston B: Epidemiology of childhood obesity in Europe. Eur J Pediatr 2000;159:S14–S34.

52 Dollman J, Norton K, Norton L: Evidence for secular trends in children's physical activity behaviour. Br J Sports Med 2005;39:892–897.
53 Tomkinson GR: Global changes in anaerobic fitness test performance of children and adolescents (1958–2003). Scand J Med Sci Sports. In press.
54 Tomkinson GR, Hamlin MJ, Olds TS: Secular changes in anaerobic test performance in Australasian children and adolescents. Pediatr Exerc Sci 2006;18:314–328.

Grant R. Tomkinson, PhD
Centre for Applied Anthropometry, School of Health Sciences
University of South Australia, City East Campus
GPO Box 2471
Adelaide SA 5001 (Australia)
Tel. +61 8 8302 1407, Fax +61 8 8302 2766, E-Mail grant.tomkinson@unisa.edu.au

Tomkinson GR, Olds TS (eds): Pediatric Fitness. Secular Trends and Geographic Variability.
Med Sport Sci. Basel, Karger, 2007, vol 50, pp 67–90

Physical Fitness of Children and Adolescents in the United States: Status and Secular Change

Robert M. Malina

Tarleton State University, Stephenville, Tex., USA

Abstract

The physical fitness of school-age children in the United States is considered from two perspectives – status and secular change. This chapter principally examines health-related fitness, including the BMI, though performance-related fitness is briefly considered. Concepts of reference data and standards and factors that may influence secular change are initially discussed. National data on the physical fitness status of school children in the continental United States are limited to the 1980s. Ethnic variation in physical fitness is not considered except for the prevalence of overweight and obesity. More recent physical fitness data, including examination of ethnic variation, are based on several statewide and more local surveys. Although results vary by test, the majority of American school children meet or exceed criterion-referenced standards, although sex differences are not consistent. Poor morphological fitness manifest in obesity is an exception. The prevalence of overweight and obesity has increased since the early 1980s. Secular data for specific fitness items are less extensive. Regression analyses suggest a recent decline in maximal aerobic power in girls, but fairly stable levels between the 1930s and today in boys. However, the highest values for boys occur in the 1960s and 1970s and more recent values are somewhat lower. The general trend may be consistent with the decline since the 1980s in aerobic performance assessed with the 20 m shuttle run. These trends highlight the need for updated national physical fitness data for American youth.

Physical fitness in the United States was historically viewed in terms of three components: muscular strength and endurance, cardiorespiratory endurance, and motor ability [1]. Surveys of the physical fitness of youth in the 1960s and 1970s and to a lesser extent into the 1980s and 1990s have thus focused on strength, motor and cardiorespiratory endurance tests. The concept of physical fitness shifted from this primary performance focus to more emphasis on health in the late 1970s [2, 3]. The shift from a performance to a health focus was driven by several factors in the 1950s and 1960s: (1) a high prevalence of failure on the Kraus-Weber test [4], specifically the toe touching item, in the 1950s, (2) political concern for the unfitness of youth, in part, in the context of the success of the former Soviet Union in its space program in the 1950s (Sputnik in 1957), and (3) the dramatic increase in mortality from coronary heart disease which reached a peak in the late 1960s [5]. The potential role of physical activity and physical fitness as preventive factors in heart disease and lower back problems and by extension obesity in adults was a driving force in the development of the concept of health-related in contrast to performance-related fitness. The distinction was to a large extent based on adult health concerns and the assumption that regular physical activity and enhanced fitness during childhood and adolescence may prevent or impede the development of these degenerative conditions and that physical activity and fitness during childhood and adolescence may favorably influence the activity and fitness of adults [5]. Relationships between childhood and adolescent activity and fitness and corresponding indicators in adulthood have been previously addressed [6–8].

The concept of physical fitness has since evolved to include morphological and metabolic components [9]. The body mass index (BMI) measured in $kg \cdot m^{-2}$ is the major indicator of morphological fitness and is often indicated as a measure of body composition. However, the BMI is essentially a measure of heaviness and not necessarily of body composition and fatness. The BMI is about equally correlated with fat mass, relative fatness and fat-free mass in children and adolescents [10]. Metabolic components of fitness include variables related to the metabolic syndrome: blood lipids and lipoproteins, blood pressures, glucose levels, intra-abdominal adipose tissue, among others [9]. Metabolic fitness is not considered in this review. Summaries of general trends in several of the components in samples of United States children and adolescents associated with age and sex [10] and with physical activity [11] are available.

Purpose

The purpose of this paper is to summarize the physical fitness of school age children and adolescents in the United States from two perspectives, status and secular change. Status refers to the state of fitness as assessed by a variety tests while secular change refers to trends in fitness scores over time. Emphasis is upon health-related fitness including the BMI in the context of obesity; skinfolds are not considered. Indicators of performance-related fitness are used in a secular context. Focus is on national data sets although several regional data sets are considered where relevant.

Reference Data and Standards

Tests of fitness provide an indication of the level of fitness attained by an individual or a group in a specific test or tests at a given point in time. The fitness status of an individual or a group is ordinarily compared to an accepted reference, i.e. data derived from a large sample of healthy youth free from overt disease and potentially handicapping conditions. These are reference data which are ordinarily presented in the form of select percentiles. A reference is '…a tool for grouping and analyzing data and provides a common basis for comparing populations' [12, p. 29]. Data from national fitness surveys labeled as 'norms' [2, 13, 14] often serve as the reference of comparison in evaluating the fitness of individuals and populations.

Reference values are not standards. A standard is prescriptive and suggests the way things (i.e. fitness) ought to be and as such has an associated value judgment. Criterion-referenced standards for physical fitness were introduced, apparently first in Canada in the early 1980s [15] and then in the United States [16–18]. These standards provide specific health-related fitness test scores that are thought to be associated with a health benefit and/or a reduced risk of disease. However, dose-response evidence on the relationship between fitness test scores and health outcomes or reduced disease risk in children and adolescents is lacking. Criterion-referenced standards are generally established by an expert panel, are arbitrary, and run the risk of misclassification. Analogous procedures are used to establish dietary reference intakes designed to accommodate the broad range of individuality in energy and nutrient needs. The Prudential *Fitnessgram* provides ranges for a 'Healthy Fitness Zone' from 5 through 17+ years. The Healthy Fitness Zone represents '…a level of fitness that offers some degree of protection against diseases which result from sedentary living' [19, p. 38].

Evaluating Status and Secular Change

Evaluation and comparison of scores on fitness tests at a single point in time (status) or across time (secular change) have several underlying assumptions and/or limitations [20].

Sampling

Are corresponding populations being compared? Sampling strategies vary across surveys. National surveys generally use representative probability samples of public school youth or the total population in the continental United States, whereas small scale studies often use convenience samples. Racial/ethnic and socioeconomic composition of samples may vary over time.

Measurement

It is assumed that measurement techniques and test protocols in different studies are the same. In-field reliability of fitness items is not ordinarily reported.

Age Groups

Although fitness data are presented for single or multiple year age groups, it is not always clear and/or not reported whether decimal ages (based on birth date and date of measurement), months, or self-reported ages are used. Age groups are not always defined. For example, '8 years' can include children between 7.50 and 8.49 years or between 8.00 and 8.99 years; the groups will differ in mean age by about half a year. Single year groups are generally defined by age at last birthday, i.e. 8.00 through 8.99 years, so that mean age approximates the mid-point of the range.

Test Personnel

Physical education teachers are commonly test administrators and/or supervisors. The use of volunteer teachers versus trained field staff and professional physical educators is an additional concern. It is assumed that all personnel are trained the same and that test protocols are administered in a similar manner. Training took place prior to several of the surveys. Unfortunately, in-field inter- and intra-observer measurement variability for fitness tests is not reported, except for skinfolds in the first National Children and Youth Fitness Study [13].

Testing Conditions

Conditions that influence performance include temperature and humidity, running and jumping surfaces, equipment, and others. They are not consistently specified and are generally assumed to be constant across surveys.

Individuals

Previous experience with the tests (potential testing or learning effects); understanding of instructions; motivation to perform, especially maximal efforts; opportunity for practice; among other factors cannot be controlled. These potential sources of variation probably balance out across time and in large samples. Nevertheless, some teachers do in fact permit children to practice test items prior to surveys.

National Surveys

Tests of physical fitness used in several national cross-sectional surveys in the United States and in the *Fitnessgram* and *Physical Best* programs are summarized in table 1. The national surveys are often used as reference data,

Table 1. Test batteries used in national surveys of the physical fitness of United States children and adolescents (note, dates of surveys or publication of reference values in parentheses)

Test	Age	Test items
AAHPER Youth Fitness Test (1958–65–75) [21, 22]	9–17+ years	speed – 50-yard dash power/coordination – standing long jump speed/agility – shuttle run upper body functional strength – pull-ups (boys), flexed arm hang (girls) abdominal strength/endurance – sit-ups power/coordination – distance throw (softball) cardiovascular endurance – 600-yard run
AAHPERD Health-Related Physical Fitness Test (1980, 1984) [2, 3]	5–17+ years	cardiovascular endurance – 1-mile run, 9-minute run, 1.5-mile run, 12-minute run (13–18 years) abdominal strength/endurance – sit-ups flexibility, lower trunk – sit and reach subcutaneous fatness – sum of triceps + subscapular skinfolds
AAHPERD Physical Best Program (1988) [17]	5–18 years	cardiovascular endurance – 1-mile run/walk flexibility, lower trunk – sit and reach abdominal strength/endurance – sit-ups upper body strength/endurance – pull-ups body composition – sum of triceps and subscapular skinfolds, BMI
President's Council on Physical Fitness and Sports (1985) [23]	6–17 years	upper arm-should girdle strength and endurance – pull-ups, flexed arm hang abdominal strength and endurance – curl ups lower limb muscle strength, endurance and agility – shuttle run explosive power of lower limbs – standing long jump running speed – 50-yard dash cardiorespiratory endurance – 1-mile run/walk, 2-mile walk hamstring, low back flexibility – V-sit and reach

Table 1. (continued)

Test	Age	Test items
National Children and Youth Fitness Study (1984, 1986) [13, 14]	I: 10–18 years II: 6–9 years	cardiorespiratory endurance – 1-mile run/walk; same at 8–9 years in phase II, 0.5 mile at 6–7 years upper body strength/endurance – chin-ups; modified pull-ups in phase II abdominal strength – bent knee-sit-ups flexibility – sit and reach body fatness – sum of triceps and subscapular skinfolds; medial calf skinfold added in phase II
Chrysler-AAU Physical Fitness Program (1980–1989) [24]	6–17 years	*required* circulo-respiratory endurance – endurance run (6–7, 0.25 mile; 8–11, 0.75 mile; older ages, 1.0 mile) strength and endurance of the arms and shoulders girls – pull-ups (boys), flexed arm hang (girls) strength and endurance of abdominal muscles and hip flexors – sit-ups flexibility of the lower back and hamstrings – sit and reach *optional* standing long jump, sprints, shuttle run, modified push-up, isometric push-up, isometric squat
Prudential Fitnessgram (1987, 1992) [16, 19]	5–17+ years	body composition – % fat (from triceps + subscapular skinfolds), BMI aerobic capacity – 1-mile run, multistage 20-meter shuttle run (*Pacer*) abdominal strength – curl-up upper body strength – push-up, modified pull-up, pull-up, flexed arm hang trunk extensor strength/flexibility – trunk lift flexibility – sit and reach, shoulder stretch

while the *Fitnessgram* and *Physical Best* are offered as criterion-referenced standards.

Physical fitness test batteries, based largely on performance-related items, were administered to representative samples of the school age population in the United States in the 1950s, 1960s, 1970s and 1980s [21–23]. Health-related fitness items were used national surveys of youth 10–17 years in the 1970s [2, 3] and in grades 1 through 12 in the 1980s [13, 14]. The fitness of boys and girls attending schools that used the Chrysler-AAU (Amateur Athletic Union) Physical Fitness Program was regularly monitored from 1980 to 1994 [24–26]. A major focus of this program was the enhancement of 'Fitness Literacy' viewed as knowledge about physical fitness, its maintenance and relationship to health, and experience in developing enhanced levels of fitness.

A series of health examination surveys of national probability samples of the American population beginning in the 1960s [10] and continuing at present [27, 28] included measures of height and weight. These data provide the basis for evaluating secular change in body size, including the BMI. The data also provide the basis for currently used 'growth charts' for weight, height and the BMI [29]. Details of the surveys including sampling and quality control have been reported [30].

Physical Fitness of United States Youth

National Surveys in the 1980s

Descriptive statistics for indicators of the health-related fitness (excluding skinfolds) for single year age groups by sex of United States children and adolescents based on the National Children and Youth Fitness Study I in 1984 [13] and II in 1986 [14] and the President's Council on Physical Fitness and Sports National School Population Fitness Survey in 1985 [23] are summarized in tables 2 and 3, respectively. Test protocols for flexibility and abdominal strength/endurance differed between the surveys. One-mile run performances and number of sit-ups in the two surveys are, on average, reasonably similar. Mean scores on tests required in the Chrysler-AAU Physical Fitness Program in 1989 [24][1] are summarized in table 4.

The data summarized in tables 2–4 provide an indication of the physical fitness status of school youth in the continental United States in the 1980s. Physical fitness improves, on average, with age during childhood into the adolescent transition, ~7–12 years, in the 1-mile run/walk, 2-mile run/walk, sit-ups and flexed

---

[1] The AAU Physical Fitness Program has continued through 1994, but these more recent data are not available at present. The untimely death of Wynn Updyke, program director, has slowed the process.

Table 2. Means, medians (Md) and 10th (P10) and 90th (P90) percentiles for indicators of health-related physical fitness in American children and adolescents 9–17 years: National Children and Youth Fitness Studies I – 1984 and II – 1986 [13, 14]

	Flexibility				Abdominal strength-endurance			
	sit and reach, cm				bent knee sit-ups, n in 60 s			
Age	mean	Md	P10	P90	mean	Md	P10	P90
Boys								
9	32.0	33.0	24.1	39.4	27.9	28	16	39
10	33.3	34.3	25.4	40.6	34.4	34	22	47
11	33.3	33.0	24.1	41.9	35.3	35	22	48
12	32.3	33.0	21.6	40.6	37.9	38	25	50
13	32.8	33.0	22.9	41.9	39.6	40	28	52
14	33.8	34.3	22.9	44.5	41.0	41	30	52
15	35.8	35.6	24.1	45.7	42.0	42	31	53
16	37.6	38.1	25.4	48.3	43.5	43	32	55
17	38.4	39.4	26.7	49.4	43.5	43	31	56
Girls								
9	35.7	35.6	27.9	43.2	25.5	26	15	36
10	36.6	36.8	26.7	44.5	31.4	31	20	43
11	37.6	38.1	29.2	45.7	31.6	32	20	42
12	39.4	39.4	30.5	48.3	33.7	33	21	46
13	40.9	40.6	30.5	50.8	33.6	33	21	46
14	41.7	43.2	31.7	49.5	34.8	35	23	47
15	43.2	43.2	34.3	50.8	34.6	35	24	45
16	44.5	44.5	35.6	52.1	35.1	35	23	49
17	43.7	45.7	34.3	52.1	35.1	36	24	47

arm hang. Subsequently, performances of boys improve while those of girls are generally stable or decline somewhat. Hence, the sex difference which is relatively small during childhood is magnified during adolescence in these fitness items. Shoulder strength as measured with chin-ups shows, on average, a larger sex difference in late childhood which gets progressively larger with age. The mean number of completed chin-ups is <1 among girls in the National Children and Youth Fitness Study; in contrast, the mean number improves linearly with age in boys from 2.7 at 10 years to 9.0 at 17 years [13, 14]. In contrast, flexibility of the lower trunk is consistently greater in girls than in boys at all ages during childhood and adolescence. It increases, on average, linearly with age in girls, but is stable or declines somewhat during childhood into early adolescence in boys and then increases in later adolescence.

Table 2. (continued)

Shoulder strength-endurance				Cardiovascular endurance			
chin-ups, n completed				1-mile run/walk, min			
mean	Md	P10	P90	mean	Md	P10	P90
				10.6	10.2	13.6	8.2
2.7	1	0	8	10.3	9.9	12.5	8.2
2.9	2	0	8	9.8	9.1	12.1	7.4
3.4	3	0	8	9.4	8.8	11.8	7.2
4.6	4	0	10	8.7	8.1	10.6	6.8
5.7	5	0	12	8.7	7.9	10.6	6.5
7.1	7	1	14	8.0	7.5	10.2	6.4
8.6	9	2	14	7.7	7.5	9.6	6.2
9.0	9	2	15	8.3	7.5	10.7	6.1
				11.6	11.2	14.5	9.2
0.9	0	0	3	11.6	11.2	14.3	9.1
0.8	0	0	3	11.9	11.3	14.6	8.7
0.8	0	0	2	11.5	11.0	14.1	8.6
0.6	0	0	2	11.1	10.9	13.7	8.5
0.8	0	0	2	10.7	10.5	13.2	8.2
0.6	0	0	2	11.2	10.8	14.1	8.4
0.9	0	0	2	11.1	10.6	13.7	8.5
0.7	0	0	2	11.0	10.6	13.8	8.3

Regional Surveys and Ethnic Variation

The Motor Performance Study of Michigan State University was begun in 1967 and continued through the 1990s [31]. It is a mixed-longitudinal study of the interrelationships between growth and performance. It has longitudinal and secular components (see below). The study includes semiannual tests of performance- and health-related fitness among children and youth 5 through 18 years: flexed arm hang, sit-and-reach, 400-foot shuttle run, standing long jump, vertical jump, 30-yard dash and 10-yard shuttle run. The data are reported as means, standard deviations and percentiles [32].

The health-related physical fitness of representative samples of children 6–9 years of age in the state of Maine in 1989 (n = 4,135 boys and 4,281 girls) was compared to national reference values [33]. Compared to reference means for

Table 3. Means, medians (Md) and 10th (P10) and 90th (P90) percentiles for indicators of health-related physical fitness in American children and adolescents 7–17 years: National School Population Fitness Survey, 1985 [23]

	Upper body strength-endurance				Abdominal strength-endurance			
	flexed arm hang, s				flexed-leg sit-ups, n in 60 s			
Age	mean	Md	P10	P90	mean	Md	P10	P90
Boys								
7	10.6	8	1	23	27.2	28	15	38
8	12.3	10	1	28	30.5	31	18	42
9	13.1	10	2	28	32.0	32	20	44
10	16.0	12	1	38	35.2	35	23	48
11	16.3	11	1	37	36.8	37	25	49
12	15.8	12	1	36	40.3	40	27	53
13	18.1	14	2	37	42.5	42	30	55
14	27.7	20	3	61	45.3	45	33	58
15	33.4	30	8	62	45.5	45	32	59
16	31.1	28	7	61	44.7	45	31	58
17	31.5	30	8	56	44.0	44	32	57
Girls								
7	9.3	6	0	21	25.4	25	15	36
8	9.7	8	0	21	28.7	29	18	40
9	10.7	8	0	23	30.0	30	19	41
10	12.5	8	0	29	30.2	30	19	42
11	10.9	7	0	25	32.4	32	20	44
12	11.0	7	0	27	34.9	35	23	47
13	11.0	8	0	28	36.4	37	23	50
14	12.8	9	0	31	37.4	37	25	49
15	13.3	7	1	34	36.8	36	23	51
16	12.4	7	0	30	35.5	35	23	49
17	12.1	7	1	29	34.1	34	22	47

the AAHPERD health-related fitness test [3], mean levels of fitness of Maine children were similar for sit-ups (except at 6 years), better in the sit and reach and 1 mile run, but poorer (i.e. fatter) for the triceps and subscapular skinfolds.

The cardiorespiratory fitness of students enrolled in physical education classes in a Midwestern community was assessed with the 20-meter shuttle run (*Pacer*) [34]. Given the age range (8–18 years) and sample size (406 males, 389 females) numbers by age group are quite small. Comparisons among samples of adolescents 10–14 years of age from this and several local/regional surveys

Table 3. (continued)

Hamstring–lower back flexibility				Cardiovascular endurance							
‘V’ sit and reach, cm				1–mile run, min				2–mile walk, min			
mean	Md	P10	P90	mean	Md	P10	P90	mean	Md	P10	P90
1.8	2.5	−7.6	10.2	12.1	11.7	16.2	8.9	33.9	32.7	40.8	27.4
0.5	1.3	−7.6	8.9	11.4	11.1	14.9	8.5	32.8	32.2	39.9	26.2
1.0	2.5	−7.6	10.2	10.8	10.5	13.9	8.2	31.7	31.2	38.3	25.9
2.3	2.5	−8.9	12.7	10.3	9.8	13.8	7.7	30.8	29.9	37.5	25.2
2.3	2.5	−8.9	12.7	9.9	9.3	13.1	7.3	30.0	28.9	36.1	25.0
1.0	2.5	−11.4	12.7	9.3	8.7	12.2	6.9	28.8	28.1	34.2	24.9
0.5	1.3	−10.2	10.2	8.7	8.1	11.7	6.7	28.9	28.2	34.6	24.7
2.8	2.5	−10.2	12.7	8.3	7.7	11.4	6.2	28.7	28.0	34.5	24.5
4.6	5.1	−7.6	15.2	7.9	7.5	10.2	6.1	28.9	28.0	34.4	24.7
6.3	7.6	−7.6	17.8	7.7	7.2	10.3	5.9	28.7	27.9	33.8	24.8
7.1	7.6	−5.1	20.3	7.4	7.1	9.4	6.0	28.7	28.1	33.5	25.0
5.7	5.1	−2.5	14.0	13.2	12.9	16.6	10.1	35.8	35.2	43.0	28.3
5.3	5.1	−2.5	12.7	12.7	12.5	15.7	9.7	34.7	33.9	41.5	27.6
6.1	5.1	−2.5	15.2	12.2	11.9	15.7	9.1	33.2	32.7	40.6	27.1
6.9	7.6	−2.5	17.8	11.6	11.4	14.5	8.8	32.0	30.5	39.8	26.3
8.4	7.6	−1.3	20.3	11.3	11.3	14.7	8.7	32.1	31.3	39.0	26.6
9.1	8.9	0.0	20.3	11.0	11.1	14.7	8.0	30.4	29.3	35.8	25.8
9.7	8.9	0.0	20.3	10.6	10.4	14.8	7.8	30.0	29.0	34.9	25.9
11.2	11.4	0.0	21.6	10.6	10.1	14.2	7.7	30.2	29.6	35.3	25.9
12.0	12.7	1.3	22.9	10.6	10.0	14.2	7.9	30.4	30.1	34.7	26.5
13.7	14.0	2.5	24.1	11.2	10.5	16.1	7.9	30.7	30.5	34.7	26.5
11.8	11.4	2.5	22.9	10.8	10.4	14.0	8.0	30.1	30.2	33.7	26.5

conducted between 1992 and 2002 indicated neither consistent differences among samples nor trends across the decade.

National surveys have not considered ethnic variation in the physical fitness of youth except for the prevalence of overweight and obesity [27]. The short-term trend between 1999 and 2004 indicates higher prevalence of obesity in Mexican-American boys and Black-American girls aged 6–19 years (table 5); however, the magnitude of ethnic variation in prevalence has declined over this short interval.

Table 4. Means for indicators of physical fitness in American children and adolescents 6–17 years: Chrysler-AAU Physical Fitness Program [24][a]

Age group	Endurance run, min[b]	Sit-ups, n in 60 s[c]	Sit-and-reach cm	Pull-ups, n	Shuttle run, s
Boys					
6–7	2.60	27.8	42	2.4	13.3
8–9	4.82	35.2	42	2.8	12.1
10–11	7.30	38.8	41	3.4	11.4
12–13	9.12	42.4	42	4.7	10.8
14–17	8.63	46.0	44	9.5	10.2
				Flexed arm hang, s	
Girls					
6–7	2.68	26.5	45	14.1	13.7
8–9	5.45	33.2	46	18.9	12.5
10–11	7.98	36.0	47	20.8	11.9
12–13	10.47	38.6	51	23.9	11.6
14–17	10.70	38.3	52	23.6	11.4

[a] Variance statistics and percentiles are not included in the report. The data are based on sub-samples randomly drawn from the total number of children and adolescents who took the AAU test throughout the United States.

[b] Distances varied by age group: 6–7, 1/4 mile; 8–9, 1/2 mile; 10–11, 3/4 mile; 12–17, 1 mile.

[c] Bent knee sit-up.

Ethnic variation in submaximal power output at a heart rate of 170 bpm (PWC_{170}) for a mixed-longitudinal sample of Black and White youth from North Carolina in the 1990s [35] is shown in figure 1. Ethnic differences in absolute PWC_{170} are small and inconsistent across age in boys, but indicate slightly greater absolute PWC_{170} in Black girls across the age range. Relative PWC_{170} does not differ during childhood but is slightly lower during adolescence in Black youth. The data from North Carolina thus suggest ethnic variation in PWC_{170} especially in adolescence [35] and in predicted $\dot{V}O_{2max}$ [36]. Predicted absolute $\dot{V}O_{2max}$ is greater while relative $\dot{V}O_{2max}$ is lower in Black compared to White youth. The differences reflect ethnic variation in body mass. Similar ethnic trends have been reported for maximal aerobic power in prepubertal boys and girls [37] and adolescent girls [38].

California state law mandates annual testing with '. . . the physical performance test designated by the State Board of Education' [39]. The *Fitnessgram* test battery was administered to 5th, 7th and 9th grade students in all schools in the state since 1999. The protocol includes self-classification of ethnicity

Table 5. Variation in the prevalence of obesity among White-American, Black-American and Mexican-American children and adolescents between 1999 and 2004 [27][a]

	6–11 years						12–19 years					
	White		Black		Mexican-American		White		Black		Mexican-American	
	%	SE	%	SE	%	SE	%	SE	%	SE	%	SE
Males												
1999–2000	11.9	2.0	17.1	2.5	26.7	2.9	11.8	1.7	21.0	2.5	27.2	3.1
2001–2002	15.5	2.2	16.9	1.8	26.0	2.9	16.6	2.0	16.7	2.5	21.8	2.4
2003–2004	18.5	3.9	17.5	3.0	25.3	2.2	19.1	2.7	18.5	1.6	18.3	1.7
Females												
1999–2000	11.6	2.9	22.4	2.3	19.8	2.4	11.0	1.8	25.2	2.7	19.3	2.7
2001–2002	14.1	3.5	23.1	4.2	13.6	3.2	13.7	2.8	22.0	2.4	20.3	2.8
2003–2004	16.9	1.9	26.5	2.8	19.4	3.9	15.4	2.9	25.4	2.0	14.1	2.0

[a] Obesity is defined as a BMI-for-age and sex ≥95th percentiles of the 2000 Centers for Disease Control and Prevention growth charts [29].

(7 groups). Ethnic variation in two indicators of aerobic capacity measured in 2002, the 1 mile run/walk (n = 767,809) or the *Pacer* 20 m shuttle run (n = 34,524), has been reported in youth 10–15 years of age [40, 41]. Teachers who administered the tests had the choice of using either of the two aerobic tests.

One-mile run/walk times adjusted for height and weight varied among the seven ethnic groups within each sex. Among males, ethnic variation declined with increasing age. American Black youth had the slowest adjusted run/walk times from 12 through 15 years, while there was considerable overlap among American White, Hispanic, Native American (including Alaska natives), Asian, Filipino and Pacific Island youth. On the other hand, ethnic variation was greater among girls and showed a different pattern with age. Ethnic variation in adjusted run/walk times was less at 10 and 11 years and increased with age through 15 years. Adjusted 1-mile run/walk times tended to be slowest among Black-American girls and fastest among White-American girls, with girls in the other ethnic groups falling between the extremes [40].

The corresponding analysis of the *Pacer* test was limited to White, Black, Hispanic and Asian students 10–15 years. Ethnic variation in the height- and weight-adjusted number of laps was negligible among boys except at 10 years, whereas among girls Hispanics completed a lower number of laps (adjusted for body size) than White girls in five of the six age groups [41].

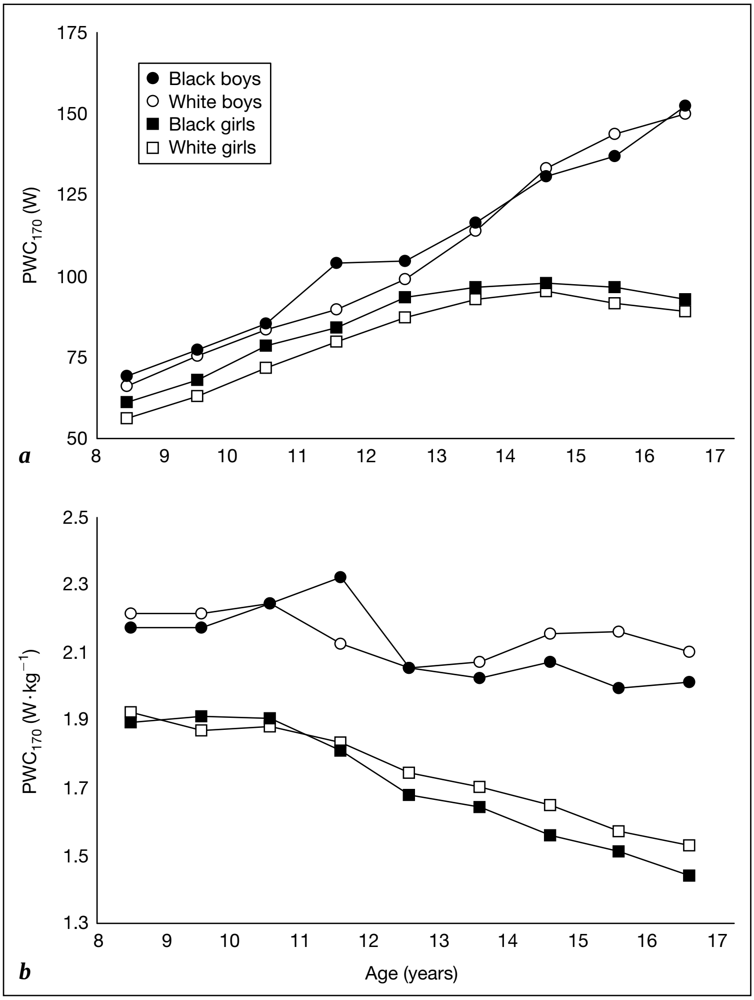


Fig. 1. Submaximal power output (PWC_{170}) in mixed-longitudinal samples American Black and White youth from North Carolina: absolute (***a***) and relative (***b***). Drawn from data reported in McMurray et al. [35].

Unfortunately, descriptive statistics for height, weight and the aerobic tests by ethnic group were not reported, which limits the comparative utility of the large data set. Moreover, children and adolescents live in an 'unadjusted' world so that absolute values of aerobic fitness are perhaps more meaningful.

A number of local studies dating to the 1930s have compared performance-related fitness items among American Blacks and Whites, and to a lesser extent

Mexican-Americans [42]. Two performance-related fitness items, running speed (dashes) and the vertical jump, show, on average, consistently better performances in Black than in White youth, particularly among boys. Data for Mexican-Americans are limited; differences relative to White children are inconsistent, but Mexican-American children do not perform as well Black children in dashes and the vertical jump.

Fitness Relative to Criterion-Referenced Standards

The majority of American youth in NCYFS I and II attained or surpassed the criteria of the *Fitnessgram* [16], although there was variation with age and test item. Sex differences were minimal for estimated fatness, flexibility and abdominal strength/endurance. More males surpassed the criteria of cardiovascular endurance and upper body strength/endurance than females, while percentages of late adolescent females (14+ years) meeting the criteria were especially low. Overall, 75% of boys and only 50% of girls in NCYFS I and II qualified for the 'I'm fit' award [18].

The health-related physical fitness of youth in the 1985 National School Population Fitness Survey [22] was compared to criteria defined in the *Fitnessgram* [16] and *Physical Best* [17]. Percentages of youth meeting or exceeding the respective criteria varied with age, sex, test and specific criteria. In the 1-mile run, 65–81% of boys and 50–79% of girls met the criteria of the *Fitnessgram*, while only 37–57% of boys and 30–55% of girls met the criteria of *Physical Best*. Passing rates did not differ by criteria for hamstring-lower back flexibility, upper body muscular strength/endurance and abdominal muscular strength/endurance, but sex differences were apparent. Passing rates for flexibility were 73–93% in girls and 48–75% in boys, for pull-ups were 49–76% in boys and 29–42% in girls, and for sit-ups were 52–83% in boys and 48–78% in girls [43].

Percentages of California students meeting the Healthy Fitness Zone criteria of the *Fitnessgram* in 2005 are shown in figure 2. Although results vary by fitness test, the majority of students meet the criteria and sex differences are not consistent across items. The percentages of students meeting the Healthy Fitness Zone criteria are lowest for aerobic capacity measured by the 1-mile run or *Pacer*. Comparison of percentages of students meeting the criteria in 5 or 6 of the tests from 1999 through 2005 indicates no change in fitness level over this short interval [39].

Ethnic variation in percentages of California School youth performing in the Health Fitness Zones on 5 or 6 of the six health-related fitness tests is summarized in table 6. Less than 50% of Black-American, Hispanic and

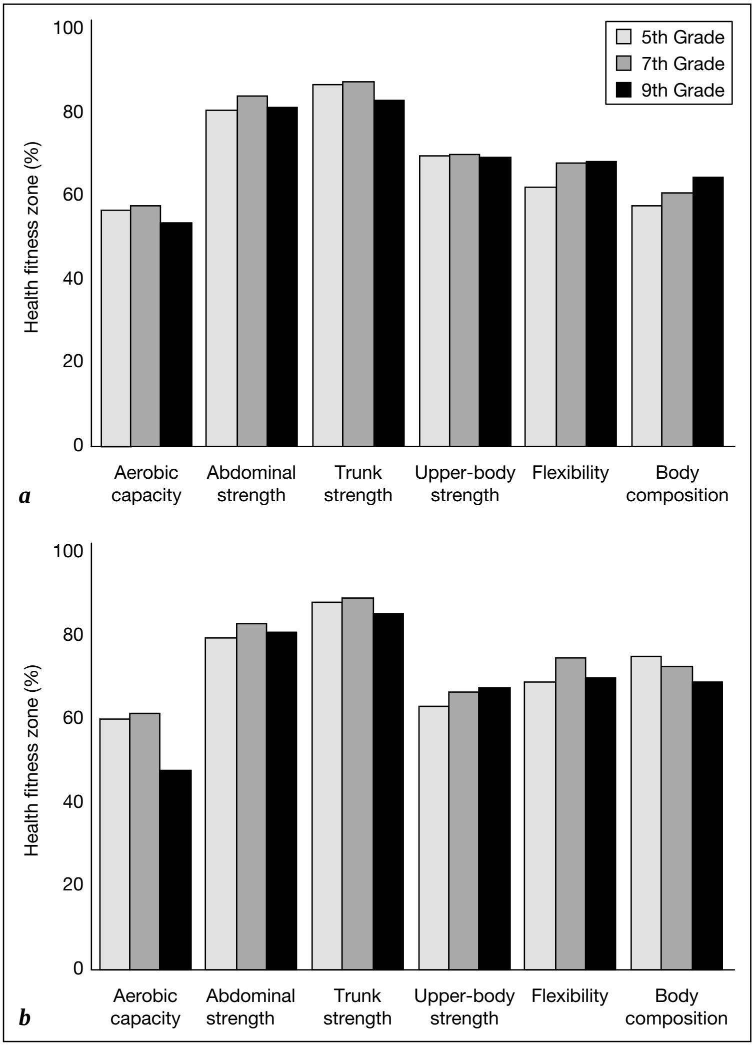


Fig. 2. Percentages of California school youth (***a*** = boys; ***b*** = girls) performing in the Health Fitness Zone for six tests of the *Fitnessgram*: aerobic capacity = 1-mile run/walk or *Pacer* test, abdominal strength = curl-up, trunk strength = trunk lift, upper-body strength = push-ups, modified pull-up and flexed arm hang, flexibility = sit-and-reach, and body composition = Body Mass Index. Drawn from the California Physical Fitness Test Results for 2005 [39].

American-Indian (except among 7th graders) youth and just above 50% of Pacific Islander youth perform in the Healthy Fitness Zones for 5 or 6 of the fitness tests. This trend is related, in part, to the elevated risk of overweight and obesity in these ethnic groups [40].

Table 6. Percentages of California school youth in grades 5, 7 and 9 in 2005 who have achieved 5 or 6 of six *Fitnessgram* Healthy Fitness Zones by ethnic group, sexes combined [49][a]

Ethnic groups	Grades		
	5th	7th	9th
White, non-Hispanic	61%	65%	62%
Black, African-American	48	49	44
Hispanic/Latino	43	47	45
American-Indian/Alaskan Native	46	51	48
Asian/Asian-American	61	70	67
Filipino/Filipino-American	54	62	59
Pacific Islander	50	54	52

[a] Ethnic groups are labeled as indicated in the report.

Results of criterion-reference evaluations of health-related physical fitness of American youth suggest that generalizations about the fitness or unfitness of the school age population need to be made with caution. Criterion-reference standards suggest acceptable ranges of health-related physical fitness. However, the relationship between indicators of health-related fitness and the health status or reduced disease risk in children and adolescents youth needs to be established. An exception is likely poor morphological fitness manifest in obesity. Many health indicators are influenced by obesity and adiposity, especially central adiposity [11].

Secular Trends in the Fitness of American Youth

Measures of physical fitness are, in part, related to body size and maturity status. Hence, the increase in size and acceleration in maturity that characterize the secular trend have implications for physical fitness [10]. Changes in lifestyle associated with specifically reduced levels of physical activity per se, reduced opportunities to be active, increased opportunities to be inactive and the relatively recent increase in the prevalence of obesity are additional factors.

Secular gains are apparent in height, weight and grip strength in American youth in Michigan between 1899 and 1964 [44] and in California between 1934/1935 and 1958/1959 [45]. The gains in strength were largely proportional to secular gains in height and weight, which was consistent with corresponding analyses in Europe and Japan [30]. Pushing and pulling strength of the shoulders, however, showed variable changes over a shorter interval from the 1930s through the 1950s. The study of California youth also included four performance-fitness items: 50-yard dash, standing long jump, vertical jump, ball throw for distance and the Brace test, a series of 20 stunt items that place a premium on coordination, balance and agility. Changes in performance over the 24-year interval were inconsistent and varied by sex [45].

The standing long jump is one of the few test items whose testing protocol is described and presumably administered in a consistent manner over time. Comparison of American boys and girls 11–15 years in the mid-1920s [46] and 1958 [21] indicated little evidence of secular improvement in mean jumping performance [10]. Adolescents in the late 1950s were taller and especially heavier than those in the 1920s [47], suggesting that jumping performance did not increase commensurately with the secular gain in body size.

Mean values for several indicators of performance- and health-related fitness based on four national surveys of American school youth 10–17 years conducted between 1958 and 1985 are summarized in figure 3. Major improvements in fitness were evident between 1958 and 1965, but there was relatively little change subsequently. The improvement in fitness from 1958 to 1965 reflected, in part, national emphasis on physical fitness testing in schools in the 1960s [5]. Contributing factors were the high failure rate of school youth on the Kraus-Weber test [5] and poor performances of American school youth in 1958 compared to British youth in 1958/1959 [48]. The only fitness item in which American boys surpassed British boys was the softball throw for distance, while American and British girls did not differ in this test item. Interest in performance-related fitness declined from the 1960s as focus shifted to health-related fitness in the 1970s, and, more recently, to problems associated with overweight/obesity and physical inactivity.

Mean heights of American children and adolescents, on average, did not change from the 1960s and through the early 1990s, which spans the interval of the national physical fitness surveys. Body weights also did not change from the 1960s into the early 1980s, but increased between 1988 and 1994 [10]. Body weight has continued to increase with a resulting continued rise in the prevalence of obesity (table 7).

Comparisons of the 1-mile run/walk performances of American youth 7–17 years in three national surveys over an interval of 7 years, 1979 [3], 1984 and 1986 [14], and 1985 [23] indicate, on average, similar times from 10 to 17 years in both boys and girls (fig. 4). At the younger ages of 7–9 years, the more recent samples have better times. The number of sit-ups performed is generally similar among surveys, while results for the sit-and-reach are mixed between

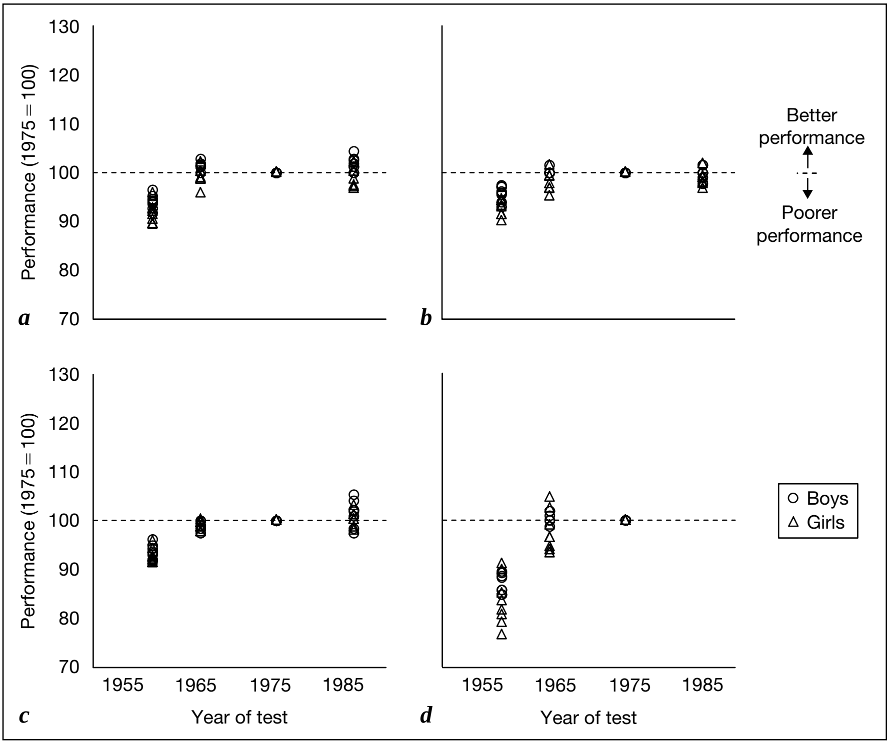


Fig. 3. Secular changes in indicators of health- and performance-related fitness (standardized to 1975 = 100) of national samples of American youth between 1958 and 1985. Drawn from data reported in Hunsicker and Reiff [21, 22] and Reiff et al. [23]. Tables of descriptive statistics for the 1958, 1965 and 1975 surveys were provided to the author by Reiff after the publication of the comparative report [22]. Higher values (i.e. >100) indicate better performance. ***a*** Standing long jump. ***b*** 50-yard (45.7 m) sprint. *c* 4 × 9 m agility shuttle run. ***d*** 600-yard (500 m) run.

two of the surveys [3, 14]. The Chrysler-AAU Physical Fitness Program indicated small changes in the fitness of American youth 6–17 years in abdominal strength/endurance (sit-ups), upper body strength/endurance (boys: pull-ups; girls: flexed arm hang) and flexibility (sit-and-reach) in the 1980s (1980–1989), but a decline in cardiorespiratory endurance (distance runs) over this interval [24, 25]. Some of the small gains may reflect emphasis on specific test items in the school programs. Abdominal muscular strength/endurance continued to improve through 1994 in youth aged 6–14 years [49]. The BMI also increased between 1980 and 1994 [26].

Table 7. Secular change in the prevalence of obesity among American children and adolescence: 1960s through 2004 [27, 28][a]

Years of survey	6–11 years				12–19 years			
	boys		girls		boys		girls	
	%	SE	%	SE	%	SE	%	SE
1963–1965/1966–1970[b]	4.0	0.4	4.5	0.6	4.5	0.4	4.7	0.3
1971–1974	4.3	0.8	3.6	0.6	6.1	0.8	6.2	0.8
1976–1980	6.6	0.8	6.4	1.0	4.8	0.5	5.3	0.8
1988–1994	11.6	1.3	11.0	1.4	11.3	1.3	9.7	1.1
1999–2000	15.7	1.8	14.3	2.1	14.8	1.3	14.8	1.0
2001–2002	17.5	1.9	14.9	2.4	17.6	1.3	15.7	1.9
2003–2004	19.9	2.0	17.6	1.3	18.3	1.9	16.4	2.3

[a] Obesity is defined as a BMI for age and sex ≥95th percentiles of the 2000 Centers for Disease Control and Prevention growth charts [29].

[b] The survey of children aged 6–11 years was done between 1963 and 1965 and that of youth 12–19 was done between 1966 and 1970.

Short-term secular changes within the Motor Performance Study of Michigan State University were evaluated in cohorts at 6, 9 and 14 years of age over an interval of 12 years, 1968–1970 to 1980–1982 [49]. Six- and 9-year-old children showed secular gains in all items except the flexed arm hang, while 14-year-old youth showed secular gains in only the agility shuttle run, 400-foot shuttle run and standing long jump. Height and weight did not differ between cohorts. The secular gains among the two younger cohorts may be related to instructional programs available to participants in the study and perhaps more involvement in youth sports programs [50].

Data for maximal aerobic power ($\dot{V}O_{2max}$, peak $\dot{V}O_2$) for American youth date to the late 1930s in boys and the 1960s in girls; hence, insights into secular changes are possible but need to be interpreted with caution [51]. The available data are based on rather small samples combined across several age groups and include both treadmill and cycle protocols. Samples are typically small and include volunteers who span several ages and who are willing to exercise to exhaustion. It is likely that overweight and obese youngsters are excluded. To account for differences between the treadmill and cycle protocols, peak $\dot{V}O_2$ for the cycle was multiplied by 1.075 [52].

The regression line for absolute aerobic power (liters $\cdot$ min^{-1}) is flat from the late 1930s to 2000 in boys aged 6–12 years, but that for boys aged 13–18 years

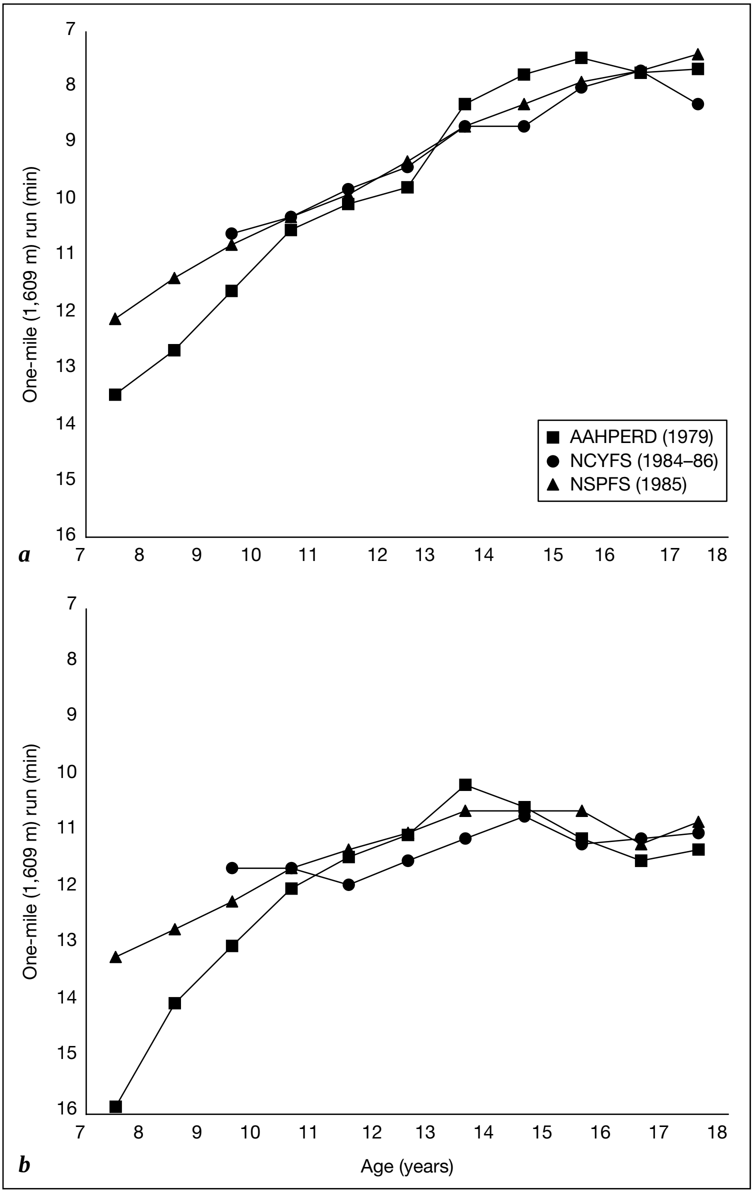


Fig. 4. Performances on the 1-mile run/walk in three national surveys: American Alliance for Health, Physical Education, Recreation and Dance, 1979 [3]; National Children and Youth Fitness Studies, 1984 and 1986 [13, 14], and the National School Population Fitness Survey, 1985 [23]. The y-axis is reversed because a lower time indicates better performance. ***a*** Boys. ***b*** Girls.

suggests an increase over time. The corresponding regression line is stable from the 1970s in girls aged 6–11 years and from the 1960s in girls aged 12–14 years, but among older girls, 15–18 years, it is curvilinear, suggesting an increase from the early 1960s to the late 1970s and a decline into the late 1990s. When the data are expressed per unit body weight ($ml \cdot kg^{-1} \cdot min^{-1}$), accommodating to some extent secular change in body mass, the regression lines indicate fairly stable levels of relative maximal aerobic power between the 1930s and the present in boys; the trends for relative maximal aerobic power in girls are similar to those for absolute values.

Trend lines, of course, need to be interpreted with care, especially since the early data points are few and may influence the regressions, especially in boys. Examination of the individual data points for absolute peak $\dot{V}O_2$ in boys suggests that the highest values occur in the late 1960s through the 1970s, whereas subsequent values are somewhat lower. From this perspective, the general trend may be consistent with the decline since the 1980s in aerobic capacity assessed with the 20-meter shuttle run [53].

References

1 Clarke HH: Basic understanding of physical fitness. Phys Fitness Res Digest 1971;1:1.

2 American Alliance for Health, Physical Education, Recreation and Dance (AAHPERD): Health Related Physical Fitness Test Manual. Reston, AAHPERD, 1980.

3 American Alliance for Health, Physical Education, Recreation and Dance (AAHPERD): Technical Manual, Health Related Physical Fitness. Reston, AAHPERD, 1984.

4 Kraus H, Hirschland RP: Minimum muscular fitness tests in school children. Res Q 1954;25: 178–188.

5 Malina RM: Fitness and performance: adult health and the culture of youth; in Parks RJ, Eckert HM (eds): New Possibilities, New Paradigms? (American Academy of Physical Education Papers No 24). Champaign, Human Kinetics, 1991, pp 30–38.

6 Malina RM: Tracking physical activity and physical fitness across the lifespan. Res Q Exerc Sport 1996;67:48–57.

7 Malina RM: Physical activity and fitness: pathways from childhood to adulthood. Am J Hum Biol 2001;13:162–172.

8 Malina RM: Tracking of physical activity across the lifespan. President's Council on Physical Fitness and Sports, Research Digest, Series 3, No 14.

9 Bouchard C, Shephard RJ: Physical activity, fitness, and health: the model and key concepts; in Bouchard C, Shephard RJ, Stephens T (eds): Physical Activity, Fitness, and Health. Champaign, Human Kinetics, 1994, pp 77–88.

10 Malina RM, Bouchard C, Bar-Or O: Growth, Maturation, and Physical Activity, ed 2. Champaign, Human Kinetics, 2004.

11 Strong WB, Malina RM, Blimkie CJR, Daniels SR, Dishman RK, Gutin B, Hergenroeder AC, Must A, Nixon PA, Pivarnik JM, Rowland T, Trost S, Trudeau F: Evidence based physical activity for school age youth. J Pediatr 2005;146:732–737.

12 World Health Organization: Physical status: the use and interpretation of anthropometry. Technical Report Series, No 584. Geneva, World Health Organization, 1995.

13 US Department of Health and Human Services, Office of Disease Prevention and Health Promotion: Summary of findings from National Children and Youth Fitness Study. J Phys Educ Rec Dance 1985;56:1–48 (Jan).

14 US Department of Health and Human Services, Office of Disease Prevention and Health Promotion: Summary of findings from National Children and Youth Fitness Study II. J Phys Educ Rec Dance 1987;58:49–96 (Nov–Dec).

15 Mosher RE, Carre FA, Schutz RW: Physical fitness of students in British Columbia: a criterion-referenced evaluation. Can J Appl Sport Sci 1982;7:249–257.

16 Cooper Institute for Aerobics Research: FITNESSGRAM User's Manual. Dallas, Cooper Institute for Aerobics Research, 1987.

17 American Alliance for Health, Physical Education, Recreation and Dance: Physical Best Test Manual. Reston, American Alliance for Health, Physical Education, Recreation and Dance, 1988.

18 Looney MA, Plowman SA: Passing rates of American children and youth on the FITNESSGRAM criterion-referenced physical fitness standards. Res Q Exerc Sport 1990;61:215–223.

19 Cooper Institute for Aerobics Research: The Prudential FITNESSGRAM Test Administration Manual. Dallas, Cooper Institute for Aerobics Research, 1992.

20 Malina RM: Secular changes in growth, maturation, and physical performance. Exerc Sport Sci Rev 1978;6:203–255.

21 Hunsicker PA, Reiff GG: A survey and comparison of youth fitness 1958–1965. J Health Phys Educ Rec 1966;37:23–25 (Jan).

22 Hunsicker PA, Reiff GG: Youth fitness report: 1958–1965–1975. J Phys Educ Rec 1977;48:31–33 (Jan).

23 Reiff GG, Dixon WR, Jacoby D, Ye GX, Spain CG, Hunsicker PA: The President's Council on Physical Fitness and Sports 1985 National School Population Fitness Survey. Ann Arbor, University of Michigan, 1986.

24 Updyke WF, Willett MS: Physical Fitness Trends in American Youth. Bloomington, Chrysler AAU Physical Fitness Program, Indiana University, 1989.

25 Updyke WF: In search of relevant and credible physical fitness standards for children. Res Q Exerc Sport 1992;63:112–119.

26 Updyke WF, Crowley KM, Willett MS: Fifteen year trends in body mass index in a large population of American children: 1980–1994 (abstract). Med Sci Exerc Sport 1997;29:S58.

27 Ogden CL, Flegal KM, Carroll MD, Johnson CL: Prevalence and trends in overweight among US children and adolescents, 1999–2000. J Am Med Assoc 2002;288:1728–1732.

28 Ogden CL, Carroll MD, Curtin LR, McDowell MA, Tabak CJ, Flegal KM: Prevalence of overweight and obesity in the United States, 1999–2004. J Am Med Assoc 2004;295:1549–1555.

29 Centers for Disease Control and Prevention: National Center for Health Statistics CDC growth charts. http://www.cdc.gov/growthcharts.htm, 2000.

30 Kuczmarski RJ, Ogden CL, Grummer-Strawn LM, Flegal KM, Guo SS, Wei R, Mei Z, Curtin LR, Roche AF, Johnson CL: CDC growth charts: United States. Advance Data from Vital and Health Statistics, 2000, No 314. Hyattsville, National Center for Health Statistics, 2000.

31 Haubenstricker JL, Branta CF, Seefeldt VD: History of the Motor Performance Study and related programs; in Haubenstricker JL, Feltz DL (eds): 100 Years of Kinesiology: History, Research, and Reflections. East Lansing, Department of Kinesiology, Michigan State University, 1999, pp 103–125.

32 Haubenstricker JL, Seefeldt VD, Branta CF: Percentile Tables for Selected Motor Tasks: Motor Performance Study. East Lansing, Department of Kinesiology, Michigan State University, 1997.

33 Lehnhard HR, Lehnhard RA, Butterfield SA, Beckwith DM, Marion SF: Health-related physical fitness levels of elementary school children ages 5–9. Percept Motor Skills 1992;75:819–826.

34 Beets MW, Pitetti KH: A comparison of shuttle run performance between Midwestern youth and their national and international counterparts. Pediatr Exerc Sci 2004;16:94–112.

35 McMurray RG, Harrell JS, Bradley CB, Deng S, Bangdiwala SI: Gender and ethnic changes in physical work capacity from childhood through adolescence. Res Q Exerc Sport 2003;74: 143–152.

36 McMurray RG, Harrell JS, Bradley CB, Deng S, Bangdiwala SI: Predicted maximal aerobic power in youth is related to age, gender, and ethnicity. Med Sci Sports Exerc 2002;34:145–151.

37 Trowbridge CA, Gower BA, Nagy TR, Hunter GR, Treuth MS, Goran MI: Maximal aerobic capacity in African-American and Caucasian prepubertal children. Am J Physiol 1997;273:E809–E814.

38 Pivarnik JM, Bray MS, Hergendoeder AC, Hill RB, Wong WW: Ethnicity affects aerobic fitness in US adolescent girls. Med Sci Sports Exerc 1995;27:1635–1638.

39 California Physical Fitness Test Results: 2004–2005 California Physical Fitness Report: Summary of results. www.cde.ca.gov/dataquest/PhysFitness, retrieved 12 April, 2006.

40 Beets MW, Pitetti KH: One-mile run/walk and body mass index of an ethnically diverse sample of youth. Med Sci Sports Exerc 2004;36:1796–1803.

41 Beets MW, Pitetti KH, Cardinal BJ: Progressive aerobic cardiovascular endurance run and body mass index among an ethnically diverse sample of 10–15 year olds. Res Q Exerc Sport 2005;76: 389–397.

42 Malina RM: Racial/ethnic variation in motor development and performance of American children. Can J Sport Sci 1988;13:136–143.

43 Corbin CB, Pangrazi RP: Are American children and youth unfit? Res Q Exerc Sport 1992;63: 96–106.

44 Montpetit RR, Montoye HJ, Laeding L: Grip strength of schoolchildren, Saginaw, Michigan: 1899–1994. Res Q 1967;38:231–240.

45 Espenschade A, Meleney HE: Motor performance of adolescent boys and girls of today in comparison with those 24 years ago. Res Q 1961;32:186–189.

46 Bliss JG: A study of progression based on age, sex, and individual differences in strength and skill. Am Phys Educ Rev 1927;32:11–21, 85–89.

47 Meredith HV: Change in stature and weight of North American boys during the last 80 years; in Lipsitt LP, Spiker CC (eds): Advances in Child Development and Behavior. New York, Academic Press, 1963, pp 69–114.

48 Pohndorf RH: Our unfit US schoolchildren. Newsletter. Wisc Assoc Health Phys Educ Rec 1961;31:1–4 (May).

49 Crowley KM, Updyke WF, Willett MS: Fifteen year trends in abdominal strength and endurance in a large population of 6–14 year old boys and girls: 1980–1994 (abstract). Res Q Exerc Sport 1997;61:29–30.

50 Haubenstricker J, Seefeldt V, Branta C, Evans S: Secular Trend in the Motor Performance of Children and Youth. East Lansing, Department of Kinesiology, Michigan State University, 1988.

51 Eisenmann JC, Malina RM: Secular change in peak oxygen consumption among United States youth in the 20th century. Am J Hum Biol 2002;14:699–706.

52 Boileau RA, Bonen A, Heyward VH, Massey BH: Maximal aerobic capacity on the treadmill and bicycle ergometer of boys 11–14 years of age. J Sports Med Phys Fit 1977;17:153–162.

53 Tomkinson GR, Leger LA, Olds TS, Cazorla G: Secular trends in the performance of children and adolescents (1980–2000): an analysis of 55 studies of the 20 m shuttle run test in 11 countries. Sports Med 2003;33:285–300.

Robert M. Malina, PhD
10735 FM 2668
Bay City, TX 77414 (USA)
E-Mail rmalina@wcnet.net

Tomkinson GR, Olds TS (eds): Pediatric Fitness. Secular Trends and Geographic Variability.
Med Sport Sci. Basel, Karger, 2007, vol 50, pp 91–103

Fitness of Canadian Children: Range from Traditional Inuit to Sedentary City Dwellers, and Assessment of Secular Changes

Roy J. Shephard

Faculty of Physical and Health Education and Department of Public Health Sciences, Faculty of Medicine, University of Toronto, Toronto, Ont., Canada

Abstract

Large amounts of motor performance test data have been collected in Canada, as in Europe and other countries, but even where representative population samples have been selected, interpretation of the findings is difficult, and most conclusions remain tenuous. Urban Canadian children apparently showed a small increase of physical performance from the mid-1960s through to about 1980, related in part to intensive governmental promotion of physical fitness and changes in gender roles of female students over this period. The two most recent decades have been marked by a shift of focus to health-related tests, the results showing a small but progressive deterioration in health-related fitness, with an accumulation of body fat, as documented by increases in body mass indices and skinfold thicknesses. In 1970, the fitness levels of urban children were substantially inferior to that of Inuit students, living in the high arctic and practicing a traditional, physically active lifestyle. However, by 1990, the Inuit children had adopted many of the sedentary habits typical of Canadian city dwellers, and had lost much of their previous advantage. At this stage, most Canadian students were not reaching their fitness potential, but their physical condition could be enhanced – in urban centers by an augmented physical education programme, and in the Inuit community by participation in programmes of active leisure. At present, Canadian students seem to be somewhat more fit than those in the US, but less fit than their peers in some European countries. Nevertheless, international comparison of Canadian data is currently hampered by differences in measurement techniques and failure of many investigators to test representative population samples.

Introduction

Nature of the Country and Its Populations

Canada is a vast country, with a geographic area second only to Russia. Much of the population is now concentrated in large and medium-sized cities, but there also remain many small and isolated settlements, difficult of access even by air or sea. In such settlements, groups of indigenous peoples such as the Inuit until quite recently have maintained a traditional Neolithic and physically demanding culture; fitness data collected in such communities offer an interesting contrast to findings obtained on the typical urban child of southern Canada [1]. Description of trends in population characteristics is further complicated by the historic differences between catholic Francophone and protestant Anglophone cultures (which are now disappearing), and substantial continued internal migration (from the scattered homesteads of rural areas to the high-rise apartments of large cities, and from the cold climates of north-eastern Canada to the more temperate west coast of British Columbia). Large numbers of legal and illegal migrants from Africa, Asia and Latin America still increase the total Canadian population by about 1% per year; such migrants have very different attitudes towards child-rearing, physical activity and health when they are compared with long-term urban residents of European origin. In some countries, the fitness of a proportion of children is affected adversely by varying degrees of malnutrition and lack of access to basic medical services. In the 1960s, Canada became a social democracy, with universal prepaid health care and a broad ‘safety-net’ protecting the less fortunate members of society. The development of a common market with the United States has forced some retrenchment of social services, but nevertheless the physical fitness of most Canadian children remains free of constraints imposed by poor health care and inadequate nutrition.

Most regions of Canada experience continental extremes of temperature, with correspondingly large seasonal variations in patterns of physical activity and resulting levels of fitness [2]. Ideally, assessments of children should be collected throughout the year, in order to allow for such environmental influences, but surveys of fitness have typically been concentrated at one season of the year (usually, the university summer vacation, when students are available for data collection).

History of Sampling and Fitness Test Methodology

As in other parts of the world, the design and methodology of Canadian fitness surveys has passed through several distinct phases. Prior to the mid-1960s, data were usually collected on convenience samples, for example, volunteers from a nearby school, or those attending an exhibition [3]. Sometimes, further bias was introduced, for example by the deliberate exclusion of children who appeared to be fat or unfit (typified by a classic survey of Swedish students) [4]. As the understanding of statistical principles increased, the mid-1960s saw a shift to the testing of ‘representative’ population samples, selected with the help of staff from Statistics Canada; however, because of considerations of cost, those living in remote areas were sometimes excluded from surveys. Several surveys suggested that those living in western Canada were somewhat fitter than those in central and eastern Canada; however, most of the reported information is for the hypothetical ‘average Canadian’.

Physical fitness in both Canada and the US was viewed historically in terms of three main components: muscular strength and endurance, cardiorespiratory endurance, and motor ability [5], and test methodology reflected this perspective. In order to allow the testing of large numbers of children, assessment was often based upon simple field tests, including strength and motor tasks assessing performance-related fitness, and distance-run assessments of cardiorespiratory endurance (e.g. the original test batteries of AAHPER [6] and CAHPER [7]). Scores on such instruments were influenced substantially by details of the testing environment (indoor or outdoor, hard surface or grass, hot or cool conditions), the instructions given by individual assessors, their success in motivating students to all-out effort, prior opportunities to practice the required skills, and (when making secular comparisons) trends in height, body mass and sexual maturation of the children at any given age.

The concept of large-scale physical fitness testing evolved from this primary focus to assume a greater emphasis upon health (‘health-related physical fitness’) in the late 1970s (e.g. the test batteries of AAHPERD [8, 9]). Although surveys in different Canadian provinces included differing specific items in their test batteries, the overall concept of ‘health-related fitness’ embraced measurements relating to cardiorespiratory endurance, muscular strength and endurance, musculoskeletal function of the lower trunk and upper thighs, and/or body composition, specifically fatness. Subsequently, morphological and metabolic components have further enhanced the more traditional model of muscular strength and endurance, motor and cardiovascular components [10].

There have been occasional attempts to collect representative data that included more sophisticated variables, ranging from a submaximal cycle ergometer test of power output at a heart rate of 170 bpm (PWC_{170}) [11] or the Canadian Home Fitness Test (a standardized step test [11]) to a detailed list of physiological measurements [13]. However, most sophisticated test data have been collected on rather small samples of children. In some studies, overweight children have been excluded, given fears concerning the safety of maximal exercise. Although theoretically ‘objective’, results of even the more sophisticated tests are influenced by details of environmental conditions, test ambience, equipment, and motivation of the subjects [3]. Moreover, if a representative sample is sought, comprehensive and representative surveys of this type are prohibitively costly to conduct. A focus on questionnaire assessments of physical activity, together with determinations of body mass and cardiac risk factors thus emerged in the early 1980s [14]. In the absence of more direct representative measurements, the assumption has commonly been made that such data provide surrogate indications of the physical fitness of the population relevant to the growing focus of governments upon 'active living' rather than exceptional athletic performance. Physical activity questionnaire scores cannot be applied to young children, and even in older students are very vulnerable to both the wording of questions and secular changes in how questions are interpreted. Changes in the average Body Mass Index of a population are generally assumed to reflect a change in body fat content, although in theory the scores observed at any given age could also reflect differences in maturation, body size, bone density and the proportion of lean tissue.

With these caveats, we will now proceed with our consideration of trends in the fitness of children in Canada.

International Comparisons Based on Early Nonrepresentative Samples

Early comparisons of data for non-representative samples of students from Canada and other countries suggested that the maximal aerobic power of urban Canadian children was greater than in some other countries (particularly the United States) [15]. Scores were apparently far lower than in a sample of urban Swedish children [4], but the detailed protocol for the latter specified that fat individuals had been excluded from the analysis. Because of differences in sampling and methodology, it is difficult to draw strong conclusions regarding differences between Canadian children and those of other nationalities.

Comparisons between Inuit and Urban Canadian Children

The International Biological programme study of the Inuit community of Igloolik, in the high arctic of Nunavut Territory, was initiated in 1969/1970. At that time, many of the adults in Igloolik were subsisting largely by the traditional arts of hunting and trapping. Long journeys on foot or by dog sled involved heavy daily energy expenditures (averaging, for the men, $15.4\,\mathrm{MJ} \cdot \mathrm{day}^{-1}$). Young children mimicked the adult activities within the settlement, and in their early teens they began to accompany their parents on these arduous expeditions, with comparable daily energy expenditures [1].

Thus, data obtained on all of the Inuit students of Igloolik in 1970 (table 1) showed values for aerobic power and muscular strength that were much greater, and skinfold thicknesses that were much lower than in a representative sample of students living in Toronto [1]. The advantage of the Inuit over other Canadian children seems to have been due largely to vigorous daily physical activity,

Table 1. Changes in measures of fitness of 11- to 12.9-year-old Inuit children from 1969/70 to 1989/90 (based on averaged data of Rode, Shephard, 1996 [16])

Variable	Boys		Girls	
	1970	1990	1970	1990
Skinfold thickness, mm	5.2	7.9	6.2	11.7
Handgrip force, N	182	144	180	97
Knee extension force, N	448	355	428	321
Predicted aerobic power, $ml \cdot kg^{-1} \cdot min^{-1}$	70.2	58.7	55.0	46.2

since their high level of physical fitness disappeared progressively between 1970 and 1990, as children from the next generation of the same families came to adopt the sedentary lifestyle typical of urban Canada. However, much of the secular trend to a loss of fitness among the male Inuit students was avoided among those who chose to enroll in a programme of active leisure pursuits [16].

Further supporting the thesis that environmental rather than genetic factors led to the fitness advantage of the Inuit in 1970, a part of the difference between urban boys and their Inuit counterparts disappeared as urban children in Québec engaged in an additional hour of physical education per day throughout their primary school years [17]; likewise, Tremblay et al. [18] demonstrated that the greater strength, aerobic fitness and leanness of old order Mennonite children relative to the general population of urban and rural schoolchildren in Saskatchewan was associated with greater habitual physical activity. In other words, the normal physical education and leisure activities of young Canadian children seem insufficient to optimize their physical fitness.

Secular Trends in Physical Performance Test Scores on Representative Populations

In 1965 and 1979/1980, the Canadian Association of Physical Education, Recreation and Dance [7, 19] applied their particular form of physical performance testing to large representative samples of Canadian school students (table 2). It is difficult to interpret such performance data in any absolute sense, since once allowance is made for the size of the individual, scores show little correlation with more objective indices of fitness such as maximal oxygen intake [20]. Indeed, results depend heavily on skill, determination, familiarity with the tests, and (if performed outdoors) with track conditions [21].

There were substantial increments of score for both standing broad jump (6.6–9.6%) and short dash (0.5–6.5%) between 1965 and 1979/1980, despite an

Table 2. Changes in physical performance test scores for representative samples of Canadian children from 1965 to 1979/1980, based on data of CAHPER [7] and Conger et al. [19] for standing broad jump (SBJ, m) and short dash ($m \cdot s^{-1}$; note distance was increased from 45.7 to 50 m in the second trial)

	Boys			Girls		
	7–9 years	10–11 years	12–13 years	7–9 years	10–11 years	12–13 years
SBJ						
1965	1.22	1.42	1.56	1.15	1.35	1.49
1979/1980	1.30	1.52	1.71	1.25	1.45	1.60
Dash						
1965	4.71	5.22	5.78	4.52	5.04	5.25
1979/1980	4.90	5.41	5.81	4.72	5.21	5.59

increase in the length of the dash from 45.7 (50 yards) to 50 meters (table 2). However, findings from the CAHPERD tests [22] were used frequently by physical education teachers when evaluating their pupils during the period 1965–1980. Scores at any given age were presented as percentiles, and students reaching a minimum achievement in each age category were eligible for a Canada Fitness Award. Thus, at least a part of apparent gains in performance from 1965 to 1980 may be due to practice effects and the incentive of the distribution of badges.

The possibility of making comparisons with findings in other nations is limited by differences in test structure and instructions to test subjects. For example, even ignoring small differences in instructions to the assessor, a comparison between the original test battery of the American Association for Health, Physical Education and Recreation [6] and the CAHPER instrument show the following discrepancies:

Fitness component	AAHPER test battery	CAHPER test battery
Back strength	Sit-ups (untimed)	One-minute speed sit-ups
Arm strength	Chin-ups	Flexed arm hang
Leg explosive power	Standing broad jump	Standing broad jump
Aerobic power	Shuttle run	Shuttle run
Anaerobic capacity	50 yards (45.7 m) dash	50 yards (45.7 m) dash
Aerobic power	600 yards (548 m) walk/run	300 yards (274 m) run
Arm explosive power	Soft-ball throw (omitted in revised versions of the test)	

As far as conclusions can be drawn, scores appear to imply a somewhat higher level of motor performance fitness in Canada than in the United States, but a lower level than in that of students from a number of European countries [3].

Sex Differences and Secular Trends in Other Fitness Measures in Urban Canada

Sex Differences

Other measures of physical performance obtained on representative population samples available for analysis of gender differences and secular trends include speed sit-ups, predictions of maximal aerobic power and handgrip force (fig. 1). In 1965–1967, female values for all three tests were substantially lower than for male students, with the discrepancy increasing into the pubertal and post-pubertal years. This likely reflects the substantial differences in gender roles which existed during the 1960s, particularly in Québec. In support of this view, sex differences in all three test scores were much smaller by the early 1980s, when there had been large changes in the expectations of both physical education teachers and their students [3].

Secular Trends

Recent decades in North America have seen a shift in North American fitness evaluations from performance to health-related tests, and ‘norms’ are no longer emphasized. Muscular strength and cardiorespiratory fitness are of particular interest in this context. Unfortunately, the available data do not allow any very clear conclusions to be drawn about secular trends.

Scores for speed sit-ups (fig. 1) increased in both sexes from 1965 [7] to the Canada Fitness Survey of 1981 [12], but these gains reflected the combined effects of test practice and the intense promotion of physical fitness by Provincial and Federal governments over this period. No further gains were seen when tests were repeated in 1988 [23].

Measurements of physical work capacity [11, 24] are in principle somewhat less vulnerable to differences in technique, but attempts to deduce maximal aerobic power from such data can have considerable systematic error, and in part for this reason there are substantial differences in predictions between cycle ergometer tests conducted by Gauthier et al. [24] in 1982, and 1981 predictions from the step test scores of the Canada Fitness Survey [3]. The cycle ergometer findings are vulnerable to effects of room temperature and test learning. Taken at face value, they suggest a lower level of predicted aerobic power than in several large European studies. The methodology was similar in the 1966 and 1982 surveys, and there seems to have been a small increase of

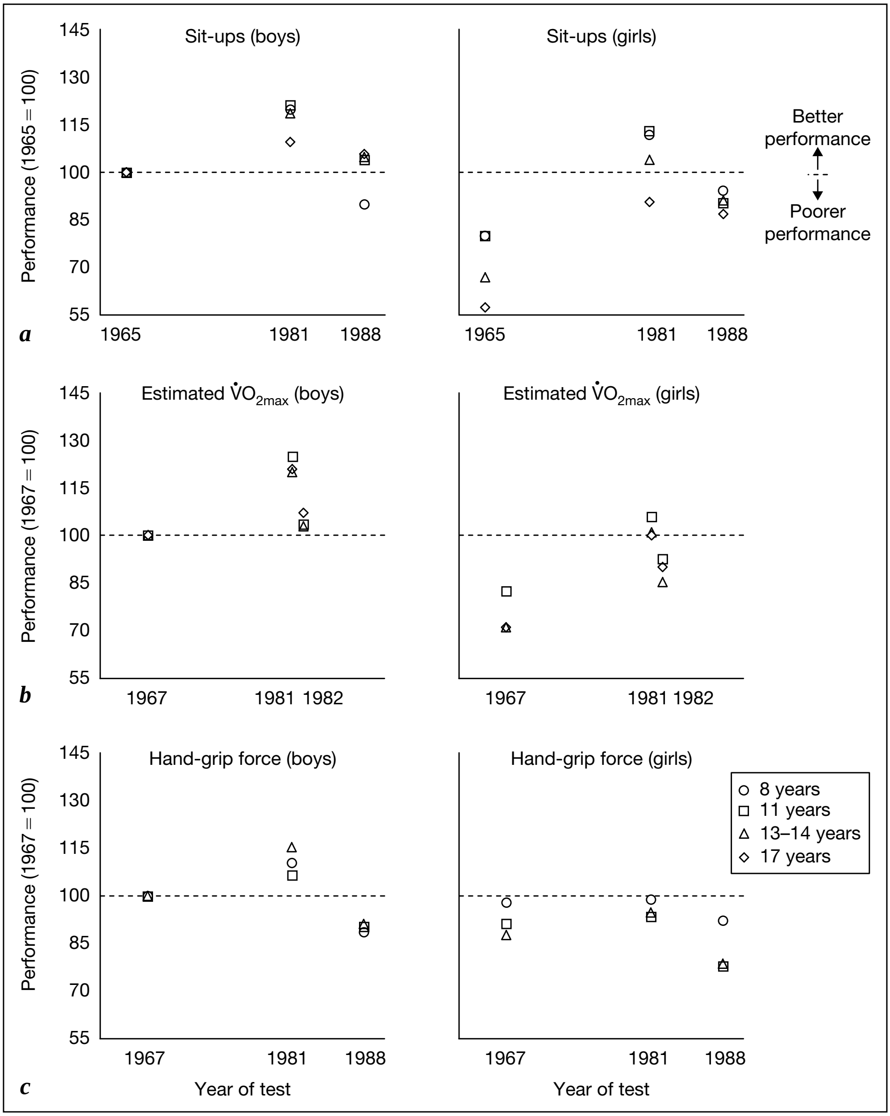


Fig. 1. ***a*** A comparison of values for 1-min speed sit-ups for representative samples of Canadian children aged 8, 11, 13.5 and 17 completed years, based on data from CAHPER [7] and the 1981 [12] and 1988 [23] CFS. All values expressed as percentages of corresponding male data for 1965 (absolute values 23.3, 28.7, 32.5 and 35.0 sit-ups, respectively). ***b*** A comparison of predicted maximal aerobic power values for representative samples of Canadian children aged 11, 13.5 and 17 completed years, based on data from 1967 and 1982 cycle ergometer surveys [11] and [24] and the 1981 Canada Fitness Survey step test data [3]. All values expressed as percentage of male values for 1967 (absolute values 40.2, 42.3 and 40.9 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively). ***c*** A comparison maximal handgrip force values for

aerobic fitness over this period, particularly in the girls (fig. 1). In keeping with the view that aerobic fitness remained static or deteriorated from the early to the late 1980s, 20 m shuttle-run scores for Québécois children aged 6–17 years showed a decrease of about 0.8% per year between 1981 and 1989/1990 [25].

Handgrip dynamometer scores were obtained on representative samples by Howell and MacNab [11] and the Canada Fitness Survey [12]. Instrumentation was comparable for the two assessments, with a small improvement of scores for both boys and girls from 1967 to 1981 (fig. 1).

Other Approaches to Fitness Assessment

Given problems in assessing physical fitness either by performance testing or more sophisticated physiological techniques, a number of Canadian investigators have considered information on habitual physical activity, body mass, Body Mass Index and body fat content.

Habitual Physical Activity

Those measuring habitual physical activity have reasoned that students undertaking the minimum of daily physical activity recommended for health are likely to be fit. Although objective monitors of physical activity are available, information on representative samples of children is based mainly on simple questionnaires.

In order to enter the ‘active’ category of the Canada Fitness Survey [12], a student had to report 3 or more hours per week of physical activity during 9 or more months of the year. Those classed as ‘moderately active’ took less than 3 hours per week of activity in 9 or more months of the year, or 3 or more hours per week for less than 9 months per year, and the ‘sedentary’ group did not meet either of these criteria. In part because of these lenient standards, the proportion classed as ‘active’ was larger than in many other international surveys (76–79% of boys, 67–73% of girls). Other technical issues that may have influenced findings included the use of an activity ‘prompt’ list, the collection of data during both peak and off-peak seasons, the assignment of an arbitrary duration of

representative samples of Canadian children age 8, 11 and 13.5 completed years, based on the data of Howell and MacNab [11] and the CFS surveys of 1981 and 1988 [12, 23]. All values expressed as percentage of male values for 1967 (absolute values 133, 204 and 283 N, respectively).

15 min when the length of an activity bout was unreported, and the inclusion not only of vigorous but also of moderate intensity.

The latest data from the 2000/2001 Canadian Community Health Survey [26] bases physical activity classification on a combination of duration and intensity. An 'active' individual has a total expenditure of more than 12.6 kJ · kg^{-1} · day^{-1}, and a moderately active person expends 6.3–12.5 kJ · kg^{-1} · day^{-1}. Excluding about 15% of data where the variability exceeded 33%, there was a substantial reduction in the proportions rated as active relative to 1981 (50–55% of boys, 33–43% of girls). The figures for active members of the population aged 12 years and older are nevertheless said to have increased by 21% relative to the results of an intermediate survey conducted in 1994/1995.

Applying more stringent criteria of those who are physically active (children developing an exercise intensity of 8 METS) and moderately active (individuals developing an intensity of 6 METS), the proportion of active students in the original 1981 survey drops to only 3.5% of both boys and girls, emphasizing the difficulty in making comparisons of self-reported physical activity from one survey to another, either within Canada or with children from other countries.

Measures of Body Composition

Substantial volumes of representative data describe the body mass, Body Mass Index and skinfold thicknesses of Canadian children. The methods of measurement are not in themselves controversial, but the interpretation of data is open to considerable debate. Further, the body fat content is influenced by regional differences and secular trends in body size and sexual maturation. The height of the average Canadian student at any given age is similar to that of peer groups in most developed nations; comparison of Canada Fitness Survey data for 1981 [12] and 1988 [23] shows a small increase (about 1.2 cm) in those aged 7–9 years (perhaps because of an earlier pre-adolescent growth spurt), but no change in those aged 10–14 years. Size effects are minimized by calculating Body Mass Indices.

Body Mass Indices

The Body Mass Index (BMI, body mass in kg · m^{-2} of standing height) can increase with accumulation of either lean tissue or fat (although in population studies, fat is the most common culprit). The average body mass of 10- to 11-year-old Canadian children has increased substantially from 1966 to 1996 (from 35.7 to 38.9 kg in boys, and from 34.9 to 38.5 kg in girls), with corresponding changes in Body Mass Index. A person is regarded as overweight if the BMI surpasses the 80th percentile, and obese if the 95th percentile is exceeded. In children, the limits are 19.8 and 24.0 at the age of 10 years [27].

The average student participating in the Canadian Fitness Survey (CFS) of 1981 was fairly close to the 50th percentile for the UK, and was far from overweight according to this definition. Nevertheless, comparisons between the 1981 CFS data, the 1988 survey of Stephens and Craig [14] and the Canadian National Longitudinal Survey of Children and Youth (NLSCY) of 1996 [28] suggest that in recent years the BMI of Canadian children has increased by about 0.1 per year, so that by 1996, 10-year-old students of both sexes had an average BMI of around 18.3 $kg \cdot m^{-2}$. Perhaps more disturbingly, the percentage of students classed as overweight and obese increased by 5 and 11%, respectively [28]. In 1988/89, NLSCY found 37% of children aged 2–11 years were overweight, including 18% who were classified as obese [26], Moreover, such data may underestimate the extent of change, since NLYCS used computer-assisted interviewing, as compared with the physical measurements of earlier surveys; at least in adults, self-reports underestimate the extent of obesity.

Skinfold Readings

Skinfold readings can be compared with reasonable confidence if a standard caliper is used, and the investigator has learned an appropriate technique from a trained anthropometrist. On this criterion, the 1981 CFS data [12] (with an average across five skinfold readings rising from 6.8 to 7.9 mm in boys and from 8.3 to 11.1 mm in girls over the age range 8 to 13–14 years) seem relatively low and of a similar order to those observed in many European countries. Nevertheless, values in traditional Inuit children (table 1) were substantially lower than those seen in urban Canada, without any obvious detrimental effect upon the health of the child. It would thus seem that even in 1981 there was scope to enhance the fitness of the average urban Canadian child, thereby reducing the amount of subcutaneous fat.

Conclusions

The fitness levels of urban Canadian students currently seem to be in the middle of the published range for developed societies. However, this should not be grounds for complacency. There were apparently small gains of performance from the mid-1960s to the early 1980s, due in part to vigorous governmental promotion of physical fitness. Nevertheless, health-related fitness has subsequently declined, with a progressive accumulation of body fat. Moreover, even in the early 1980s, the fitness of students did not match that seen in physically active Inuit children. New approaches seem needed if the average student is to reach his or her physical potential.

References

1 Shephard RJ, Rode A: The Health Consequences of ‘Modernization.’ Evidence from Circumpolar Peoples. London, Cambridge University Press, 1996.

2 Lavallee H, Jequier JC, LaBarre R, Rajic M, Shephard RJ: Seasonal differences in aerobic power; in Shephard RJ, Lavallée H (eds): Physical Fitness Assessment. Principles, Practice and Applications. Springfield, Thomas, 1978, pp 194–210.

3 Shephard RJ: Fitness of a Nation: Lessons from the Canada Fitness Survey. Basel, Karger, 1986.

4 Åstrand PO: Experimental Studies of Physical Working Capacity in Relation to Age and Sex. Copenhagen, Munksgaard, 1952.

5 Clarke HH: Basic understanding of physical fitness. Physical Fitness Research Digest, series 1, no 1. Washington, US President’s Council on Physical Fitness, 1971.

6 American Association for Health, Physical Education and Recreation: Youth Fitness Test Manual. Washington, National Educational Association, 1958.

7 Canadian Alliance for Health, Physical Education, Recreation (CAHPER): Fitness Performance Test Manual for Boys and Girls 7 to 17 years of age. Toronto, CAHPER Publications, 1966.

8 American Alliance for Health, Physical Education, Recreation and Dance (AAHPERD): Health Related Physical Fitness Test Manual. Reston, AAHPERD, 1980.

9 American Alliance for Health, Physical Education, Recreation and Dance (AAHPERD): Technical Manual, Health Related Physical Fitness. Reston, AAHPERD, 1984.

10 Bouchard C, Shephard RJ: Physical activity, fitness, and health: the model and key concepts; in Bouchard C, Shephard RJ, Stephens T (eds): Physical Activity, Fitness, and Health. Champaign, Human Kinetics, 1994, pp 77–88.

11 Howell ML, MacNab RBJ: The Physical Work Capacity of Canadian Children 7–17 years. Ottawa, Canadian Association of Physical Education and Recreation, 1968.

12 Canadian Fitness Survey: Canadian Youth and Physical Activity. Ottawa, Fitness and Amateur Sport, 1983.

13 Shephard RJ, Allen C, Bar-Or O, Davies CT, Degre S, Hedman R, Ishii K, Kaneko M, LaCour JR, Di Prampero PE, Seliger V: The working capacity of Toronto schoolchildren. Can Med Assoc J 1968;98:977–984.

14 Stephens T, Craig C: The well-being of Canadians: the 1988 Campbell’s Survey. Ottawa, Canadian Fitness and Lifestyle Research Institute, 1990.

15 Shephard RJ: World standards of cardiorespiratory performance. AMA Arch Environ Health 1966;13:664–672.

16 Rode A, Shephard RJ: Acculturation and loss of fitness in the Inuit: the preventive role of active leisure. Arctic Med Res 1993;52:107–112.

17 Shephard RJ, Lavallée H: Impact of enhanced physical education in the prepubescent child: trois Rivières revisited. Pediatr Exerc Sci 1993;5:177–189.

18 Tremblay MS, Barnes JD, Copeland JL, Esliger DW: Conquering childhood inactivity: is the answer in the past? Med Sci Sports Exerc 2005;37:1187–1194.

19 Conger PR, Quinney HA, Gauthier R, et al: The CAHPER fitness performance test 1966–1979. J CAHPER 1981;47:3–10, 21.

20 Cumming G, Keynes R: A fitness performance test for school children and its correlation with physical working capacity and maximal oxygen uptake. Can Med Assoc J 1967;96:1262–1269.

21 Knuttgen H, Steendahl K: Fitness of Danish school children during the course of one academic year. Res Q 1963;34:34–40.

22 Canadian Alliance for Health, Physical Education, Recreation and Dance (CAHPERD): CAHPERD Fitness-Performance II Test Manual: Canadian Youth Ages 6–17. Ottawa, CAHPERD Publications, 1980.

23 Stephens T, Craig CI: The Well-Being of Canadians: The 1988 Campbell’s Survey. Ottawa, Canadian Fitness & Lifestyle Research Institute, 1990.

24 Gauthier R, Massicotte D, Hermiston R, McNab R: The physical work capacity of Canadian children, aged 7–17. J CAHPER 1983;50:4–9.

25 Tomkinson GR; Léger LA, Olds TS, Cazorla G: Secular trends in the performance of children and adolescents (1980–2000): an analysis of 55 studies of the 20 m Shuttle Run test in 11 countries. Sports Med 2003;33:284–300.

26 Statistics Canada: Cat. no. 11–001-XIE. Ottawa, Statistics Canada, 2001.

27 Cole TJ, Bellizi MC, Flegal KM, Dietz WH: Establishing a standard definition for child overweight and obesity worldwide: international survey. Br Med J 2000;320:1–6.

28 Tremblay MS, Willms JD: Secular trends in the Body Mass Index of Canadian children. Can Med Assoc J 2000;163:1429–1433.

Prof. Roy J. Shephard
PO Box 521
41390 Dryden Rd
Brackendale BC V0N 1H0 (Canada)
Tel. +1 604 898 5527, Fax +1 604 898 5734, E-Mail royjshep@shaw.ca

Tomkinson GR, Olds TS (eds): Pediatric Fitness. Secular Trends and Geographic Variability.
Med Sport Sci. Basel, Karger, 2007, vol 50, pp 104–128

Who Are the Eurofittest?

Grant R. Tomkinson[a], *Timothy S. Olds*[b], *Jan Borms*[c]

[a]Centre for Applied Anthropometry and [b]Nutritional Physiology Research Centre, School of Health Sciences, University of South Australia, Adelaide, Australia; [c]Faculty of Physical Education and Physical Therapy, Vrije Universiteit Brussel, Brussels, Belgium

Abstract

Introduction: Despite several studies highlighting differences in aerobic test performance among age-matched children and adolescents from different countries, little is known about the geographic variability in children's performances on tests measuring other fitness components. By cumulating studies reporting Eurofit data for children and adolescents, the aim of this study was to describe the variability in fitness test performance among children and adolescents from different parts of Europe. **Methods:** Sixty-seven studies reporting on the Eurofit test performances of healthy European children and adolescents were included in the analysis. Following corrections for methodological variation where appropriate, all data for each test were expressed in a common metric. Raw data were combined with pseudodata generated using Monte Carlo simulation. Performances on each fitness test were expressed as z-scores relative to all children of the same age and sex from all countries. For each Eurofit test, sample-weighted mean z-scores were calculated for each country across all age × sex groups for which data were available. **Results:** Data were collated on 1,185,656 Eurofit test performances by 7- to 18-year-old Europeans from 23 countries. There was considerable variability in the mean z-scores among countries, with the variability among countries differing by test. Overall, the best performing children came from northern and central European countries (0.3–0.4 standard deviations above the overall European average). **Discussion/ Conclusion:** There is evidence that performance was related to socio-cultural factors, such as the place of exercise and sport in the national psyche.

There have been few systematic attempts to compare the fitness test performances of children and adolescents from different parts of the world. Fitness test results are largely incommensurable due to the wide variety of tests used, differences in test methodologies even when the same test has been used, and a lack of mechanisms and incentives for data sharing. Despite these difficulties, several studies [1–5] have highlighted differences in performance among age-matched children and adolescents from different countries, with the majority of studies highlighting differences in aerobic performances. Little is therefore known about the geographical variability of children's performances on tests measuring other fitness components (e.g. muscular strength and endurance). This is unfortunate, because transnational comparisons based on standard instruments often yield interesting insights (e.g. socio-economic factors associated with pediatric fitness) [2].

Since its description in 1988 (though provisionally described in 1983), the Eurofit test battery has been widely used throughout Europe with children and adolescents [6]. Developed as a standardized European fitness test battery used to assess the effectiveness of physical education and to measure the health-related fitness of schoolchildren [7], the Eurofit comprises numerous health- and performance-related fitness tests, including: (1) field tests measuring balance, cardio-respiratory (aerobic) endurance, muscular endurance (abdominal and upper body), flexibility, power, speed, speed agility and strength; (2) anthropometric tests measuring height, mass and skinfold thicknesses at various sites, and (3) age and sex identification data [7]. The tests are simple to administer, practical in the school- and club-setting, reliable, and where appropriate criterion measures have been identified (e.g. aerobic fitness tests), valid estimates of 'construct' fitness [6]. Despite a plethora of data, no attempt has been made to cumulate the results of studies that have used the Eurofit. The aim of this study, therefore, was to cumulate studies using the Eurofit test battery with European children and adolescents, in order to describe the variability in fitness test performance among children and adolescents from different parts of Europe. It was also of interest to examine associations between children's fitness test performance and broad indicators of each country's economic, sporting and geographical status.

Methods

Data Sources

Any study which used the Eurofit [7, 8] or provisional Eurofit [9] test batteries to assess the fitness of healthy European children and adolescents was considered as a candidate study for this meta-analysis. Studies reporting data on elite young sportspeople or groups with specific disabilities or disease conditions (e.g. obesity, mental retardation) were not considered. Studies were located from the extensive review of literature by Olds et al. [2] and by searching online and CD-ROM bibliographic databases (Australian Sport, CINAHL, Current Contents, Digital Dissertations, ERIC, Medline, and Sports Discus) using the key word 'Eurofit' and the modifiers 'child', 'adolescent', 'boy', 'girl', 'youth' and 'pediatric'. No language or date restrictions were applied. All relevant references contained in the studies were examined, cross-referenced and followed up. Attempts were also made to personally contact the authors of each study to request raw data, to clarify details of their own study and to ask if they knew of further studies.

One hundred and one candidate studies were located, of which, 34 were excluded because data were reported for: (1) individuals not aged between 7 and 18 years; (2) large, undifferentiated age ranges (e.g. 12- to 15-year-olds); (3) a sample not distinguished by sex, and (4) a sample previously reported in other located studies. Studies were also excluded by examining them in combination with other studies reporting data for children from the same country. For example, for some countries (e.g. Denmark and the Republic of Ireland), data were only reported for a single Eurofit test or a single age × sex group. A country (and hence all relevant studies) was excluded if data were reported for fewer than three Eurofit tests or fewer than three age × sex groups. Comparative data were available for the following Eurofit tests: flamingo balance (balance), plate tapping (speed), sit-and-reach (flexibility), standing broad jump (power), hand-grip strength (strength), sit-ups (abdominal muscular endurance), bent arm hang (upper body muscular endurance), 10 × 5 m agility shuttle run (speed agility), and 20 m endurance shuttle run (cardio-respiratory endurance). Note, data for the physical work capacity at a heart rate of 170 beats per minute (PWC_{170}) were not analyzed because PWC_{170} data were available for less than 25% of countries.

Of the 67 included studies, 60% (40 of 67) were peer-reviewed scientific journal articles or books, 3% (2 of 67) were published book chapters, 16% (11 of 67) were published conference papers or abstracts, 9% (6 of 67) were post-graduate theses, 9% (6 of 67) were commissioned reports, and 3% (2 of 67) were unpublished datasets. Most studies used convenience samples (51% or 34 of 67), with 42% (28 of 67) using randomized-stratified samples and 7% (5 of 67) using stratified-proportional samples. Data were collected at the country (16% or 11 of 67), state/province (19% or 13 of 67), city (31% or 21 of 67) and local (33% or 22 of 67) level. Table 1 summarizes the studies used in this analysis.

Data Entry

Raw data on 81,204 test performances were available from five studies (7% of all studies), while the remaining studies gave descriptive summary statistics at the age × sex × test level in the form of mean and standard deviation (SD) values. All raw data were checked for outliers by running automated range checks. Aberrant raw data were eliminated if they were more than 3 SDs either side of the mean. All hard-copy data were manually entered into a spreadsheet and checked for transcription errors, with corrections made where appropriate. Age and measurement year were recorded using the methods described by Tomkinson et al. [74].

Data Treatment and Statistical Analysis

The general methodological approach used in this meta-analysis has been adapted from Olds et al. [2] and is outlined in figure 1. To compare studies, it is important to know which test protocol was used and to express test results in a common metric. While only studies using Eurofit (or provisional Eurofit) test protocols were analyzed in this study, it was assumed that methodological variation existed among studies. For example, Tomkinson et al. [74] reported that there are at least three major variants of the 20 m endurance shuttle run (ESR) test extant today. Therefore, following attempts to personally contact the study authors where any clarification regarding protocols or results was required, corrections of ESR test protocols were made using the methods described by Tomkinson et al. [74]. For each test, the measurement units reported in the Eurofit handbook [8] were used as the common metric across studies, except for the ESR, where running speed ($km \cdot h^{-1}$) at the last completed stage was used.

Table 1. Summary of the Eurofit studies used in this analysis

Reference	Country	Years	Sex	Age range, years	n	Eurofit tests								
						FLB	PLT	SAR	SBJ	HGR	SUP	BAH	SHR	ESR
Markola et al. [10]	Albania	1994–1995	M, F	7–18	2,706	•	•	•	•	•	•	•	•	
Baquet et al. [11]	Belgium	1997	M, F	11–19	624			•	•	•	•		•	•
Beunen et al. [12]	Belgium	1990	M, F	6–18	7,011	•	•	•	•	•	•	•	•	•
Deroanne et al. [26]	Belgium	ND	M, F	13, 15, 17, 19	2,628	•	•	•	•		•	•	•	
Lefèvre et al. [13]	Belgium	1993	M, F	12–18	2,779	•	•	•	•	•	•	•	•	•
Lefèvre et al. [13]	Belgium	1997	M, F	12–18	3,198	•	•	•	•	•	•	•	•	•
Levarlet–Joye and Fievetz [21]	Belgium	ND	M	11–14	65	•	•	•	•	•	•	•	•	•
Pirnay [14]	Belgium	1991–1992	M, F	10–18	3,444	•	•	•	•	•	•	•	•	•
Telama et al. [5]	Belgium	1994–1995	M, F	12, 15	2,225			•	•					•
Van Poelvoorde and Levarlet–Joye [25]	Belgium	ND	M, F	7–10	91	•	•	•		•	•	•	•	
Dimitrova [15]	Bulgaria	1998–1999	M, F	7–17	606	•	•	•	•	•	•	•	•	
Telama et al. [5]	Czech Republic	1994–1995	M, F	12, 15	439			•	•					•
Jürimäe and Volbekiene [16]	Estonia	1992	M, F	11–17	3,188	•	•	•	•	•	•	•	•	•
Raudsepp and Jürimäe [17]	Estonia	1994–1995	M	7–10	203	•	•	•	•	•	•	•	•	•
Raudsepp and Jürimäe [18]	Estonia	1994–1995	F	7–10	215	•	•	•	•	•	•	•	•	•
Jürimäe and Saar [19]	Estonia	1996–1997	F	15–17	216		•	•	•					
Kull and Jürimäe [20]	Estonia	1992	M, F	17	339	•	•	•	•	•	•	•	•	•
Telama et al. [5]	Estonia	1994–1995	M, F	12, 15	1,290			•	•					•
Telama et al. [5]	Finland	1994–1995	M, F	12, 15	1,109			•	•					•
Van Praagh et al. [22]	France	ND	M, F	10–11	139	•	•	•	•	•	•	•	•	•
Brandet [23]	France	ND	M, F	8–12	295				•					
Cazorla [24]	France	1987	M, F	7–12	5,893		•		•		•	•	•	•

Table 1. (continued)

Reference	Country	Years	Sex	Age range, years	n	Eurofit tests								
						FLB	PLT	SAR	SBJ	HGR	SUP	BAH	SHR	ESR
Baquet et al. [27]	France	1997	M, F	10–15	549			•	•	•	•		•	•
Baquet et al. [28]	France	2000	M, F	8–10	86			•	•	•	•		•	•
Brunet and Van Praagh [29]	France	1984–1985	M, F	7–10	266		•		•		•	•	•	•
Telama et al. [5]	Germany	1994–1995	M, F	12, 15	977			•	•					•
Georgiadis [30]	Greece	1990–1991	M, F	6–18	6,674		•	•	•	•	•	•		•
Barabás [31]	Hungary	1982–1985	M ,F	6–18	27,274				•	•	•			
Barabás [32]	Hungary	ND	F	14–18	435									•
Telama et al. [5]	Hungary	1994–1995	M, F	12, 15	439			•	•					•
Friðriksson and Gunnarsson [33]	Iceland	1996	M, F	12	59	•	•	•	•	•	•	•	•	
Hördur Grétar Gunnarsson, pers. commun.	Iceland	1998	M, F	6–15	8,179			•	•		•	•	•	•
Sæmundsen [34]	Iceland	1985	M, F	10–15	2,020	•	•	•	•		•	•	•	
Bellucci [35]	Italy	1994	M, F	12–14	98	•	•	•	•	•	•	•	•	•
Cilia and Bellucci [36]	Italy	1992	M, F	12–14	1,416	•	•	•	•	•	•	•	•	•
Cilia et al. [37]	Italy	1995	M, F	12–15	1,171	•	•	•	•	•	•	•	•	•
Cilia et al. [38]	Italy	1997	M, F	12–19	4,181	•	•	•	•	•	•	•	•	•
Cilia et al. [39]	Italy	1997	M, F	14–19	573	•	•	•	•	•	•	•	•	•
Council of Europe	Italy	1985–1986	M, F	8–12; 14–19 (F)	1,448	•	•	•	•		•		•	•
Dr. Pavel Mustafin, pers. commun. 2002	Latvia	1995–2001	M, F	6–18	6,317	•		•	•		•	•	•	
Jürimäe and Volbekiene [16]	Lithuania	1992	M, F	11–17	1,601	•	•	•	•	•	•	•	•	•

van Mechelen [41]	Netherlands	1987	M, F	12–16	1,870		•	•	•	•	•	•	•	•
Czeczelewski et al. [42]	Poland	ND	M, F	11–15	205	•	•	•	•	•	•		•	
Kusy [43]	Poland	ND	M	14	291				•	•				
Maciaszek and Osinski [44]	Poland	ND	M, F	10–14	3,123	•	•	•	•	•	•		•	•
Mleczko et al. [45]	Poland	1991–1992	M, F	15–19	2,192	•	•	•	•	•	•			•
Osinski and Biernacki [46]	Poland	1990	M, F	10–15	804		•	•	•	•	•	•	•	
Raczynski et al. [47]	Poland	ND	M, F	11–15	384	•	•	•	•	•	•		•	
Stupnicki et al. [48]	Poland	1999	M, F	7–19	73,071				•	•	•	•		•
Wilczewski et al. [49]	Poland	ND	M, F	11–15	988	•	•	•	•	•	•	•	•	
Federatia Sportul pentru Toti [50]	Romania	1995	M, F	7–18	330	•	•	•	•	•	•	•	•	
Kasa and Majherová [51]	Slovakia	1996	M, F	11–14	323	•	•	•	•	•	•	•	•	•
Kyselovicová [52]	Slovakia	ND	F	15–16	128			•	•		•	•		•
Moravec [53]	Slovakia	1993	M, F	7–19	4,269	•	•	•	•	•	•	•	•	•
Brito et al. [54]	Spain	ND	M, F	10–19	819		•	•	•	•	•	•	•	•
García Bæna [55]	Spain	1999	M, F	13–18	605			•	•	•	•			•
Marrodán Serrano et al. [56]	Spain	1995–1996	M, F	14–18	401		•	•	•	•	•	•	•	
Prat et al. [57]	Spain	1984–1985	M, F	10–18	4,237		•	•	•	•	•	•	•	•
Sainz [58]	Spain	1986–1989	M, F	10–15	1,348	•	•	•		•	•	•		•
Sainz [59]	Spain	1990–1994	M, F	9–17	6,658	•	•	•	•	•	•	•	•	•
Ureña Villanueva [60]	Spain	1995	M, F	14–16	613	•	•	•	•	•	•	•	•	•
Cauderay et al. [61]	Switzerland	1996–1997	M, F	9–19	3,298		•	•	•		•		•	•
Akgün et al. [62]	Turkey	ND	M, F	11–18	671			•	•	•			•	
Akgün [63]	Turkey	ND	M, F	11–17	984			•	•	•	•	•	•	
Çalis et al. [64]	Turkey	1991	M	15	72		•	•	•		•	•	•	•
Demirel et al. [65]	Turkey	1989–1990	M, F	7–11	470		•	•		•	•	•	•	
Gökbel and Uzuncan [66]	Turkey	1991	M	10–12	62			•	•	•	•	•	•	
Boreham et al. [67]	UK (Nth. Ireland)	1986	M, F	13, 15	70	•	•	•	•	•	•	•	•	•

Table 1. (continued)

Reference	Country	Years	Sex	Age range, years	n	Eurofit tests								
						FLB	PLT	SAR	SBJ	HGR	SUP	BAH	SHR	ESR
Mahoney [68]	UK (Nth. Ireland)	1990–1991	M, F	12	103									•
Mahoney and Boreham [69]	UK (Nth. Ireland)	ND	M, F	7, 9, 11	587			•	•	•	•		•	•
Nichols and Riddoch [70]	UK (Nth. Ireland)	1986	M, F	12–15	648									•
Paliczka et al. [71]	UK (Nth. Ireland)	1986	M, F	12–16	2,311			•	•	•	•	•	•	
Riddoch [72]	UK (Nth. Ireland)	1988–1989	M, F	11–18	3,229			•	•	•	•		•	•
Watkins et al. [73]	UK (Wales)	1981–1983	F	13, 15, 17	913	•	•	•	•	•	•	•	•	

Shown for each reference are the country and year(s) when the measurements were taken, the sex and age range of the children and adolescents tested, the sample size (n), and the Eurofit test(s) for which descriptive summary data were reported.

F = Female; M = male; ND = not determined.

BAH = Bent arm hang; ESR = 20 m endurance shuttle run; FLB = flamingo balance; HGR = hand-grip; PLT = plate tapping; SAR = sit-and-reach; SBJ = standing broad jump; SHR = 10 × 5 m agility shuttle run; SUP = sit-ups.

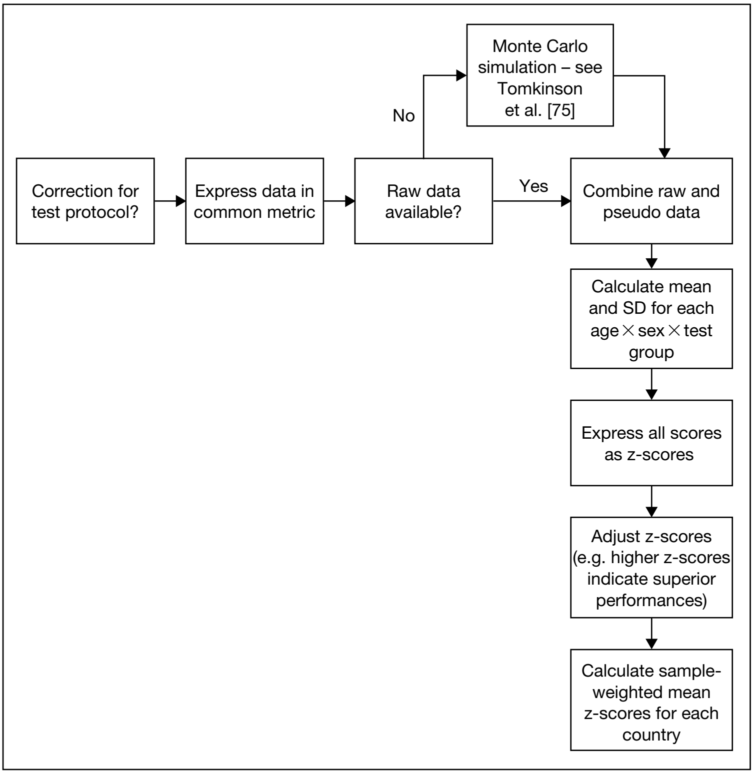


Fig. 1. Flowchart showing the steps taken to combine datasets prior to calculating relative z-scores for each country.

To compare Eurofit test performances across countries, it was necessary to combine raw and descriptive summary data. Datasets were combined using the methods described in Tomkinson et al. [75]. All Eurofit test performances were expressed as z-scores relative to the grand mean for all children within each age × sex × test group, with a mean z-score (and corresponding SD) calculated for each country. All z-scores were adjusted such that positive z-scores indicated performances superior to the mean and negative z-scores performances inferior to the mean. For each Eurofit test, sample-weighted mean z-scores were calculated for each country across all age × sex groups for which data were available. These sample-weighted mean z-scores represent the overall standardised deviation of the fitness test performance of a country's children from European age × sex × test-specific means. The overall z-score for a country was calculated as the sample-weighted mean z-score across those tests for which data were available. The standard error of a sample-weighted mean z-score was approximated using equations described by Tomkinson [76].

Results

Data were collated on 1,185,656 Eurofit test performances by 7- to 18-year-old Europeans from 23 countries. There were a total of 216 age × sex × test groups representing an average of 14 countries (range 6–23) and involving an average of 29 (range 9–59) country × study × age × sex × test reports.

The mean z-scores for each country and test for which data were available are shown in tables 2–6. On average, Wales was the best performing country on the flamingo balance test; the Netherlands on the plate tapping and agility shuttle run; Switzerland on the sit-and-reach and sit-ups; Iceland on the standing broad jump; Slovakia on the hand-grip and bent arm hang; and Estonia on the endurance shuttle run. There was considerable variability in the mean z-scores among countries, ranging from a minimum of 0.70 SDs for flamingo balance to a maximum of 1.94 SDs for hand-grip.

Table 7 shows the overall ranking of each country, calculated as the sample-weighted mean z-score across those tests for which data were available. Finland, Slovakia and Iceland were the best performing countries overall.

Discussion

The main finding of this study is that there was considerable variability in the relative performance of European children on the tests of the Eurofit battery. There were large differences in the average performance of young people from different countries. On the endurance shuttle run, for example, only 6% of Greek boys would have beaten the average Estonian. Only 4% of Welsh girls would have done better than the average Swiss girl on the sit-ups test, and just 3% of Albanian boys would have outperformed the average Slovakian on the hand-grip test. Figure 2 quantifies the differences among countries using the standing broad jump and endurance shuttle run performances of 12-year-old boys. Note, endurance shuttle run performances were compared by using the speed at the last completed stage to estimate the time taken to complete the 1,600 m run test, and hence, the distance behind the best runner.

A second finding is that the countries of northern and central Europe consistently outperformed those of western and southern Europe. When nations were ranked on the mean overall z-score across all nine tests, northern Europe [Finland (1st), Iceland (3rd), Estonia (5th), and Lithuania (7th)] and central

Table 2. Sample-weighted mean z-scores, standard errors of the z-scores and sample size for the flamingo balance and plate tapping tests for boys and girls from each country where data were available (higher z-scores indicate superior performance)

	Flamingo balance						Plate tapping					
	boys			girls			boys			girls		
	z	SE	n	z	SE	n	z	SE	n	z	SE	n
Albania	−0.20	0.02	1,422	+0.27	0.02	1,284	+0.19	0.02	1,422	+0.15	0.03	1,283
Belgium	−0.01	0.01	8,003	−0.14	0.01	8,043	−0.27	0.01	8,026	−0.11	0.01	8,063
Bulgaria	−0.04	0.05	314	+0.13	0.05	292	+0.18	0.05	314	+0.23	0.04	292
Estonia	+0.17	0.02	1,815	−0.06	0.02	2,346	−0.02	0.02	1,815	+0.04	0.02	2,124
France	+0.24	0.04	950	+0.13	0.03	672	−0.20	0.02	4,073	−0.14	0.02	3,710
Greece							+0.14	0.02	3,186	+0.09	0.01	3,113
Iceland	+0.16	0.03	1,072	−0.14	0.02	961	+0.22	0.03	1,100	+0.24	0.02	979
Italy	−0.12	0.02	3,831	+0.28	0.02	3,601	−0.07	0.01	4,253	−0.02	0.02	3,986
Latvia	−0.07	0.02	3,063	+0.04	0.02	3,458						
Lithuania	+0.25	0.03	764	−0.22	0.03	837	0.00	0.04	764	−0.08	0.03	837
Netherlands							+0.37	0.03	1,026	+0.62	0.02	848
Poland	−0.06	0.02	3,328	−0.14	0.02	3,131	+0.25	0.01	3,744	+0.20	0.01	3,519
Romania	−0.23	0.08	135	−0.16	0.07	180	0.00	0.09	138	−0.03	0.05	191
Slovakia	−0.09	0.02	2,458	+0.27	0.02	1,737	+0.53	0.02	2,474	+0.34	0.02	1,764
Spain	+0.15	0.01	4,355	−0.10	0.01	4,238	−0.05	0.01	7,028	−0.07	0.01	6,940
Switzerland							+0.08	0.02	1,601	−0.05	0.02	1,624
Turkey							−0.07	0.06	323	+0.28	0.04	219
UK (Northern Ireland)	−0.54	0.24	35	+0.29	0.13	35	−0.38	0.17	35	−0.55	0.06	285
UK (Wales)				+0.38	0.02	913				−0.71	0.04	663

Table 3. Sample-weighted mean z-scores, standard errors of the z-scores and sample size for the sit-and-reach and standing broad jump tests for boys and girls from each country where data were available (higher z-scores indicate superior performance)

	Sit-and-reach						Standing broad jump					
	boys			girls			boys			girls		
	z	SE	n	z	SE	n	z	SE	n	z	SE	n
Albania	+0.58	0.02	1,422	+0.52	0.02	1,284	−0.28	0.02	1,422	−0.30	0.03	1,284
Belgium	−0.04	0.01	9,523	−0.02	0.01	9,379	+0.10	0.01	9,519	+0.13	0.01	9,361
Bulgaria	+0.12	0.05	314	−0.04	0.05	292	+0.40	0.04	314	+0.22	0.05	292
Czech Republic	−0.23	0.07	224	+0.11	0.06	215	+0.41	0.06	224	+0.49	0.05	215
Estonia	+0.30	0.02	2,258	+0.29	0.02	2,775	+0.44	0.02	2,461	+0.43	0.02	2,990
Finland	+0.54	0.05	511	−0.04	0.04	598	+0.30	0.04	511	+0.30	0.03	598
France	−0.11	0.03	1,276	−0.18	0.02	982	+0.21	0.01	4,498	+0.15	0.01	4,121
Germany	−0.01	0.05	497	−0.04	0.04	480	+0.12	0.04	497	+0.19	0.04	480
Greece	−0.11	0.02	3,187	+0.05	0.02	3,114	−0.48	0.02	3,186	−0.70	0.02	3,114
Hungary							−0.51	0.01	14,889	−0.35	0.01	12,855
Iceland	−0.02	0.02	4,910	+0.31	0.01	4,525	+0.73	0.01	5,028	+0.89	0.01	4,730
Italy	−0.38	0.02	4,077	−0.15	0.02	3,795	−0.56	0.01	4,274	−0.70	0.02	4,007
Latvia	−0.04	0.02	3,046	−0.21	0.02	3,481	+0.21	0.02	3,012	+0.06	0.01	3,458
Lithuania	+0.44	0.03	764	+0.16	0.03	837	+0.46	0.03	764	+0.41	0.03	837
Netherlands	−0.10	0.03	1,024	+0.16	0.03	846	−0.31	0.04	1,025	−0.14	0.03	838
Poland	+0.01	0.02	3,744	−0.17	0.01	3,519	+0.08	0.005	40,215	+0.08	0.005	38,626
Romania	+0.28	0.05	138	+0.05	0.05	195	−0.23	0.06	138	−0.18	0.06	192
Slovakia	+0.04	0.02	2,705	+0.02	0.02	1,871	+0.40	0.02	2,464	+0.43	0.02	1,875
Spain	−0.04	0.01	7,203	−0.09	0.01	7,289	+0.11	0.02	6,596	−0.02	0.01	6,653
Switzerland	+0.75	0.03	1,475	+0.84	0.03	1,625	+0.31	0.02	1,595	+0.24	0.02	1,607
Turkey	+0.43	0.02	1,061	+0.13	0.02	1,126	+0.09	0.03	902	+0.17	0.03	887
UK (Northern Ireland)	−0.28	0.02	2,998	−0.42	0.02	3,129	−0.46	0.02	3,024	−0.64	0.02	2,665
UK (Wales)				−0.65	0.04	913				−0.73	0.02	1,431

Table 4. Sample-weighted mean z-scores, standard errors of the z-scores and sample size for the hand-grip and sit-ups tests for boys and girls from each country where data were available (higher z-scores indicate superior performance)

	Hand-grip						Sit-ups					
	boys			girls			boys			girls		
	z	SE	n	z	SE	n	z	SE	n	z	SE	n
Albania	−1.17	0.02	1,422	−1.09	0.03	1,284	−0.25	0.02	1,327	−0.46	0.02	1,190
Belgium	+0.31	0.01	8,228	+0.36	0.01	8,201	+0.15	0.01	8,348	+0.07	0.01	8,307
Bulgaria	+0.17	0.04	314	+0.19	0.05	292	−0.27	0.04	314	−0.13	0.04	292
Estonia	+0.45	0.02	1,815	+0.22	0.02	2,130	+0.33	0.02	1,815	+0.22	0.02	2,130
France	−0.33	0.04	499	−0.33	0.04	434	−0.33	0.01	4,332	−0.43	0.01	3,956
Greece	−0.28	0.01	3,187	−0.22	0.01	3,110	−0.17	0.01	3,185	−0.20	0.02	3,114
Hungary	+0.34	0.01	14,461	+0.53	0.01	12,404	−0.88	0.01	14,461	−0.76	0.01	12,404
Iceland	+0.14	0.16	30	+0.27	0.18	29	−0.28	0.01	4,920	−0.18	0.01	4,487
Italy	−0.50	0.01	3,366	−0.35	0.02	3,150	−0.38	0.01	4,230	−0.26	0.02	3,901
Latvia							+0.21	0.02	2,957	+0.12	0.01	3,370
Lithuania	+0.04	0.03	764	−0.12	0.03	837	+0.71	0.03	764	+0.65	0.02	837
Netherlands	+0.39	0.03	1,034	+0.62	0.03	884	+0.13	0.02	3,459	−0.16	0.03	842
Poland	−0.15	0.005	39,831	−0.25	0.005	37,889	+0.35	0.005	37,269	+0.33	0.005	38,629
Romania	−0.05	0.05	140	+0.15	0.04	178	+0.02	0.06	140	+0.19	0.05	186
Slovakia	+0.79	0.02	2,456	+0.84	0.02	1,715	+0.57	0.02	2,462	+0.64	0.02	1,864
Spain	+0.04	0.02	6,927	+0.05	0.02	6,947	−0.11	0.01	7,288	−0.11	0.01	7,268
Switzerland							+0.83	0.02	1,599	+0.77	0.02	1,614
Turkey	+0.14	0.03	1,130	+0.67	0.03	1,163	−0.55	0.02	950	−0.81	0.03	730
UK (Northern Ireland)	−0.26	0.01	3,034	−0.06	0.01	3,161	+0.10	0.02	3,013	−0.19	0.02	3,122
UK (Wales)				−0.04	0.02	913				−0.97	0.02	913

Table 5. Sample-weighted mean z-scores, standard errors of the z-scores and sample size for the bent arm hang and agility shuttle run tests for boys and girls from each country where data were available (higher z-scores indicate superior performance)

	Bent arm hang						Agility shuttle run					
	boys			girls			boys			girls		
	z	SE	n	z	SE	n	z	SE	n	z	SE	n
Albania	+0.06	0.02	1,422	−0.09	0.02	1,284	−0.31	0.02	1,422	−0.32	0.02	1,284
Belgium	−0.07	0.01	7,972	−0.05	0.01	7,963	−0.37	0.01	8,295	−0.22	0.01	8,270
Bulgaria	−0.53	0.01	314	−0.54	0.01	292	+0.16	0.03	314	+0.06	0.03	292
Estonia	+0.21	0.02	1,815	+0.01	0.02	2,130	+0.16	0.02	1,815	+0.15	0.02	2,130
France	−0.05	0.01	4,035	−0.13	0.01	3,693	+0.17	0.01	4,377	+0.15	0.01	4,007
Greece	−0.21	0.02	3,139	−0.25	0.01	3,073						
Iceland	+0.19	0.02	3,630	+0.21	0.02	3,714	+0.45	0.01	4,894	+0.58	0.01	4,502
Italy	−0.46	0.01	3,897	−0.40	0.01	3,317	−0.36	0.02	4,445	−0.54	0.02	3,675
Latvia	+0.07	0.02	3,027	+0.05	0.02	3,423	−0.10	0.02	2,688	−0.09	0.02	3,431
Lithuania	+0.27	0.03	764	−0.02	0.03	837	−0.20	0.02	661	−0.04	0.02	837
Netherlands	+0.12	0.03	1,026	+0.07	0.03	843	+0.56	0.02	1,020	+0.69	0.02	829
Poland	+0.03	0.01	29,118	+0.07	0.01	33,291	−0.29	0.02	2,760	−0.23	0.02	2,744
Romania	−0.03	0.03	140	−0.41	0.01	187	−0.31	0.07	138	−0.49	0.07	186
Slovakia	+0.46	0.02	2,453	+0.27	0.03	1,862	+0.35	0.02	2,436	+0.32	0.02	1,716
Spain	−0.02	0.01	7,025	−0.03	0.01	6,949	+0.30	0.02	6,336	+0.28	0.02	6,308
Switzerland							+0.17	0.02	1,589	+0.09	0.02	1,603
Turkey	−0.10	0.03	914	−0.24	0.03	654	+0.02	0.04	1,139	+0.26	0.02	1,101
UK (Northern and)	+0.03	0.03	1,139	−0.08	0.03	1,327	−0.20	0.01	3,018	−0.45	0.02	3,103
UK (Wales)				−0.15	0.03	663				−0.23	0.02	913

Table 6. Sample-weighted mean z-scores, standard errors of the z-scores and sample size for the endurance shuttle run test for boys and girls from each country where data were available (higher z-scores indicate superior performance)

	Endurance shuttle run					
	boys			girls		
	z	SE	n	z	SE	n
Belgium	+0.11	0.01	9,375	−0.02	0.01	9,229
Czech Republic	+0.43	0.06	224	+0.73	0.08	215
Estonia	+0.91	0.02	2,461	+1.05	0.02	2,774
Finland	+0.53	0.05	511	+0.73	0.04	598
France	+0.46	0.02	3,535	+0.39	0.02	3,385
Germany	+0.17	0.05	497	+0.15	0.04	480
Greece	−0.42	0.01	3,070	−0.51	0.01	2,997
Hungary	−0.01	0.02	428	+0.38	0.02	885
Iceland	+0.65	0.02	3,960	+0.94	0.02	3,681
Italy	−0.15	0.02	2,322	−0.48	0.02	3,217
Lithuania	+0.69	0.02	764	+0.58	0.02	837
Netherlands	−0.09	0.02	1,021	−0.18	0.03	853
Poland	−0.17	0.01	37,249	−0.13	0.01	36,496
Slovakia	+0.16	0.02	2,445	+0.10	0.02	1,858
Spain	+0.02	0.01	7,090	−0.05	0.01	7,012
Switzerland	−0.26	0.02	1,588	−0.40	0.02	1,589
Turkey	−0.20	0.10	72			
UK (Northern Ireland)	+0.20	0.02	2,274	−0.08	0.02	2,365

Europe [Slovakia (2nd) and the Czech Republic (4th)] dominated. On individual tests, Estonia performed best on the endurance shuttle run, Iceland on the standing broad jump, and Slovakia on the hand-grip and bent arm hang. In contrast, the lowest ranked countries overall were from the British Isles [Northern Ireland (19th) and Wales (23rd)] and southern Europe [Albania (18th), Greece (20th) and Italy (22nd)].

The superior fitness of northern and central European children has been a recurrent theme in studies since the 1960s. In 1960, Knuttgen [77] reported that 99% of Danish 7th–12th grade girls, and 96% of Danish boys outperformed their peers from the US on the 600-yard (550 m) walk/run test. Shephard [78] found that Scandinavian children were far superior to children from North America on tests measuring peak oxygen uptake. Rutenfranz [3] reported that 10-, 15- and 17-year-old German boys and girls performed decidedly better on a PWC_{170} test ($W \cdot kg^{-1}$) than comparable Canadian children, and were of similar fitness

Table 7. Rankings for the 23 countries based on the overall sample-weighted mean z-score across those tests for which data were available

Country	Overall z-score	Rank
Finland	+0.39	1
Slovakia	+0.35	2
Iceland	+0.35	3
Czech Republic	+0.32	4
Estonia	+0.32	5
Switzerland	+0.28	6
Lithuania	+0.22	7
Netherlands	+0.16	8
Germany	+0.10	9
Turkey	+0.06	10
Poland	+0.02	11
Bulgaria	+0.02	12
Latvia	+0.02	13
Spain	+0.01	14
France	+0.01	15
Belgium	0.00	16
Romania	−0.09	17
Albania	−0.17	18
UK (Northern Ireland)	−0.22	19
Greece	−0.23	20
Hungary	−0.27	21
Italy	−0.31	22
UK (Wales)	−0.42	23

to Czech children measured in other studies. More recently, Murphy [79] reported that the motor test performance (muscular endurance, flexibility, power and strength) of Icelandic children was superior to that of their peers from Australia, North America and other European countries. Similarly, in a comparative study of motor test performances of 12- and 15-year-olds from six European countries, Telama et al. [5] found that children from northern and central Europe typically outperformed children from Western Europe. Koenig-McIntyre [1] compared the 1-mile (1,609 m) run performance of 10-year-old Finnish, Norwegian and Swedish children to those of United States children. The passing percentages on criterion-referenced tests of the northern European children (54–85%) easily exceeded those of United States children (42–44%). Fredrikson [80] compared directly measured peak oxygen uptake values of European children, finding that children from northern Europe were superior to

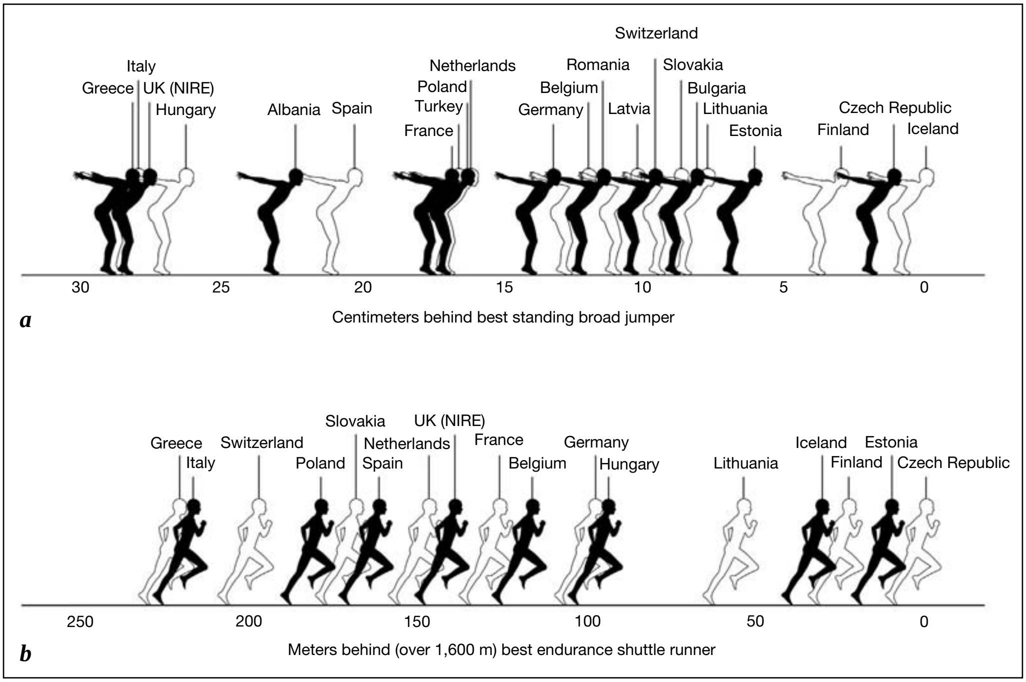


Fig. 2. The magnitude of differences in European children's Eurofit test performance (1981–2001). Shown are the average values for 12-year-old boys from 22 countries. ***a*** Average distance (cm) behind the best standing broad jump average. ***b*** Average distance (m) behind (over 1,600 m) the fastest endurance shuttle run average. UK (NIRE) = United Kingom (Northern Ireland).

their peers from other parts of Europe. In a recent meta-analysis of 109 reports of the performance of 418,026 children and adolescents from 37 countries tested on the 20 m endurance shuttle run, Olds et al. [2] found that the best performing children came from northern European countries.

Fitness differentials may reflect physical activity gradients. Vincent et al. [81] found that Swedish children took more daily steps than Australian children, who in turn were more active than American children. Riddoch et al. [82] found the following order in the activity levels of children from different countries using accelerometry: Norway, Estonia, Portugal, Denmark.

The enduring superiority of young people from these regions points either to genetic or to embedded socio-cultural differences. These may be related to the long tradition of institutionalized and organized participation in physical activity in northern and central Europe, starting with the gymnastics movements in central and northern Europe in the early 1800s: Jahn's Turnvereine in

Germany, Sokol gymnastics in central Europe, and Ling gymnastics in Sweden. These developed into massive youth movements throughout the twentieth century. As Europe becomes more economically and culturally integrated in the 21st century, it will be interesting to see whether these differentials persist.

Factors Related to Performance

An obvious question is what factors are related to this wide scatter of performance scores. Using Spearman's rho, the strength of the linear relationships between relative performance and some broad indicators of each country's economic, sporting and geographical status, as well as the average BMI z-score (a crude index of relative fatness), was explored.

Economic Status

An a priori case can be made to suggest that a country's wealth could be related to performance. Wealthy countries may have the resources, at the school and broader community level, to engage children in active recreation. Alternatively, they may offer more opportunities for sedentary pastimes and an 'effortless' lifestyle. To examine the relationship between wealth and performance, wealth was operationalized as per capita Gross Domestic Product (GDP) in Parity Purchasing Power (PPP) dollars [83] an index of the real purchasing power of average yearly income. The GDPs ranged from USD 4,900 for Albania to USD 33,800 for Switzerland. Gross Domestic Product was not significantly related to the overall mean z-score ($r = +0.04$, $p = 0.87$), nor to the mean z-score for any specific test. Finland (GDP = USD 29,000) returned the highest overall mean z-score (+0.39), but only marginally ahead of the Czech Republic (+0.32), with a GDP barely half as great (USD 16,800).

Another economic index of interest is the distribution of wealth within a country, which is captured by the Gini Index [84]. It is arguable that countries with a very inequitable distribution of wealth (high Gini Index) may perform worse because of pockets of relative disadvantage, and pockets of excessive affluence. The Gini Indexes ranged from 24.4 for Hungary to 42.0 for Turkey. However, the Gini Index was not significantly related to overall mean z-score ($r = +0.26$, $p = 0.19$). The country with the second most inequitable income distribution (Estonia, Gini Index = 37.0) performed only slightly worse than the country with the second most equitable distribution (Czech Republic, Gini Index = 25.4). The fitness of young Europeans therefore appears to be unrelated to major indices of economic status.

Sporting Status

Does the place of sport and exercise in the 'national psyche' of a country affect the performance of young people on fitness tests? Two indices which might reflect a national ‘commitment’ to sport are performance at the Olympic Games and the time devoted to school-based physical education (PE). Olympic performance was quantified using an index which took into account both the country’s population and the frequency of its appearance at the summer and winter games [85]. Olympic medals may not always be a good indicator of sporting success or national interest in sport. Very small countries may be disadvantaged, and the inclusion of Winter Olympic Games tends to exclude hot countries. However, there are few other markers for which international data are available. The Olympic success indexes ranged from 47.3 for Finland to 0 for Albania. Olympic performance was moderately and significantly related to overall mean z-score ($r = +0.45$, $p = 0.03$), with the most successful Olympic country (Finland, Olympic Index = 47.3) also having the best Eurofit performance. This association may be interpreted as evidence of a ‘trickle-down’ effect (elite athletic performance inspires emulation at the grass roots level), or as evidence of a ‘trickle-up’ effect (grass roots participation produces elite athletes). It is also possible that a third factor – for example, the cultural importance placed on sport – affects each index independently.

The minutes devoted per week to school PE ranged from 60 in Finland to 150 in France [86]. However, minutes of PE were unrelated to fitness performance ($r = +0.11$, $p = 0.68$). This last observation is of interest, and suggests that activity outside of school outweighs school-based activity; that the time notionally devoted to PE is not a good measure of the effectiveness of PE classes; or else that compensation for activity at school occurs outside of school hours [87].

Geographic Factors

Previous studies have found a relationship between climate and children’s fitness performance [2], with colder countries registering superior performance. In the current study, both latitude [88] and mean annual temperature [89] were related to overall mean z-score ($r = +0.51$, $p = 0.01$ for latitude; $r = +0.63$, $p = 0.03$ for temperature). This relationship may reflect the popularity of vigorous outdoor winter sports such as skating and cross-country skiing, or may be an artefact of the superior performance of northern European countries. It is also possible that the extremely hot southern summers discourage physical activity. However, temperature was also related to Olympic performance ($r = +0.67$, $p = 0.02$), so it is possible that the relationship was mediated by the societal importance placed upon sport.

Body Mass Index

Given the cross-sectional relationship between fatness and performance on some fitness tests, and plausible mechanistic links, it would be expected that

Table 8. Correlation matrix for mean z-scores for the nine tests

	FLB	PLT	SAR	SBJ	HGR	SUP	BAH	SHR	ESR
FLB		+0.06	−0.04	+0.01	+0.20	−0.23	+0.01	+0.10	−0.10
PLT			+0.57	+0.64	+0.43	+0.30	+0.24	+0.45	+0.11
SAR				+0.82	+0.61	+0.41	+0.39	+0.60	+0.52
SBJ					+0.60	+0.26	+0.55	+0.84	+0.51
HGR						+0.46	+0.55	+0.54	+0.13
SUP							+0.53	−0.02	+0.01
BAH								+0.50	+0.14
SHR									+0.47
ESR									

BAH = Bent arm hang; ESR = 20 m endurance shuttle run; FLB = flamingo balance; HGR = hand-grip; PLT = plate tapping; SAR = sit-and-reach; SBJ = standing broad jump; SHR = 10 × 5 m agility shuttle run; SUP = sit-ups.

national-level markers of pediatric fatness would correlate with fitness performance. Livingstone [90] found a north-south gradient in the obesity levels of European children, with children from the south (Italy, Spain and Greece – but also Hungary) being fatter than children from northern Europe. More recently, Lobstein and Frelut [91] confirmed this trend, with high levels of child overweight in Spain, Italy and Greece compared to Denmark, Germany, the Czech Republic and Slovakia. In the present study, BMI z-scores were not related to overall mean z-scores, but were significantly related to performance on the endurance shuttle run ($r = +0.53$, $p = 0.03$). Olds et al. [this vol., pp. 226–240] found a similar relationship between fatness and aerobic performance across a larger sample of countries.

Consistency across Tests, and between Boys and Girls

Do countries which perform well on one test tend to perform well on the others? Table 8 shows the inter-correlations between mean z-scores for the nine tests. Some tests (e.g. standing broad jump) were strongly correlated with many others; some (such as flamingo balance) show only weak correlations. Only three countries (Estonia, Finland and Slovakia) recorded positive mean z-scores on all tests, and no country recorded negative z-scores on all tests. On average, the range of z-scores for a country across the tests was 0.80, varying from the consistent Germany (−0.03 to +0.16) to the erratic Albania (−1.13 to +0.55).

‘Fitness’ as measured by the Eurofit test battery appears to be a multi-dimensional construct.

There was, however, a great deal of consistency between boys’ and girls’ relative performances within a country. The correlations between boys’ and girls’ mean z-scores range from -0.53 ($p = 0.05$) for the flamingo balance to $+0.96$ ($p < 0.0001$) for the standing broad jump, with all correlations positive (except that for the flamingo balance). Across all tests, the correlation is $+0.86$ ($p < 0.0001$). If the boys from a given country perform well on a given test, the girls are also likely to perform well (and vice versa, of course).

Methodological Issues

A problem common to almost all cumulation studies of this sort, is the issue of representativeness. Despite using Eurofit test protocols, tests may not have always been conducted under precisely the same conditions (e.g. weather, test surfaces, practice, etc.). Such factors were seldom reported and were therefore uncontrollable. There were also differences in sampling protocols, ranging from convenience samples to randomized national surveys. The subjects may have come from different ethnic, cultural, socio-economic and socio-demographic groups, and from groups differing in their exposure to physical activity. It is likely that the sheer number of data points in this study will dampen irregularities arising from sampling inconsistencies. This is particularly true where there have been a number of different studies from the same country. For example, results from Belgium, Estonia, France, Italy, Poland, Spain and the UK (Northern Ireland) were based on at least 5,000 children and at least six separate studies each. They typically represented a wide within-country geographical dispersion. The confidence in these results therefore, is much greater that those based on one or two small-sample studies (e.g. Bulgaria, Czech Republic and Romania).

All children were tested between 1981 and 2001. With recent reports of a European decline in children’s aerobic fitness test performance [Tomkinson and Olds, this vol., pp. 46–66], direct comparisons of aerobic performances among countries would disadvantage those countries where the bulk of the data were collected recently and advantage those countries where the bulk of the data were collected earlier. In contrast, there have been reports [92] of performance stability in European children tested on power, speed and speed agility tests, suggesting that a time-related correction for these tests is unwarranted. However, secular data on other Eurofit tests are few, and are available only for several European countries [see Jürimäe et al., this vol., pp. 129–142]. Given that secular data were not available for all European countries for which Eurofit data were available, time-related corrections of fitness test performances are impossible, although it is acknowledged that the relative performances of some fitness test results may warrant correction.

Conclusion

This study represents the largest cumulation to date of data on the performance of European children and adolescents on standardized fitness tests. The analysis of these data confirms the higher performance levels of young people from northern and central Europe. The lack of relationship between performance and gross indicators of economic status, and the apparent irrelevance of scheduled minutes of school PE, suggest that the availability of resources may not be the critical factor in determining performance levels. Barring genetic differentials, it seems likely that socio-cultural factors are important. The place of exercise and sport in the national psyche, the background expectations regarding physical activity, and the tradition of participation may be the greatest influences on European youth.

References

1 Koenig-McIntyre C: Are American children and youth fit? Some international perspectives. Fitness of 10-year-old youth: a cross-cultural perspective. Res Quart Exerc Sport 1992;63:451–452.

2 Olds TS, Tomkinson GR, Léger LA, Cazorla G: Worldwide variation in the performance of children and adolescents: an analysis of 109 studies of the 20 m shuttle run test in 37 countries. J Sports Sci 2006;24:1025–1038.

3 Rutenfranz J, Berndt I, Frost H, Mocell R, Singer R, Sbresny W: Physical performance capacity determined as W_{170} in youth; in Bar-Or O (ed): Pediatric Work Physiology. Proceedings of the Fourth International Symposium, Wingate Institute, April 1972. Natanya, Wingate Institute, 1973, pp 245–249.

4 Shephard RJ: World standards of cardiorespiratory performance. Arch Environ Health 1966;13: 664–672.

5 Telama R, Naul R, Nupponen H, Rychtecky A, Vuolle P: Physical Fitness, Sporting Lifestyles and Olympic Ideals: Cross-Cultural Studies on Youth Sport in Europe. Schorndorff, Verlag Karl Hofmann, 2002.

6 Kemper HCG, Van Mechelen W: Physical fitness testing of children: a European perspective. Pediatr Exerc Sci 1996;8:201–214.

7 Council of Europe: Eurofit: Handbook for the Eurofit Tests of Physical Fitness, ed 2. Strasbourg, Council of Europe, 1993.

8 Council of Europe: Eurofit: Handbook for the Eurofit Tests of Physical Fitness. Rome, Council of Europe, 1988.

9 Council of Europe: Testing Physical Fitness. Eurofit Experimental Battery: Provisional Handbook. Strasbourg, Council of Europe, 1983.

10 Markola L, Bellova I, Kokoneci G: Eurofit per femije: Për moshat 7–18 vjeç. Tirane, Qendra Kerkimore Shkencore e Sportit, 1997.

11 Baquet G, Berthoin S, Padovano C, Legros L, Stœfs M, Noterman P, Deman J, Legulier C, Vanlierde F, Gerbeaux M, Van Praagh E: Effets d'un cycle de course de duree de type intermittent (court-court) sur la condition physique des adolescents. Rev Educ Phys 2000;40:51–60.

12 Beunen, G, Borms J, Vrijens J, Lefèvre J, Clæssens AL, Pion J: Fysieke fitheid en sportbeœfening van de Vlaamse jeugd. Volumen 1: Fysieke fitheid van de jeugd van 6 tot 18 jaar [Physical Fitness and Sports Participation of the Flemish Youth. Volume 1: Physical Fitness of Youth 6 to 18 years of Age]. Brussels, Bloso, 1991.

13 Lefèvre J, Bouckært J, Duquet W: De barometer van de fysieke fitheid van de Vlaamse jeugd 1997: De resultaten [The barometer of the physical fitness of Flemish youth 1997: results]. Sport (Bloso Brussel)1988;4:16–22.
14 Pirnay F: Le baromètre de la condition physique. Sport 1995:3–61.
15 Dimitrova D: Physical Fitness of Children and Adolescents in Relation with Age-Specific Changes in Body Composition; diss. Sofia, National Sports Academy, 2001.
16 Jürimäe T, Volbekiene V: Eurofit test results in Estonian and Lithuanian 11 to 17-year-old children: a comparative study. Eur J Phys Educ 1998;3:178–184.
17 Raudsepp L, Jürimäe T: Relationships between somatic variables, physical activity, fitness and fundamental motor skills in prepubertal boys. Biol Sport 1996;13:279–289.
18 Raudsepp L, Jürimäe, T: Relationships of physical activity and somatic characteristics with physical fitness and motor skill in prepubertal girls. Am J Hum Biol 1997;9:513–521.
19 Jürimäe T, Saar M: Shuttle-run test: The role of jumping ability, flexibility, coordination and balance. J Hum Mov Studies 1998;35:201–217.
20 Kull M, Jürimäe T: Using the Eurofit Test Battery in Estonian 16–18 years old Adolescents. Acta et Commentationes Universitatis Tartuensis, Tartu, Estonia. University of Tartu, 1994, pp 49–52.
21 Levarlet-Joye H, Fievetz AF: Les tests Eurofit et les jeunes de 11 à 14 ans. 6th European Research Seminar: The Eurofit Tests of Physical Fitness, Izmir, 26–30 June, 1990. Strasbourg, Council of Europe, 1990, pp 29–54.
22 Van Praagh E, Lofi A, Brandet JP, Cazorla G: Evaluation of the Eurofit battery in French schools. 5th European Research Seminar on Testing Physical Fitness, Formia, 1986. Strasbourg, Council of Europe, 1987, pp 52–57.
23 Brandet JP: Compte-rendu critique d'une campagne de tests d'aptitudes physiques chez des enfants (opération Eurofit). Proceedings of Activites Physiques, Sports: Journees d'automne, 1985. Beaune, ACAPS, 1985, pp 4–5.
24 Cazorla G: Batterie France-eval: Mesures, épreuves et barêmes: évaluation des qualités physiques des jeunes Français d'âge scolaire: 7–11 ans. Rapport pour le Secrétariat d'Etat Auprès du Premier Ministre Chargé de la Jeunesse et de Sports. Paris, Ministère de la Jeunne et de Sports, 1987.
25 Van Pœlvoorde F, Levarlet-Joye H: Bilan des capacités motrices des enfants gymnastes et non sportifs de 7 à 10 ans. Sport 1990;33:3–15.
26 Deroanne R, Delbrouck E, Dumont P: Application de la batterie de tests d'aptitude physique Eurofit à des élèves de l'enseignement secondaire. Rev Educ Phys 1986;26:12–43.
27 Baquet G, Berthoin S, Gerbeaux M, Van Praagh E: High-intensity aerobic training during a 10 week one-hour physical education cycle: effect on physical fitness of adolescents aged 11 to 16. Int J Sports Med 2001;22:295–300.
28 Baquet G, Berthoin S, Dupont G, Blondel N, Fabre C, Van Praagh E: Effects of high intensity intermittent training on peak $\dot{V}O_2$ in prepubertal children. Int J Sports Med 2002;23:439–444.
29 Brunet J, Van Praagh E: Batterie experimentale de tests moteurs Eurofit: Rapport d'activité de la Région Auvergne – 1984–1985. Clermont-Ferrand, Universite de Clermont-Ferrand, 1985.
30 Georgiadis G: Evaluation of Physical Fitness of Greek Youth Aged 6–18 years; diss. Athens, Faculty of Physical Education and Sport Sciences, University of Athens, 1993.
31 Barabás A: Eurofit and Hungarian school children; in 6th European Research Seminar: The Eurofit Tests of Physical Fitness, Izmir, 1990. Strasbourg, Council of Europe, 1990, pp 223–232.
32 Barabás A: Measurement of aerobic power by field tests; in Coudert J, Van Praagh E (eds): Pediatric Work Physiology: Children and Exercise XVI. Paris, Masson, 1992, pp 39–41.
33 Friðriksson H, Gunnarsson SO: Kynslóð kyrrsetumanna? Rannsókn á líkamshreysti og þoli 12 ára skólabarna (A sedentary generation? A study on the fitness and endurance of 12 year old schoolchildren); diss. Reykjavik, University of Iceland, 1996.
34 Sæmundsen G: Report on the Icelandic experimentation. 5th European Research Seminar on Testing Physical Fitness, Formia, 1986. Strasbourg, Council of Europe, 1987, pp 115–127.
35 Bellucci M: I test Eurofit nella scuola media Mameli di Roma. Alcmeone 1997;1:22–27.
36 Cilia G, Bellucci M: Eurofit: Tests Europei di attitudine fisica. Roma, Istituto Superiore Statale di Educazione Fisica, 1993.
37 Cilia G, Bellucci M, Riva M, Venerucci I: Eurofit 1995. Roma, Istituto Superiore Statale di Educazione Fisica, 1996.

38 Cilia G, Bellucci M, Bazzano C, Riva M: Eurofit 1997: Banche dati per la scuola. Alcmeone 1997;3: 13–32.

39 Cilia G, Bazzano C, Bellucci M, Riva M, Annino G, Venerucci I, Riccardi R, Sicari M, Zarro I, Russo P, De Santis M, Ciamberlano P, Ciccarelli D, Selleri C, Chinellato L: I risultati dei test Eurofit nella scuola Matteuccii di Roma. Alcmeone 1998;2:16–20.

40 Council of Europe: Évaluation de l'aptitude physique: Eurofit batterie expérimentale. Rome, Council of Europe, 1986.

41 van Mechelen W, van Lier WH, Hlobil H, Crolla I, Kemper HCG: Eurofit: Handleiding met referentieschalen voor 12- tot en met 16-jarige jongens en meisjes in Nederland. Haarlem, Uitgeverij de Vrieseborch, 1991.

42 Czeczelewski J, Sklad M, Saczuk J, Raczynski G: Relationships between feeding manner, somatic features and physical fitness in children at adolescence. Biol Sport 2001;18:147–159.

43 Kusy K: Strength performance in 14-year-old boys from urban population against a background of their leisure time physical activity; in Komadel L (ed): Physical Education and Sports of Children and Youth: Proc Int Conf, Bratislava, 1995. Bratislava, Slovak Scientific Society for Physical Education and Sports, 1995, pp 32–34.

44 Maciaszek J, Osinski W: Poziom sprawnosci fizycznej u chlopców i dziewczat Poznanskich w wieku 10–14 lat. Rocz Nauk AWF Poznaniu 2001;50:3–17.

45 Mleczko E, Ozimek M: Rozwój somatyczny i motoryczny mlodziezy Krakowskiej miedzy 15 a 19 rokiem zycia z uwzglednieniem czynników srodowiskowych. Kraków, Akademia Wychowania Fizycznego, 2000.

46 Osinski W, Biernacki J: Sprawnosc fizyczna dzieci Poznanskich na tle ich rówiesników z wybranych krajów Europejskich. Wychowanie Fizyczne Sport 1993;37:3–31.

47 Raczynski G, Czeczelewski J, Sklad M, Stupnicki R: Interrelationships among food intake, somatic traits, and physical fitness in 10.5- to 15.5-year-old children from eastern Poland. Int J Sport Nutr 1998;8:388–400.

48 Stupnicki R, Przewęda R, Milde K: Centylowe siatki sprawności fizycznej Polskiej młodziezy wg testów Eurofit. Warsaw, Akademia Wychowania Fizycznego, 2003.

49 Wilczewski A, Sklad M, Krawczyk B, Saczuk J, Majle B: Physical development and fitness of children from urban and rural areas as determined by Eurofit test battery. Biol Sport 1996;13:113–126.

50 Federatia Sportul pentru Toti: Statia pilot de aplicare a testului Eurofit la copii de 7–18 ani. Bucharest, Author, 1995.

51 Kasa J, Majherová, M: Physical and motor development of children by Eurofit. Studia Psychol 1997;39:270–274.

52 Kyselovicová O: Programy aerobiku z aspektu rozvoja telesnej zdatnosti dievcat na gymnáziu. Acta Facult Educ Physic Universitatis Comenianae 2000;41:5–61.

53 Moravec R: in Moravec R, Kampmiller T, Sedlácek J (eds): Eurofit – Physique and Motor Fitness of the Slovak School Youth. Bratislava, Slovak Scientific Society for Physical Education and Sports, 1996, pp 9–22.

54 Brito Ojeda EM, Navarro Valdivielso M, García Afonso D, Sánchez García MJ, García Manso JM, Navarro García R, Ruiz Caballero JA: La condición física en la población escolar de gran Canaria (10–19 años). Las Palmas de Gran Canaria, Excmo. Cabildo Insular de Gran Canaria, 1995.

55 García Bæna J: La condición fisica en la educación secundaria. Trabajo de investigación; diss. Madrid, Facultad de Educación, Universidad Nacional de Educación a Distancia, 1999.

56 Marrodán Serrano MD, Callejo Gea ML, Moreno-Heras E, González-Montero de Espinosa M, Mesa Santurino MS, Gordón Ramos PM, Fernández García F: Anthropometría nutricional y aptitud física en adolescentes urbanos de Madrid. Anal Españ Pediatr 1999;51:9–15.

57 Prat JA, Casamort J, Balagué N, Martínez M, Povill J-M, Sánchez A, Silla D, Santigosa S, Pérez G, Riera J, Vela JM, Portero P: Eurofit: La batería Eurofit en Catalunya. Barcelona, Secretaria General de l'Esport, 1998.

58 Sainz RM: Aptitudes psiquicas y fisicas: Estudio ed la aptitud fisica de los adolescentes de la provincia de Vizcaya y su relacion con la personalidad; diss. Bilbao, Facultad de Filosofia y Ciencias de la Educacion, Universidad de Deusto, 1992.

59 Sainz RM: La batería Eurofit en Euskadi. Vitoria-Gasteiz, Instituto Vasco de Educación Fisica, 1996.

60 Ureña Villanueva F: Valoración y baremación de la aptitud física en el alumnado de segundo ciclo de educación secundaria obligatoria de la comunidad autonoma de Murcia. Su utilización según los postulados de la reforma; diss. Murcia, University of Murcia, 1996.
61 Cauderay M, Narring F, Michaud P-A: A cross-sectional survey assessing physical fitness of 9- to 19-year-old girls and boys in Switzerland. Pediatr Exerc Sci 2000;12:398–412.
62 Akgün N, Ergen E, Ertat A, Islegen C, Colakoglu H, Emlek Y: Preliminary results of motor fitness, cardiorespiratory fitness and body measurements in Turkish children. 5th European Research Seminar on Testing Physical Fitness, Formia, 1986. Strasbourg, Council of Europe, 1987, pp 25–51.
63 Akgün N: Eurofit test results in the western part of Turkey. 6th European Research Seminar: The Eurofit Tests of Physical Fitness, Izmir, 1990. Strasbourg, Council of Europe, 1990, pp 69–116.
64 Çalis M, Ergen E, Turnagöl H, Arslan O: Beden egitimi derslerinin bir ögretim yili boyunca 15–16 yas grubu ögrenciler üzerindekifizyolojik etkilerinin Eurofit test bataryasi ile izlenmesi; in 3 Ulusal Spor Bilinleri Kongresi. Ankara, Hacettepe Universitesi, 1992, pp 367–372.
65 Demirel H, Açikada T, Bayar P, Turnagöl H, Erkan U, Hazir T, Demirci R, Haner B, Pehlivan M, Ayalp Y: Ankara'da yükselis koleji ilkokul bölümünde 7–11 yas gurubu çocuklarda Eurofit uygulamasi; in Spor Bilimleri 1 Ulusal Sempozyumu Bildirileri. Ankara, Hacettepe Universitesi, 1990, pp 601–610.
66 Gökbel H, Uzuncan H: Eurofit testleri ile 10–12 yaslarindaki erkeklerin aerobik güç ve fiziksel uygunluklarinin ölçülmesi. Spor Hekimligi Dergisi 1992;27:59–67.
67 Boreham CAG, Paliczka VJ, Nichols AK: Fitness testing of Belfast schoolchildren. 5th European Research Seminar on Testing Physical Fitness, Formia, 1986. Strasbourg, Council of Europe, 1987, pp 52–57.
68 Mahoney C: 20-MST and PWC170 validity in non-Caucasian children in the UK. Br J Sports Med 1992;26:45–47.
69 Mahoney CA, Boreham CAG: Eurofit in Belfast primary schools. Scot J Phys Educ 1991;19:1–4.
70 Nichols AK, Riddoch CJ: The development of fitness test batteries for use in higher education, schools and clubs; in Trends and Developments in Physical Education. Proc VIII Commonwealth Int Conf Sport, Physical Education, Dance, Recreation and Health. London, E&FN Spon, 1986, pp 378–384.
71 Paliczka VJ, Boreham CAG, Kerr MJ: The physical fitness of Belfast schoolchildren; in Kinanthropometry III. Proc VIII Commonwealth Int Conf Sport, Physical Education, Dance, Recreation and Health. London, E&FN Spon, 1987, pp 165–171.
72 Riddoch CJ: Northern Ireland Health and Fitness Survey – 1989: The Fitness, Physical Activity, Attitudes and Lifestyles of Northern Ireland Post-Primary Schoolchildren. Belfast, The Queen's University of Belfast, 1990.
73 Watkins J, Farrally MR, Powley AE: The Anthropometry and Physical Fitness of Secondary Schoolgirls in Strathclyde. Glasgow, Jordanhill College of Education, 1983.
74 Tomkinson GR, Léger LA, Olds TS, Cazorla G: Secular changes in the performance of children and adolescents (1980–2000): an analysis of 55 studies of the 20 m shuttle run in 11 countries. Sports Med 2003;33:285–300.
75 Tomkinson GR, Hamlin MJ, Olds TS: Secular changes in anaerobic test performance in Australasian children and adolescents. Pediatr Exerc Sci 2006;18:314–328.
76 Tomkinson GR: Secular Changes in Fitness Performance of Australasian Children and Adolescents; diss. Adelaide, University of South Australia, 2004.
77 Knuttgen HG: Comparison of fitness of Danish and American school children. Res Q 1960;32: 191–196.
78 Shephard RJ: World standards of cardiorespiratory performance. Arch Environ Health 1966;13: 664–672.
79 Murphy NM: The Relationship Between Physical Activity, Physical Fitness, and Selected Lifestyle Factors in Northern Irish School Children; diss. Belfast, Queen's University of Belfast, 1991.
80 Fredriksen PM, Thaulow E, Nystad W, Ingjer F: AErobic capacity among children and adolescents: nordic results over the past 45 years [in Swedish]. Tidsskr Nor Lœgeforen 1998;118: 3106–3110.

81 Vincent SD, Pangrazi RP, Raustorp A, Tomson LM, Cuddihy TF: Activity levels and body mass index of children in the United States, Sweden, and Australia. Med Sci Sports Exerc 2003;35: 1367–1373.
82 Riddoch CJ, Andersen LB, Wedderkopp N, Harro M, Klassen-Heggebø L, Sardinha LB, Cooper AR, Ekelund U: Physical activity levels and patterns of 9- and 15-year old European children. Med Sci Sports Exerc 2004;36:86–92.
83 http://www.odci.gov/cia/publications/factbook/fields/2004.html.
84 http://www.odci.gov/cia/publications/factbook/fields/2172.html.
85 http://users.skynet.be/hermandw/olymp/reloly.html.
86 Kemper HCG: Role of the pediatric exercise scientist in physical education sports training and physiotherapy. Int J Sports Med 2000;21(suppl 2):S118–S124.
87 Mallam KM, Metcalf BS, Kirkby J, Voss LD, Wikin TJ: Contribution of timetabled physical education to total physical activity in primary school children: cross-sectional study. Br Med J 2003;327:592–593.
88 http://www.infoplease.com/ipa/A0001769.html.
89 http://www.infoplease.com/ipa/A0004587.html.
90 Livingstone MB: Epidemiology of childhood obesity in Europe. Eur J Pediatr 2001;159(suppl 1): S14–S34.
91 Lobstein T, Frelut ML: Prevalence of overweight among children in Europe. Obesity Rev 2003;4:1195–2000.
92 Tomkinson GR: Global changes in anaerobic fitness test performance of children and adolescents (1958–2003). Scand J of Med Sci Sports; in press.

Grant R. Tomkinson, PhD
Centre for Applied Anthropometry, School of Health Sciences
University of South Australia, City East Campus
GPO Box 2471
Adelaide SA 5001 (Australia)
Tel. +61 8 8302 1407, Fax +61 8 8302 2766, E-Mail grant.tomkinson@unisa.edu.au

Tomkinson GR, Olds TS (eds): Pediatric Fitness. Secular Trends and Geographic Variability.
Med Sport Sci. Basel, Karger, 2007, vol 50, pp 129–142

Changes in Eurofit Test Performance of Estonian and Lithuanian Children and Adolescents (1992–2002)

Toivo Jürimäe[a], *Vida Volbekiene*[b], *Jaak Jürimäe*[a], *Grant R. Tomkinson*[c]

[a]Institute of Sport Pedagogy and Coaching Sciences, Center of Behavioral and Health Sciences, University of Tartu, Tartu, Estonia; [b]Department of Physical Education, Lithuanian Academy of Physical Education, Kaunas, Lithuania; [c]Centre for Applied Anthropometry, School of Health Sciences, University of South Australia, Adelaide, Australia

Abstract

Introduction: Both Estonia and Lithuania have a long history of pediatric fitness testing, but due to a lack of standardized test batteries spanning a substantial number of years, secular changes in fitness test performance have not been previously reported. Using the Eurofit test battery, the aim of this study was to quantify the secular changes in fitness test performance of Estonian and Lithuanian children and adolescents during the first ten years of independence. **Methods:** Two cross-sectional surveys of Estonian and Lithuanian 11- to 17-year-old tested on the Eurofit in 1992 and 2002 were compared. Secular changes were calculated by first, expressing mean values (at the country × age × sex × test level) in 2002 as a percentage of mean values in 1992, and second, by subtracting 100 from the resultant and then dividing 10 to express the changes as percentage changes per annum (p.a.). Negative values indicated secular declines, and positive values secular improvements. **Results:** Secular changes in Eurofit test performance were calculated for 12,226 Estonian and Lithuanian children and adolescents over the 10-year period. Across all Eurofit tests, secular changes ranged on average from -0.98 to $+0.49\%$ p.a., with performances less variable for Estonian children than for Lithuanian children. Secular changes were strikingly consistent across age and sex groups. **Discussion/Conclusion:** This is the first study to have described the secular changes in Eurofit test performance of children and adolescents from the Baltic states. It shows that between 1992 and 2002, changes in Eurofit performance varied among tests and were not always in line with European and global changes.

It has widely been reported in the popular literature that the fitness of children and adolescents has declined in recent decades. Based on the assumption that unfit children become unfit adults (though fitness tracks only moderately well from childhood and adolescence into adulthood [1]), today's children are thought to be at increased risk for cardiovascular disease. This is because low fitness is significantly associated with a higher prevalence of numerous cardiovascular disease risk factors [2].

This widespread popular belief is somewhat surprising, given that the peer-reviewed scientific literature which has explicitly dealt with secular changes in pediatric fitness is extremely exiguous [3]. Most of the available research, rather than focusing on secular changes in 'gold standard' laboratory-based measures of fitness, has focused on secular changes in children's performance on field tests of fitness, where a good lineage of data exists. Some authors (e.g. Tomkinson and Olds [this vol., pp. 46–66] and [4]) have collectively summarized this literature and comprehensively described global changes in jumping (power), agility- and sprint-running (speed), and distance-running (aerobic) performances. However, little is known about secular changes in performances on other fitness tests, such as motor skill (e.g. balance) and muscular fitness tests (e.g. strength, endurance and flexibility).

In spite of a rich history of pediatric fitness testing, secular changes in fitness test performance have not been previously reported for children and adolescents from the Baltic states (Estonia, Latvia and Lithuania). Due to a lack of standardized test batteries spanning a substantial number of years, the fitness test results of Baltic children and adolescents are largely incommensurable. However, the introduction of the Eurofit [5] – a standardized health- and performance-related fitness test battery – into the Baltic States immediately after these countries gained independence from the Soviet Union in 1991, allowed for the development of population-based reference data for Estonia and Lithuania [6]. The aim of this study was to quantify the secular changes in Eurofit test performance of children and adolescents from two Baltic states (Estonia and Lithuania) during the first ten years of independence. It was also of interest to compare secular changes and Eurofit test performances of Baltic children and adolescents to those of their peers from other countries.

Methods

Subjects

In 1992, a cross-sectional sample of 4,789 healthy Estonian and Lithuanian 11- to 17-year-old were tested using the Eurofit test battery [6]. Ten years later, a second cross-sectional sample of 7,437 healthy 11- to 17-year-old was tested using identical procedures. Subjects were conveniently selected from five cities comprising between 40,000 and 750,000 inhabitants each, with one school from each city district represented. Only students from schools which used the Estonian or Lithuanian languages for study were recruited. All subjects participated in 2 × 1 h compulsory physical education classes per week. Oral consent for testing was given by both the child and their parents/guardians.

Testing Procedures

The exact testing procedures have been previously described in detail by Jürimäe and Volbekiene [6]. All tests were performed and scored using Eurofit protocols [5]. The same two teams (Estonian and Lithuanian) of qualified personnel conducted the testing sessions, with testing held in the morning in school gymnasiums as part of compulsory physical education classes. All testing was conducted in the April-May period, with no systematic differences between surveys. Testing procedures were standardized by running training sessions for testing personnel prior to data collection, and by routinely calibrating all testing equipment throughout the testing period. All subjects were familiar with the testing equipment, and completed all fitness tests.

The testing sessions were structured such that all anthropometric testing preceded fitness testing. Height and mass were measured using a Martin metal anthropometer (±0.1 cm) and a medical balance scale (±0.05 kg), respectively. Following a brief (≈10 min), standardized warm-up consisting of light running, jumping and static stretching, all Eurofit tests were performed in the following order: sit-and-reach (flexibility), flamingo balance (balance), hand-grip strength (strength), standing broad jump (power), 10 × 5 m agility shuttle run (speed agility), plate tapping (speed), bent arm hang (upper body muscular endurance), sit-ups (abdominal muscular endurance), and 20 m endurance shuttle run (cardiorespiratory endurance). Note, because different types of dynamometers were used for the two surveys, no secular comparisons were made for hand-grip strength.

Data Entry and Treatment

All hard copy data were manually entered into a spreadsheet and checked for transcription errors, with corrections made where appropriate. All endurance shuttle run scores were converted from the number of completed minutes to the speed at the last completed minute using the procedures of Tomkinson et al. [7].

Statistical Analysis

Data were grouped into country × age × sex × test groups (e.g. Estonian 11-year-old boys tested on the standing broad jump), with mean values for 1992 and 2002 calculated. Mean values for 2002 were then expressed as a percentage of the mean values for 1992, with percentages adjusted such that those greater than 100 indicated improvements in performance.

For comparative purposes, all secular changes were expressed as a percentage of mean values per annum (p.a.), by subtracting 100 from the percentage values and dividing the resultant by 10. Negative values indicated secular declines, and positive values secular improvements. Mean changes (weighted by the square root of sample size) and their corresponding standard errors (SE) and 95% confidence intervals (CI) were calculated using the procedures of Tomkinson [3; this vol., pp. 46–66], with CIs used to compare among groups (e.g. different fitness tests) and to estimate the likelihood of a 'real' change (i.e. when the CI did not include zero).

Results

Secular changes in Eurofit test performance were calculated for 12,226 11- to 17-year-old Estonians (n = 5,747) and Lithuanians (n = 6,470) over the period 1992–2002. Changes were calculated for height, mass and fitness tests measuring aerobic, balance, flexibility, muscular endurance, power, speed and speed agility performance.

Table 1 shows the mean changes for each country × test group. Overall, mean changes ranged from a decline of −0.98% p.a. (CI −1.11 to −0.85% p.a.) for Lithuanians tested on the sit-and-reach to an improvement of +0.49% p.a. (CI +0.36 to +0.62% p.a.) for Lithuanians tested on the flamingo balance. Country × test changes for Estonians were consistently smaller than for Lithuanians. There was no significant change overall for Estonians in height, mass, plate tapping, standing broad jump, sit-ups, agility shuttle run and endurance shuttle run. There was a decline in flamingo balance and sit-and-reach, and an improvement in bent arm hang. The overall picture for Lithuanians was somewhat different. As for Estonians, there was no change in height, plate tapping, sit-ups and agility shuttle run, and a decline in sit-and-reach. In contrast however, there was a decline in bent arm hang, standing broad jump and endurance shuttle run, an improvement in flamingo balance, and an increase in mass.

While table 1 shows the variability among country × test groups, figure 1 shows the variability within country × test groups, by plotting the mean country × age × sex × test performances in 2002 as a percentage of the respective performances in 1992. Figure 1 shows that there was considerable variability within country × test groups, with performances in 2002 (relative to 1992) ranging from 84 to 115% for Lithuanians tested on the Flamingo balance to 98 to 101% for Estonians tested on the endurance shuttle run. With the exception of the sit-and-reach, the variability within country × test groups was always greater for Lithuanians than for Estonians. Country × age × sex × test changes did not vary systematically with sample size.

Secular changes were strikingly similar among older children (11–12 years), younger adolescents (13–15 years) and older adolescents (16–17 years) (table 1). There were however some exceptions. For example, bent arm hang performance declined at –0.68% p.a. (CI −0.91 to −0.45% p.a.) in older Lithuanian children, and remained stable in both younger [−0.15% p.a. (CI −0.34 to +0.04% p.a.)] and older [−0.01% p.a. (CI −0.29 to +0.27% p.a.)] Lithuanian adolescents. There was also remarkable secular consistency in boys and girls, with the majority of the boy and girl changes consistent in direction.

Table 1. Mean changes in Eurofit test performance for Estonian and Lithuanian children and adolescents (1992–2002)

Variable	Δ % p.a. (SE)					
	11–12 years	13–15 years	16–17 years	boys	girls	all
Estonia						
Height, cm	0.00 (0.13)	−0.01 (0.10)	+0.02 (0.15)	−0.01 (0.10)	+0.01 (0.10)	0.00 (0.07)
Mass, kg	+0.01 (0.13)	+0.11 (0.10)	+0.13 (0.15)	+0.18 (0.10)	+0.01 (0.10)	+0.09 (0.07)
Flamingo balance, n in 60 s	−0.05 (0.13)	−0.43 (0.10)	−0.05 (0.15)	−0.10 (0.10)	−0.34 (0.10)	−0.22 (0.07)
Plate tapping, s	+0.02 (0.13)	+0.04 (0.10)	−0.07 (0.15)	0.00 (0.10)	+0.02 (0.10)	+0.01 (0.07)
Sit-and-reach, cm	−0.39 (0.13)	−0.11 (0.10)	−0.37 (0.15)	−0.10 (0.10)	−0.40 (0.10)	−0.25 (0.07)
Standing broad jump, cm	+0.01 (0.13)	−0.04 (0.10)	−0.11 (0.15)	−0.05 (0.10)	−0.04 (0.10)	−0.04 (0.07)
Sit-ups, n in 30 s	+0.15 (0.13)	+0.11 (0.10)	+0.16 (0.15)	+0.05 (0.10)	+0.22 (0.10)	+0.14 (0.07)
Bent arm hang, s	+0.06 (0.13)	+0.24 (0.10)	+0.24 (0.15)	+0.10 (0.10)	+0.26 (0.10)	+0.19 (0.07)
Agility shuttle run, s	−0.02 (0.13)	+0.07 (0.10)	−0.01 (0.15)	0.00 (0.10)	+0.04 (0.10)	+0.02 (0.07)
Endurance shuttle run, km $\cdot$ h^{-1}	−0.04 (0.13)	−0.07 (0.10)	−0.08 (0.15)	−0.04 (0.10)	−0.09 (0.10)	−0.07 (0.07)
Lithuania						
Height, cm	+0.08 (0.12)	+0.01 (0.10)	+0.01 (0.14)	+0.07 (0.09)	0.00 (0.09)	+0.03 (0.07)
Mass, kg	+0.31 (0.12)	+0.12 (0.10)	+0.05 (0.14)	+0.25 (0.09)	+0.07 (0.09)	+0.16 (0.07)
Flamingo balance, n in 60 s	+0.49 (0.12)	+0.67 (0.10)	+0.17 (0.14)	+0.03 (0.09)	+0.93 (0.09)	+0.49 (0.07)
Plate tapping, s	+0.25 (0.12)	−0.07 (0.10)	−0.18 (0.14)	+0.04 (0.09)	−0.05 (0.09)	0.00 (0.07)
Sit-and-reach, cm	−1.09 (0.12)	−1.25 (0.10)	−1.27 (0.14)	−1.27 (0.09)	−1.15 (0.09)	−1.21 (0.07)
Standing broad jump, cm	−0.44 (0.12)	−0.22 (0.10)	−0.25 (0.14)	−0.08 (0.09)	−0.51 (0.09)	−0.30 (0.07)
Sit-ups, n in 30 s	−0.07 (0.12)	+0.23 (0.10)	+0.14 (0.14)	−0.01 (0.09)	+0.24 (0.09)	+0.12 (0.07)
Bent arm hang, s	−0.68 (0.12)	−0.15 (0.10)	−0.01 (0.14)	−1.02 (0.09)	+0.46 (0.09)	−0.27 (0.07)
Agility shuttle run, s	−0.01 (0.12)	+0.16 (0.10)	+0.21 (0.14)	+0.34 (0.09)	−0.09 (0.09)	+0.12 (0.07)
Endurance shuttle run, km $\cdot$ h^{-1}	−0.86 (0.12)	−0.87 (0.10)	−0.75 (0.14)	−0.89 (0.09)	−0.79 (0.09)	−0.84 (0.07)

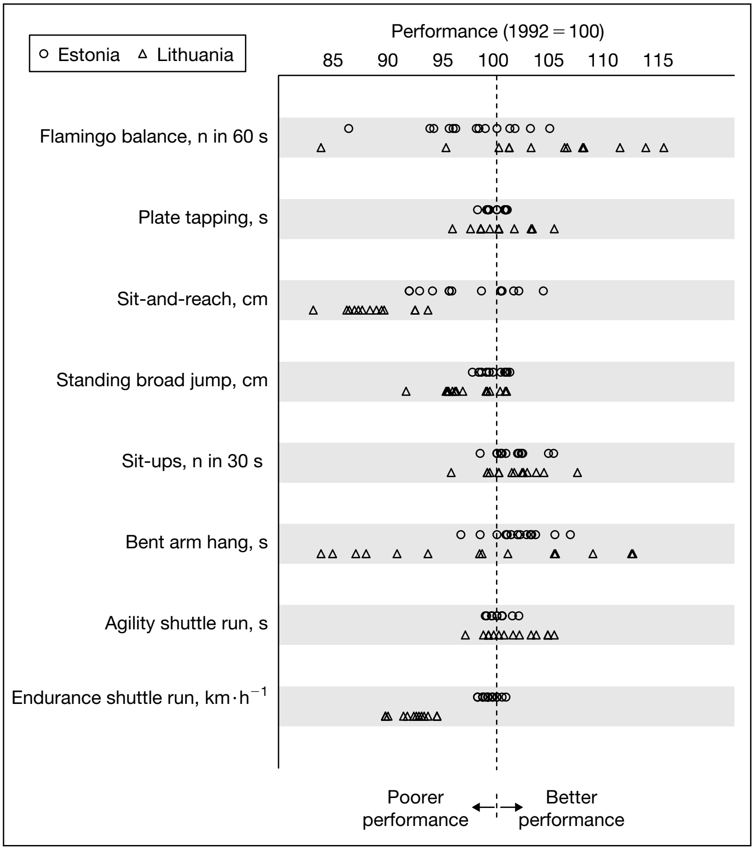


Fig. 1. Univariate plot of mean Eurofit performances (standardized to 1992 = 100) of Estonian (circles) and Lithuanian (triangles) children and adolescents. Each point represents a single country × age × sex × test mean performance in 2002. Higher values (i.e. those to the right of the dashed vertical line) indicate better performances.

Discussion

Despite recent reports of global declines in pediatric aerobic test performance, equivalent to about 4–5% per decade since 1970 [Tomkinson and Olds, this vol., pp. 46–66], this study showed that between 1992 and 2002, there was no change in aerobic performance of Estonian children, and a decline nearly double that of the global decline in Lithuanian children. However, in line with global changes, there has been little recent change in anaerobic performance of Estonian and Lithuanian children. Secular changes, while remarkably consistent for children of different ages and for boys and girls, were not consistent among different Eurofit tests and between Estonians and Lithuanians.

It is not obvious why there has been little overall secular change in Estonian children and why performance (e.g. aerobic) has declined more in Lithuania than in Estonia. It is important to note that the main aim of this study was to quantify the secular changes in Eurofit test performances of Baltic children, rather than the mechanistic factors underlying those performances (the reader is referred to the chapter by Tomkinson and Olds [this vol., pp. 46–66] for a description of a plausible mechanistic model). It is the ability to balance and bend the body, move it faster and for longer, and lift and support it off the ground which expands a child's play potential and is important for children's physical activity levels, irrespective of the underlying causal mechanisms.

Secular Comparisons with Other European Countries and the World

Given that few studies have explicitly reported on secular changes in pediatric fitness test performance, secular comparisons among countries are extremely rare. Such comparisons are undoubtedly affected by differences in the time periods over which the changes were calculated. However, by describing the global time-related patterns of change and time-related patterns of performance, the large meta-analyses of Tomkinson and Olds [this vol., pp. 46–66] and Tomkinson [4] provide a global context for changes in power, speed and aerobic performance of Estonian and Lithuanian children. Data from Tomkinson and Olds [this vol., pp. 46–66] and Tomkinson [4] represent cumulated jumping, and agility-, sprint-, and distance-running performances on over 74 million children and adolescents from 31 countries over the period 1958–2003.

Between 1992 and 2002, it has been estimated that there have been global declines in pediatric power (−0.23% p.a.), speed (−0.04% p.a.) and aerobic (−0.51% p.a.) performance [Tomkinson and Olds, this vol., pp. 46–66; 4]. However, the Baltic changes are not always consistent with global changes. Figure 2 contrasts secular changes for Estonia, Lithuania and the world, by plotting the time-related patterns of performance (standardized to 1992 = 100) for power, speed and aerobic fitness tests. Figure 2 shows that since 1992: (1) power test performances of Estonian children have changed little, and those of Lithuanian children have declined in line with the global change; (2) speed test performances of both Estonian and Lithuanian children have changed little and are in line with the global change, and (3) aerobic test performances of Estonian children have changed little, and those of Lithuanian children have declined at a rate greater than the global change.

While figure 2 provides some clues (for power, speed and aerobic performance at least) regarding whether Estonia and Lithuania are part of the global

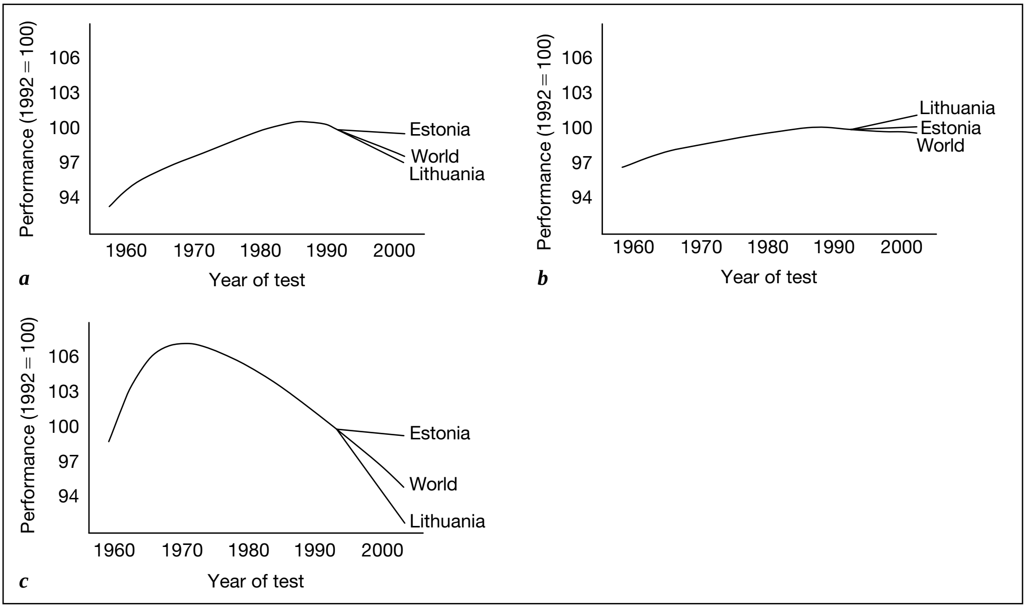


Fig. 2. Comparison of Estonian, Lithuanian and world time-related patterns of performance (standardised to 1992 = 100) for (***a***) power, (***b***) speed and (***c***) aerobic fitness tests. World data are from Tomkinson and Olds [this vol., pp. 46–66] and Tomkinson [4], and span the period 1958–2002, while Estonian and Lithuanian data span the period 1992–2002. Higher values indicate better performance.

change, table 2 allows the calculated changes in Eurofit test performance to be embedded in a European context. Using Eurofit data [8–35] from Tomkinson et al. [this vol., pp. 104–128], and the statistical procedures adopted in this study (see above 'Statistical Analysis'), secular changes were calculated for all country × age × sex × test groups, which included at least two country × age × sex × test × year of test reports spanning a minimum of five years. For comparative purposes, only secular changes for 11- to 17-year-old were considered. Therefore, in addition to the secular data presented on Baltic (Estonia and Lithuania) 11- to 17-year-old in this study, secular data were available for boys and girls of similar age from Northern (Iceland), Eastern (Poland), Southern (Italy and Spain) and Western (Belgium and France) Europe, tested using the Eurofit between 1985–2002.

Examination of table 2 shows that for some Eurofit tests, the secular changes among European countries are remarkably consistent (e.g. sit-and-reach,

Table 2. Summary of secular changes in Eurofit test performance of European children and adolescents (11–17 years)

Reference(s)	Country	Years	Sex	Age range	Number of samples	Δ % p.a. (SE)							
						FLB	PLT	SAR	SBJ	SUP	BAH	SHR	ESR
[8]	Belgium	1990–1997	M, F	12–17	585–862	−0.48 (0.05)	−0.78 (0.05)	−0.71 (0.05)	−0.31 (0.05)	−0.26 (0.05)	−0.72 (0.05)	−0.24 (0.05)	−0.32 (0.05)
[9–12]	France	1985–1998	M, F	11–12	203–549				−0.34 (0.13)	−1.79 (0.14)		+0.58 (0.14)	−0.44 (0.14)
[13]; Gunnarsson, pers. commun.	Iceland	1986–1999	M, F	11–15	351–754			−1.01 (0.07)	−0.59 (0.06)	−0.47 (0.07)	−2.93 (0.07)	+0.63 (0.07)	
[14–18]	Italy	1993–1998	M, F	12–14	616–993	+1.46 (0.07)	−0.45 (0.07)	−1.16 (0.07)	+0.17 (0.07)	−0.81 (0.07)	−0.25 (0.07)	+0.23 (0.07)	−0.36 (0.07)
[19–26]	Poland	1991–2001	M, F	11–17	69–4,499	−1.95 (0.09)	+0.05 (0.07)	−0.91 (0.07)	+0.26 (0.02)	+0.19 (0.02)	+2.83 (0.03)	+0.12 (0.07)	−1.18 (0.04)
[27–33]	Spain	1985–2000	M, F	11–17	392–1,147		−0.44 (0.05)	−1.72 (0.04)	+0.17 (0.05)	+0.83 (0.04)	+2.03 (0.05)	−0.80 (0.05)	
	Europe	1985–2002	M, F	11–17	69–4,499	−0.14 (0.03)	−0.29 (0.02)	−1.01 (0.02)	−0.03 (0.02)	+0.04 (0.02)	+0.60 (0.02)	−0.04 (0.02)	−0.56 (0.02)
This study	Estonia	1992–2002	M, F	11–17	241–502	−0.22 (0.07)	+0.01 (0.07)	−0.25 (0.07)	−0.04 (0.07)	+0.14 (0.07)	+0.19 (0.07)	+0.02 (0.07)	−0.07 (0.07)
This study	Lithuania	1992–2002	M, F	11–17	280–557	+0.49 (0.07)	0.00 (0.07)	−1.21 (0.07)	−0.30 (0.07)	+0.12 (0.07)	−0.27 (0.07)	+0.12 (0.07)	−0.84 (0.07)

The table shows the study reference, country, span of years over which testing took place, age range of the children tested, the range of sample sizes for each country × age × sex × test change, and the calculated $\sqrt{n}$-weighted mean change (Δ % p.a.) for eight Eurofit tests. The standard errors of the mean changes (SE) are shown in parentheses. Mean changes (and their SEs) are shown for flamingo balance (FLB), plate tapping (PLT), sit-and-reach (SAR), standing broad jump (SBJ), sit-ups (SUP), bent arm hang (BAH), 10 × 5 m agility shuttle run (SHR) and 20 m endurance shuttle run (ESR).

Note, the span of testing years and the age range of tested children are not consistent for all mean changes.

agility shuttle run and endurance shuttle run), while for others there is considerable variability (e.g. flamingo balance and bent arm hang). It is possible that those tests which show very large secular variability may reflect differences in test methodology (e.g. the scoring of bent arm hang performances requires some subjective judgment). Relative to other countries, the secular changes across of all Eurofit tests have been much more consistent in Estonian children. On average, there have been declines in balance, flexibility, speed and aerobic performance of European children, with improvements in upper body muscular endurance performance, and no change in power, speed agility and abdominal muscular endurance performance. Relative to mean European declines, the rate of decline in flexibility and aerobic performance was much less in Estonian children (note, there was a nonsignificant decline in aerobic performance in Estonia) and much greater in Lithuanian children. On the other hand, secular changes in abdominal muscular endurance performance of Estonian and Lithuanian children are similar to European changes, as are the changes in power performance for Estonian and European children. Despite a general European trend for poorer performances on speed tests, there has been no change over time in speed performance of Estonian and Lithuanian children.

Performance Comparisons with Other European Countries

While the main aim of this study was to quantify secular changes in Eurofit test performance, it was also of interest to compare the performances of Estonian and Lithuanian children and adolescents to those of other Europeans of similar age. Using data on 1,185,656 Eurofit test performances of children and adolescents from 23 European countries, Tomkinson et al. [this vol., pp. 104–128] reported that the performances of Estonian and Lithuanian boys and girls (those tested in 1992) was superior to their European peers on most Eurofit tests, with Estonian boys and girls the best performing endurance shuttle runners and Lithuanian boys the best performing flamingo balancers (fig. 3). On average, the Eurofit test performances of Estonian and Lithuanian children were +0.32 (range −0.06 to +1.05) and +0.22 (range −0.22 to +0.71) standard deviations above European means. Estonia was the 5th best performing country overall, and Lithuania the 7th best. While it is beyond the scope of this study to discuss why Baltic children typically outperform most other European children, the reader is referred to the chapter by Tomkinson et al. [this vol., pp. 104–128] for a discussion on the geographical variability in pediatric Eurofit test performances.

Though the data of Tomkinson et al. [this vol., pp. 104–128] represent the best available comparative Eurofit data, it should be borne in mind that comparisons were made using only data from the 1992 survey. Given that secular data were not available for all European countries for which Eurofit

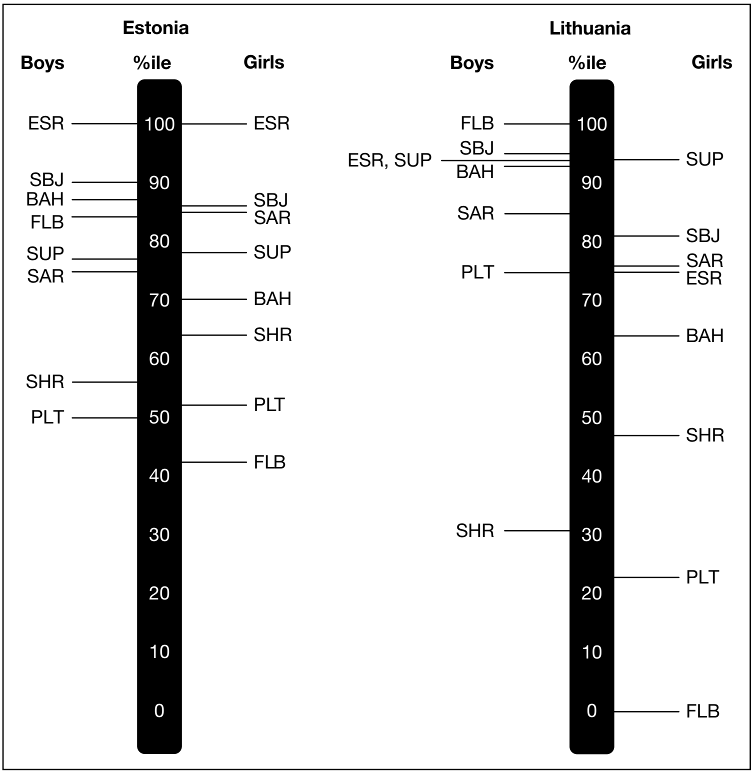


Fig. 3. Test-specific mean percentile values for Eurofit test performances in Estonian and Lithuanian boys and girls, relative to their peers from 21 European countries. Data are from Tomkinson et al. [this vol., pp. 104–128]. Higher percentile values indicate better performance. BAH = Bent arm hang; ESR = 20 m endurance shuttle run; FLB = flamingo balance; PLT = plate tapping; SAR = sit-and-reach; SBJ = standing broad jump; SHR = 10 × 5 m agility shuttle run; SUP = sit-ups.

data were available, time-related corrections of fitness test performances are impossible. It is acknowledged therefore, that the relative performances of Estonian and Lithuanian children reported by Tomkinson et al. [this vol., pp. 104–128] may differ somewhat if the 2002 data were used. For example, assuming time-related corrections based on the secular changes shown in table 2, Estonian children should still be ranked at the top for the endurance shuttle run, but the ranking for Lithuanian children (fig. 3) may drop somewhat, given that the secular decline in Lithuanian children is greater than the European average. This would also hold true for the relative rankings of children from other countries.

Methodological Issues

Ideally, a study examining secular changes in Eurofit test performance of Estonian and Lithuanian children and adolescents would compare large, nationally representative samples over time. Unfortunately, the samples used in this study cannot be regarded as nationally representative, given the convenient sampling method and use of only children from single-language schools resident in large cities. Nonetheless, they do represent urban children from both countries, and those who regularly participate in structured physical education. While some of these factors will produce performances unrepresentative of the general population, there is no evidence of systematic, time-related biases in these factors, so estimates of mean secular changes should not be biased. It is noteworthy that secular differences in power, speed and aerobic performance have been reported for urban and rural children (e.g. rural Chinese children fared consistently better over time than did their urban counterparts [3]), and the secular changes reported in this study, may not reflect those of the general pediatric Estonian and Lithuanian populations.

While sampling may be considered a weakness, a clear strength of this study is that data in both surveys were collected under precisely the same test conditions. All fitness testing was conducted indoors on identical ground surfaces, at the same time of day and year, using Eurofit test protocols administered by the same groups of trained personnel. As a result, factors such as motivation and peer dynamics are less likely to be systematically biased. Ultimately, this study presents the ‘best’ available secular data on the fitness test performance of Estonian and Lithuanian children and adolescents.

Conclusion

This study described recent secular changes in Eurofit test performance of children and adolescents from Estonia and Lithuania. It showed that secular changes in fitness test performance, while consistent between children of different ages and sexes, varied by test and were not always in line with European or global changes. It also showed that on average, Estonian and Lithuanian children outperform their European colleagues on fitness tests.

Acknowledgements

We would like to thank our colleagues at the Institute of Sport Pedagogy and Coaching Sciences (University of Tartu) and Department of Physical Education (Lithuanian Academy of Physical Education) for their help with testing.

References

1 Malina RM: Physical activity and fitness: pathways from childhood to adulthood. Am J Hum Biol 2001;13:162–172.

2 Williams PT: Physical fitness and activity as separate heart disease risk factors: a meta-analysis. Med Sci Sports Exerc 2001;33:754–761.

3 Tomkinson GR: Secular changes in fitness performance of Australasian children and adolescents; unpublished PhD thesis, University of South Australia, Adelaide, 2004.

4 Tomkinson GR: Global changes in anaerobic fitness test performance of children and adolescents (1958–2003). Scand J Med Sci Sports. In press.

5 Council of Europe: Eurofit: Handbook for the Eurofit Tests of Physical Fitness. Rome, Council of Europe, 1988.

6 Jürimäe T, Volbekiene V: Eurofit test results in Estonian and Lithuanian 11 to 17-year-old children: a comparative study. Eur J Phys Educ 1998;3:178–184.

7 Tomkinson GR, Léger LA, Olds TS, Cazorla G: Secular changes in the performance of children and adolescents (1980–2000): an analysis of 55 studies of the 20 m shuttle run in 11 countries. Sports Med 2003;33:285–300.

8 Lefèvre J, Bouckaert J, Duquet W: De barometer van de fysieke fitheid van de Vlaamse jeugd 1997: De resultaten. Sport (Bloso Brussel) 1988;4:16–22.

9 Baquet G, Berthoin S, Gerbeaux M, Van Praagh E: High-intensity aerobic training during a 10 week one-hour physical education cycle: effect on physical fitness of adolescents aged 11 to 16. Int J Sports Med 2001;22:295–300.

10 Brandet JP: Compte-rendu critique d'une campagne de tests d'aptitudes physiques chez des enfants (opération Eurofit). Proceedings of Activites Physiques, Sports: Journees d' automne, 1985, Beaune, ACAPS France, 1985, pp 4–5.

11 Cazorla G: Batterie France-eval: Mesures, épreuves et barêmes: évaluation des qualités physiques des jeunes Français d'âge scolaire: 7–11 ans. Rapport pour le Secrétariat d'Etat Auprès du Premier Ministre Chargé de la Jeunesse et de Sports. Paris, Ministère de la Jeunne et de Sports, 1987.

12 Van Praagh E, Lofi A, Brandet JP, Cazorla G: Evaluation of the Eurofit battery in French schools. 5th European Research Seminar on Testing Physical Fitness, Formia, 1986. Strasbourg, Council of Europe, 1987, pp 52–57.

13 Saemundsen G: Report on the Icelandic experimentation. 5th European Research Seminar on Testing Physical Fitness, Formia, 1986. Strasbourg, Council of Europe, 1987, pp 115–127.

14 Bellucci M: I test Eurofit nella scuola media Mameli di Roma. Alcmeone 1997;1:22–27.

15 Cilia G, Bellucci M: Eurofit: Tests Europei di attitudine fisica. Roma, Istituto Superiore Statale di Educazione Fisica, 1993.

16 Cilia G, Bellucci M, Riva M, Venerucci I: Eurofit 1995. Roma, Istituto Superiore Statale di Educazione Fisica, 1996.

17 Cilia G, Bellucci M, Bazzano C, Riva M: Eurofit 1997. Banche dati per la scuola. Alcmeone 1997;3:13–32.

18 Cilia G, Bazzano C, Bellucci M, Riva M, Annino G, Venerucci I, Riccardi R, Sicari M, Zarro I, Russo P, De Santis M, Ciamberlano P, Ciccarelli D, Selleri C, Chinellato L: I risultati dei test Eurofit nella scuola Matteuccii di Roma. Alcmeone 1998;2:16–20.

19 Czeczelewski J, Sklad M, Saczuk J, Raczynski G: Relationships between feeding manner, somatic features and physical fitness in children at adolescence. Biol Sport 2001;18:147–159.

20 Kusy K: Strength performance in 14-year-old boys from urban population against a background of their leisure time physical activity; in Komadel L (ed): Physical Education and Sports of Children and Youth. Proc Int Conf, Bratislava, 1995. Bratislava, Slovak Scientific Society for Physical Education and Sports, 1995, pp 32–34.

21 Maciaszek J, Osinski W: Poziom sprawnosci fizycznej u chlopców i dziewczat Poznanskich w wieku 10–14 lat. Rocz Nauk AWF Poznaniu 2001;50:3–17.

22 Mleczko E, Ozimek M: Rozwój somatyczny i motoryczny mlodziezy Krakowskiej miedzy 15 a 19 rokiem zycia z uwzglednieniem czynników srodowiskowych. Kraków, Akademia Wychowania Fizycznego, 2000.

23 Osinski W, Biernacki J: Sprawnosc fizyczna dzieci Poznanskich na tle ich rówiesników z wybranych krajów europejskich. Wychowanie Fizyczne Sport 1993;37:3–31.
24 Przeweda R: KBN Research Project No. 002–15. Warsaw, Akademia Wychowania Fizycznego, 1999.
25 Raczynski G, Czeczelewski J, Sklad M, Stupnicki R: Interrelationships among food intake, somatic traits, and physical fitness in 10.5- to 15.5-year-old children from eastern Poland. Int J Sport Nutr 1998;8:388–400.
26 Wilczewski A, Sklad M, Krawczyk B, Saczuk J, Majle B: Physical development and fitness of children from urban and rural areas as determined by Eurofit test battery. Biol Sport 1996;13: 113–126.
27 Brito Ojeda EM, Navarro Valdivielso M, García Afonso D, Sánchez García MJ, García Manso JM, Navarro García R, Ruiz Caballero JA: La condición física en la población escolar de gran Canaria (10–19 años). Las Palmas de Gran Canaria, Excmo. Cabildo Insular de Gran Canaria, 1995.
28 García Baena J: La condición fisica en la educación secundaria. Trabajo de investigación; diss., Madrid, Facultad de Educación, Universidad Nacional de Educación a Distancia, 1999.
29 Marrodán Serrano MD, Callejo Gea ML, Moreno-Heras E, González-Montero de Espinosa M, Mesa Santurino MS, Gordón Ramos PM, Fernández García F: Anthropometría nutricional y aptitud física en adolescentes urbanos de Madrid. Anal Españ Pediatr 1999;51:9–15.
30 Prat JA, Casamort J, Balagué N, Martínez M, Povill J-M, Sánchez A, Silla D, Santigosa S, Pérez G, Riera J, Vela JM, Portero P: Eurofit: La batería Eurofit en Catalunya. Barcelona, Secretaria General de l'Esport, 1998.
31 Sainz RM: Aptitudes psiquicas y fisicas: Estudio ed la aptitud fisica de los adolescentes de la provincia de Vizcaya y su relacion con la personalidad; diss., Bilbao, Facultad de Filosofia y Ciencias de la Educacion, Universidad de Deusto, 1992.
32 Sainz RM: La batería Eurofit en Euskadi. Vitoria-Gasteiz, Instituto Vasco de Educación Fisica, 1996.
33 Ureña Villanueva F: Valoración y baremación de la aptitud física en el alumnado de segundo ciclo de educación secundaria obligatoria de la comunidad autonoma de Murcia. Su utilización según los postulados de la reforma; diss., Murcia, Universidad de Murcia, 1996.

Prof. Toivo Jürimäe
Institute of Sport Pedagogy and Coaching Sciences
Center of Behavioral and Health Sciences, University of Tartu
18 Ülikooli Street
50090 Tartu (Estonia)
Tel. +372 7 375 372, Fax +372 7 375 373, E-Mail toivo.jurimae@ut.ee

Tomkinson GR, Olds TS (eds): Pediatric Fitness. Secular Trends and Geographic Variability.
Med Sport Sci. Basel, Karger, 2007, vol 50, pp 143–167

Evolution and Variability in Fitness Test Performance of Asian Children and Adolescents

Duncan J. Macfarlane[a], *Grant R. Tomkinson*[b]

[a]Institute of Human Performance, The University of Hong Kong, Hong Kong; [b]Centre for Applied Anthropometry, School of Health Sciences, University of South Australia, Adelaide, Australia

Abstract

Although Asia represents well over half of the world's population, the comparative lack of resources and infrastructure in many of these countries is likely to have contributed to only sporadic data being available to examine secular changes and geographical variability in the fitness test performances of Asian children and adolescents. Given the concerns that currently exist in the development of childhood obesity including, in many Asian countries, knowledge on the secular changes in nutrition and physical fitness and activity would seem germane to developing proactive public health strategies. The aim of this study therefore was to summarize existing literature reporting explicitly on secular changes in the fitness test performance of Asian children and adolescents, and where possible, comment on the geographical variability of such performances. Using a meta-analytical strategy, this study summarizes the secular changes in power, speed and cardiovascular endurance test performance of over 23.5 million 6- to 19-year-olds from seven Asian countries, tested between 1917 and 2003. In addition, it summarizes the geographic variability in fitness test performance of Asian children and adolescents within, and outside of, Asia. There has been very little change in the power and speed test performances of Asian children and adolescents in recent decades, yet alarmingly, there have been consistent declines in cardiovascular endurance fitness performance across all studied Asian nations over the past 10–15 years. Given the association between cardiovascular endurance fitness and numerous degenerative conditions (e.g. diabetes, obesity and metabolic syndrome), recent declines in cardiovascular endurance fitness performance of Asian children and adolescents should be an issue of major concern for public health authorities throughout Asia.

Physical fitness is widely considered to be an important component of health and has the benefit that it can be relatively easily measured given the existence of many well-known valid and reliable test batteries [1]. In this study, our concept of fitness will therefore not be restricted to the limited information provided by laboratory-based measures of peak aerobic power [2], but rather to include a variety of well known field-based performance tests, where a good lineage of data exists. Because physical fitness is significantly associated, at least in adults, with the risk of developing a variety of degenerative conditions, then any changes in the fitness of a nation are therefore likely to provide some insight into future changes in a nation's health. It is of concern then that in Asia, a continent containing 60% of the world's population, an apparent lack of resources and infrastructure is likely to have contributed to limited representative data being available to examine secular changes in the fitness, and by association the health, of its inhabitants. Recent concerns in the development of childhood obesity have been well documented [3], with many rapidly developing Asian countries succumbing to this problem [4], yet much of Asia has little representative data on the health and fitness of its children and adolescents. Fortunately, a number of Asian countries have accumulated and published representative data on fitness that are well suited to secular analysis, with the most extensive databases likely to be those of the Japanese, Korean and Singaporean Ministries of Education, which have annual fitness test data dating back several decades. Asian countries need to place a greater importance on the periodic collection and publication (e.g. every 3–5 years) of appropriate representative data on both the nutritional and physical fitness/activity habits of its population, as its subsequent analysis for secular changes would seem germane to developing proactive public health strategies throughout this highly populated and rapidly developing region of the world.

The aim of this study, therefore, is to examine existing datasets for secular changes and geographical variability in the fitness test performance of Asian children and adolescents.

Secular Changes in Fitness Test Performance

This study reviews studies that either have explicitly commented on secular changes in fitness test performances of normal Asian children and adolescents or have published data from which secular changes can be estimated. Studies were obtained from searching the Medline and Sports Discus databases, from the extensive doctoral research of Tomkinson [5], and the results from a global request posted on the Sportscience e-mail forum [6]. Only studies reporting on secular changes in power, speed and speed agility, cardiovascular endurance test performance, and peak oxygen uptake were considered. As the typically large surveys reported here could not be undertaken in highly controlled laboratory settings, most studies relied on well-known field tests of fitness. With the availability of a wide variety of field tests, secular data on similar field tests (i.e. tests which impose similar physiological demands on the participants' energy systems and which have typically been validated against criterion standards) were grouped by fitness component to provide a more comprehensive secular analysis. Secular changes in power were therefore estimated using single-jump tests (e.g. vertical jump, standing broad jump), in speed by sprint- and agility-running tests (e.g. 50 m sprint, 4 × 10 m agility run), and in cardiovascular endurance by distance-running tests (e.g. 1,000 m, 9 min run). These secular changes therefore reflect only changes in performances on tests commonly used to estimate power, speed and cardiovascular endurance. Other than the secular peak oxygen uptake data, these rubrics may not perfectly represent changes in the underlying physiological mechanisms – they are terms which broadly reflect common usage.

Because changes over short time periods can be quite labile, only studies reporting secular changes spanning a minimum measurement period of three years were considered. Unfortunately, this meant that some extensive and well-known cross-sectional studies [17, 18, 35, 36] were excluded from the analysis, because secular changes could not be calculated. A heavy reliance was placed on studies published in English, although several key datasets were kindly provided by local experts in countries such as Mainland China, Korea, Thailand, and Japan, where the original reports were not published in English.

Few studies systematically quantified the secular changes in fitness test performance, so descriptive summary data were analyzed to allow comparisons to be made. All rates of change in fitness test performance were calculated at the country × study × age × sex × test level using the procedures of Tomkinson and Olds [this vol., pp. 46–66]. Least-squares linear regression weighted by the square root of sample size ($\sqrt{n}$) was used to determine the regression coefficient, and hence the absolute rate of change. The square root of sample size was chosen as the weighting method because our confidence in the estimation of each group mean (i.e. the standard error) is proportional to the square root of the sample size. Unweighted least-squares linear regression was used to determine the regression coefficient if sample size (*n*) statistics were not reported. Relative rates of change [% change per annum (p.a.)] were determined by expressing the regression coefficient as a percentage of the respective $\sqrt{n}$-weighted group mean (if *n* was known) or the unweighted group mean (if *n* was not known). Ninety-five percent confidence intervals (CI) were calculated as the range spanning 1.96 standard errors either side of the mean performance change, with the standard error of a mean performance change estimated using procedures described in Tomkinson [5]. CIs could only be calculated for country × study × age × sex × test groups for which *n* was known. Negative values were used to indicate performance declines, and positive values performance improvements. It should be noted that while linear regression provides a consistent analysis method across studies, it is recognized that not all secular changes are linear.

This study summarizes the secular changes in at least 630 country × study × age × sex × test reports, on over 23.5 million 6- to 19-year-old Asians, tested between 1917 and 2003. The following sections describe the secular changes in the fitness test performances of children and adolescents from Mainland China, Hong Kong, Japan, Korea, Singapore, India and Thailand. Table 1 summarizes the studies and performance changes used in this analysis.

Mainland China

No published reports describing secular changes in the fitness test performance of Chinese children and adolescents were found. However, analysis of five national surveys of health and fitness of Chinese children and adolescents spanning 21 years [7–11], provides some information. In 1985 [8], 1991 [9], 1995 [10] and 2000 [11], nationally representative samples of Chinese 7- to 19-year-olds were tested for power on the standing broad jump, speed on the 50 m sprint, and cardiovascular endurance on the 400 (7- to 12-year-old), 800 (13- to 19-year-old girls) and 1,000 m runs (13- to 19-year-old boys). In the 1979 [7] national survey, Chinese of similar age and sex were tested on the standing broad jump and 400 m run. Height and mass were recorded in all five surveys. In total, performance test data were available on 1,181,600 Chinese from both urban and rural areas.

In general, power and speed test performances improved over time, while cardiovascular endurance test performances declined. Power test performances improved at an average rate of +0.44% (CI +0.43% to +0.45%) per annum p.a., while speed test performances improved at +0.10% (CI +0.09% to +0.11%) p.a. On the other hand, declines in the 400, 800 and 1,000 m runs were observed, averaging −0.28% (CI −0.29 to −0.27%) p.a. Concurrent increases in body mass index (BMI) were also observed over the 21-year period. Rural Chinese performed consistently better over time, with rates of improvement in power and speed test performance greater, and rates of decline in cardiovascular endurance test performances less than those of their urban counterparts. However, when a 3rd-order polynomial was fitted to the data (anchored at 1991 = 100), it appears that since 1995, power test performances have started to decline (fig. 1), while declines in cardiovascular endurance test performances have accelerated (fig. 2).

Two relatively recent papers [12, 13] report identical datasets on the peak aerobic power of children and adolescents in China. The researchers aimed at collecting data from 150 students in one primary school and 350 students in two secondary schools in Beijing, using a stratified cluster sampling procedure. Using a Bruce treadmill protocol together with a Jaeger Ergo-Oxyscreen, metabolic data were collected on 215 males and 248 females, aged 10–19 years. Lin and

Table 1. Summary of the studies and performance changes used in this analysis

Ref.	Country	Years	Sex	Age range years	Sample No.	Power		Speed		CVE	
						test(s)	Δ % p.a. (SE)	test(s)	Δ % p.a. (SE)	test(s)	Δ % p.a. (SE)
7–11	China	1979–2000[a]	M, F	7–19	10,898–23,868	SBJ	+0.44 (0.005)	50 m	+0.10 (0.005)	400 m, 800 m, 1,000 m	−0.28 (0.005)
20	Hong Kong	1998–2003	M, F	12–19	381–694					9 min	−0.95 (0.06)
21	Japan	1917–1969	M, F	8–18	ND	SBJ	−0.10[d]	50 m, 100 m	−0.13[d]	5 min	+0.06[d]
22	Japan	1984–1993	M, F	10–19	8,963–18,831	RBJ, VJ	−0.20 (0.005)	50 m	−0.06 (0.01)	1,000 m, 1,500 m	−0.25 (0.01)
23	Japan	1968–1989	M, F	12, 18	512–895			50 m	−0.06 (0.09)	1,000 m, 1,500 m	−0.23 (0.11)
24	Japan	1964–1997	M, F	11, 14, 17	7,693–12,360	RBJ, VJ	+0.36 (0.005)[c]	50 m	+0.16 (0.01)[c]	1,000 m, 1,500 m	+0.13 (0.01)[c]
26	Korea	1978–1986	M, F	G9, G12	1,944–1,951	SBJ	+0.16 (0.08)	100 m	+0.07 (0.08)	800 m, 1,000 m	−0.36 (0.08)
27	Korea	1988–1998	M, F	6–17	834–1,265	SBJ	–0.68 (0.03)	50 m	−0.33 (0.03)	1,200 m	−1.16 (0.04)
28	Korea	1968–1984	M, F	10–17	441,482–2,746,884					600 m, 800 m, 1,000 m	−0.05 (0.002)
28	Korea	1985–2000	M, F	10–17	17,614–20,914					600 m, 800 m, 1,000 m	−0.88 (0.005)
29	Singapore	1980–1992	M, F	12–19	132–393	SBJ	+0.25 (0.08)	SHR4 ×10	+0.41 (0.08)	2,400 m	−0.16 (0.08)
33	Thailand	1990–2003	M, F	8–12	2,926[b]	SBJ	−0.81 (0.03)	50 m	−0.50 (0.03)		

For each study, the country and span of measurement years, the sex and age range of the children and adolescents tested, the range of sample sizes for each country × age × sex × test group, the fitness tests, the mean power-, speed- and cardiovascular endurance-related performance changes (Δ % p.a.), and the standard errors of the mean changes (SE), are shown.

CVE = Cardiovascular endurance; M = male; F = female; G = grade (see Age range, years); ND = not determined.

50 m = 50 m sprint; 100 m = 100 m sprint; 400 m = 400 m run; 600 m = 600 m run; 800 m = 800 m run; 1,000 m = 1,000 m run; 1,200 m = 1,200 m run; 1,500 m = 1,500 m run; 2,400 m = 2,400 m run; 5 min = 5 min run; 9 min = 9 min run; RBJ = running broad jump; SBJ = standing broad jump; SHR4 ×10 = 4 × 10 m agility shuttle run; VJ = vertical jump.

[a] Secular changes for speed span the period 1985–2000.

[b] Values derived from reported descriptive summary data.

[c] Secular changes reported as a composite score but shown here as the secular changes for individual fitness components.

[d] SEs not shown because sample size statistics were not available.

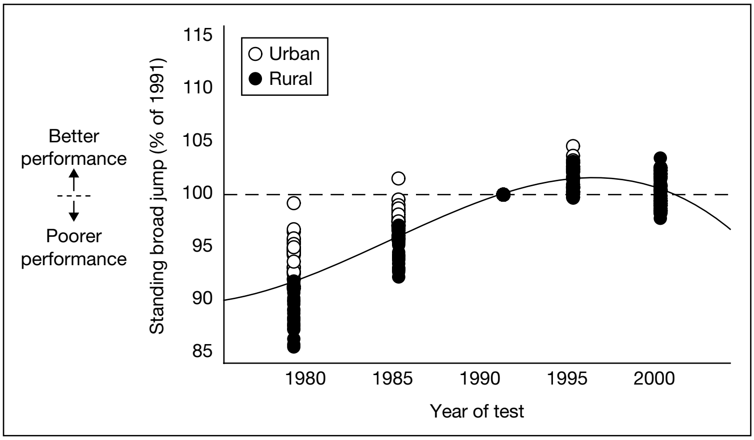


Fig. 1. Secular changes in the standing broad jump of Chinese youths aged 7–19 years (standardized to 1991 = 100). Each point represents a single age × gender × year report. Higher values indicate better performance. Open circles indicate urban dwellers, closed circles indicate rural dwellers, and the solid line represents a third-order polynomial fitted to all points.

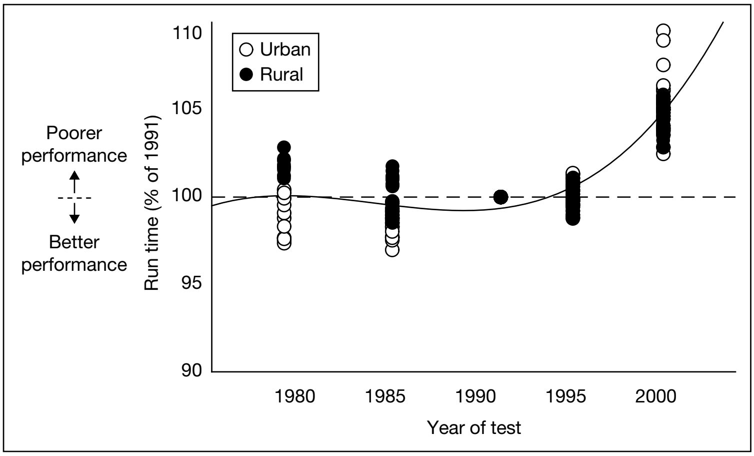


Fig. 2. Secular changes in the 400/800/1,000 m run times of Chinese youths aged 7–19 years (standardized to 1991 = 100). Each point represents a single age × gender × year report. Lower values indicate better performance. Open circles indicate urban dwellers, closed circles indicate rural dwellers, and the solid line represents a third-order polynomial fitted to all points.

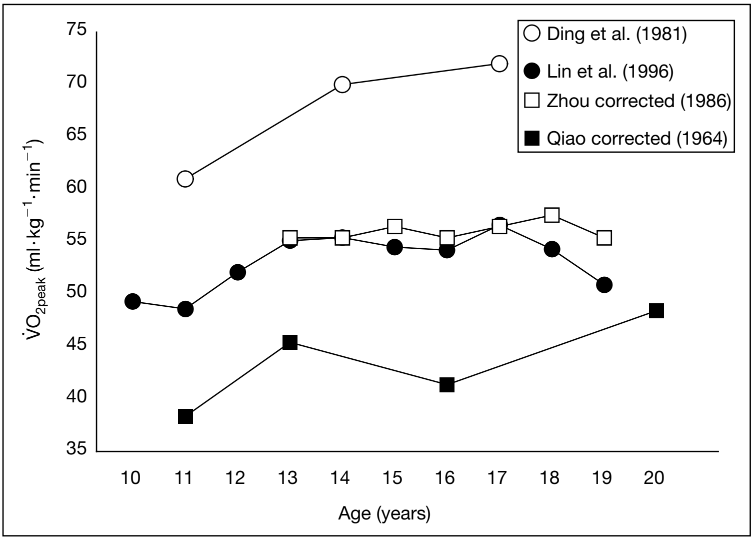


Fig. 3. Comparison of peak oxygen uptake recorded from four studies on Chinese male children and adolescents. Adapted from Lin et al. [12] with permission of Wiley-Liss, Inc., a subsidiary of John Wiley and Sons, Inc.

colleagues [13] made comparisons with other peak oxygen uptake data collected on boys in Beijing by Qiao [14] (reported as using 'running in place'), Zhou and Lu [15] (reported as using cycle ergometry) and Ding et al. [16] (treadmill ergometry). The extremely high values reported by Ding et al. [16] exceeding 70 ml · kg^{-1} · min^{-1} in both the 14- and 17-year-old boys, suggest these data may not be representative of a normal school population. The lower values reported in the other three studies appear likely to be more representative, and also show a gradual improvement in aerobic power across all ages from 1964 to 1986, and then to 1996 (fig. 3). However, as mentioned by Lin et al. [12] the slightly higher values of aerobic power may in part reflect the expected higher values found using treadmill ergometry when compared to cycle or stepping protocols. Though peak oxygen uptake data on girls are lacking, it appears that little has changed since the mid-1980s [12].

Hong Kong

Only over relatively recent years have standardized measurement techniques been employed in Hong Kong to be able to assess secular changes. One of the earliest and most comprehensive fitness studies on children and adolescents was performed by the Chinese University of Hong Kong, in conjunction with Michigan University, using the nine-item Asian Committee's Standardized

Physical Fitness Test [17]. The resulting normative data from 9,770 students aged 10–18 years were then used in 1991 to promote the Physical Fitness Award Scheme for Secondary Schools by the Education Department and the Hong Kong Childhealth Federation. After the formation of the Hong Kong Sport Development Board in 1991, an even larger survey [18] of 20,304 Hong Kong school children was performed. This study used the Asian youth version of the International Council for Health, Physical Education, Recreation, Sports and Dance (ICHPER.SD-Asia) health-related fitness test that was adopted in 1989 by a regional meeting of ICHPER.SD-Asia [19] and the data subsequently used to update the School Fitness Award Schemes norms.

In 1998–1999 and 2002–2003, the Physical Education Section of the Education Department, aided by the Hong Kong Physical Fitness Association, conducted two territory-wide surveys of Hong Kong secondary schools. Data were collected on approximately 300 students at the age × sex level, resulting in nearly 5,000 students in each study [20]. Changes could be determined in cardiovascular endurance (9 min timed run), and abdominal (sit-ups) and upper body strength (push-ups). There were consistent declines in all fitness tests (which were greater for boys than for girls), with the 9 min run performances declining at an average of −0.95% (CI −1.06 to −0.84%) p.a.

Japan

In Japan, there has been a long history of research tracking changes in fitness test performance of children and adolescents. The first Japanese study examining secular changes in fitness performance was by Ikai and Fukunaga [21], which looked at the evolution of power, speed and cardiovascular endurance performance over the period 1917–1969. In this study, performances on the standing broad jump, 50 m (girls) and 100 m (boys) sprint and 5 min run tests were compared between 1917 and 1969 in Japanese 8- to 18-year-olds. Performances over time were relatively stable in all tests, the exception being boys' 100 m sprint performances. Over the period 1929–1969, standing broad jump performance declined at an average rate of −0.10% (range −0.36 to +0.08%) p.a. There was little change in the 50 m sprint, with age × sex changes ranging from a decline of −0.11% p.a. to an improvement of +0.22% p.a. (average +0.04% p.a.). In the 100 m sprint, however, performance declined, averaging −0.31% (range −0.54 to −0.12%) p.a. Performance changes in the 5 min run were small, increasing at an average rate of +0.06% (range −0.13 to +0.20%) p.a.

Using large datasets from the Japanese Ministry of Education, Culture, Sports, Science and Technology's annual nation-wide survey of physical fitness and athletic ability, Matsuura [22] described the secular changes in body size and fitness performance of 10-, 13-, 16- and 18-year-old Japanese students between 1984 and 1993. Every year since 1964, a national survey of physical fitness and athletic ability has been conducted in Japan, using the same tests and sampling procedures, on children and adolescents aged 10–19 years. Each year, about 1,000 students per age × sex × test group are tested on a battery of 14 fitness tests – seven which mark physical fitness and seven athletic ability. The fitness test battery includes tests measuring power (the vertical and running broad jumps), speed (50 m sprint) and cardiovascular endurance (the 1,000 m run for girls and the 1,500 m run for boys), as well as flexibility (trunk flexion and extension), and muscular strength (back and grip strength). Height and mass are also measured annually.

Fitness performance generally declined across the period 1984–1993. Vertical jump performance declined at an average rate of −0.08% (CI −0.10 to −0.06%) p.a. The average rate of decline was four times larger in the running broad jump, averaging −0.32% (CI −0.34 to −0.30%) p.a. Secular changes in the 50 m sprint for speed were similar to those observed for the vertical jump for power, averaging −0.06% (CI −0.08 to −0.04%) p.a. Rates of decline in cardiovascular endurance tests on the other hand were similar to those observed in the running broad jump. On average, 1,000 and 1,500 m distance run performance declined at the average rate of −0.25% (CI −0.27 to −0.23%) p.a. Moreover, Japanese children and adolescents in 1993 were taller, heavier, less flexible and weaker than their counterparts were in 1984.

A mixed-longitudinal study of Japanese students enrolled in a single Tokyo secondary school examined the secular changes in running performance and developmental patterns [23]. Anthropometric and fitness tests were administered in physical education classes to first year students in late May each year, from 1968 to 1989 inclusive. At the time of testing, first-year students were 12 years of age. Students were tested annually over the duration of their 6-year stay at the school. Changes in speed (50 m sprint) and cardiovascular endurance (the 1,000 m run for girls and the 1,500 m run for boys) performance were reported for first-year (12-year-old) and final-year (18-year-old) students over the 21-year period. In total, 1,720 students were tested for speed, and 1,028 for cardiovascular endurance. Over the period 1968–1989, 50 m sprint performance remained stable at −0.06% (CI −0.23 to +0.11%) p.a., while distance run test performance declined at −0.23% (CI −0.45 to −0.01%) p.a.

To examine the effects of physical education on health promotion in Japanese students, Noi and Masaki [24] analyzed the physical fitness (n = 218,540) and athletic ability (n = 233,287) test results of 11-, 14- and 17-year-olds over a 34-year period, from 1964 to 1997. The 11-year-olds represented students from elementary school, the 14-year-olds from junior high school and the 17-year-olds from full-time senior high school. Data came from the annual nationwide survey of physical fitness and athletic ability conducted by the Ministry of Education, Culture, Sports, Science and Technology over 1965–1998. Changes in ‘overall’ physical fitness and athletic ability (scaled, composite scores from seven tests of physical fitness and seven tests of athletic ability, respectively) were reported. Performance in the vertical jump test (power), as well as tests of flexibility, and muscular strength and endurance, contributed to overall physical fitness. For athletic ability, performance in the running broad jump (power), 50 m sprint (speed), and 1,000 m (girls) and 1,500 m (boys) runs (cardiovascular endurance) all played a part.

Noi and Masaki [24] reported that educational practice throughout Japan was set by the government-issued ‘Guideline for Teaching’ and is bound by law. Since the end of the Second World War, school physical education has been revised almost every decade, with ‘systematic athletic exercise’ emphasized in physical education in the 1960s, ‘physical fitness’ in the 1970s, ‘play’ in the 1980s and ‘pleasurable play’ in the 1990s. The authors examined secular changes in overall physical fitness and athletic ability over each ‘Guideline for Teaching’ period. Changes in overall physical fitness and athletic ability were markedly similar in the direction of change, yet somewhat different in the magnitude of change. Overall physical fitness improved in the 1960s (+0.71% p.a.) and 1970s (+0.28% p.a.), changed little in the 1980s (−0.01% p.a.), and declined in the 1990s (−0.26% p.a.). In athletic ability, large improvements were seen in the 1960s (+1.90% p.a.) and smaller improvements in the 1970s (+0.39% p.a.), but declines of −0.38 and −0.91% p.a. in the 1980s and 1990s, respectively (fig. 4). The changes in each decade were similar in boys and girls. Interestingly, 100% (12 of 12) of the age × sex reports for overall physical fitness and athletic ability in the 1960s were improvements. In the 1970s and 1980s, the respective figures were 83% (10 of 12) and 50% (6 of 12). In the 1990s all reports were declines.

Few data are available to allow examination of secular changes in peak oxygen uptake in Japanese children. A study by Miyashita and Sadamoto [25] compared peak oxygen uptake data ($ml \cdot kg^{-1} \cdot min^{-1}$) taken from two previous reports of Japanese 10- to 12-year-olds collected in 1969 and 1978–1979. All age × sex reports showed declines, ranging from a minimum of −0.63% p.a. to a maximum of −1.96% p.a., at an average of −1.24% p.a. Figure 5 contrasts the peak oxygen uptake of Japanese 10- to 12-year-olds in 1969 and 1978–1979.

Korea

Three studies reporting on secular changes in fitness test performance of Korean children and adolescents were obtained. The first of these Korean studies contrasted the fitness test performances of over 1,900 randomly selected public school students (grades 9 and 12) tested on the Korean Student Physical Fitness Test (KSPFT) in 1978, 1979 and 1986 [26]. Though the KSPFT has changed over the years, several consistent test items, at least over the 1978–1986 period, were the standing broad jump (power), 100 m sprint (speed),

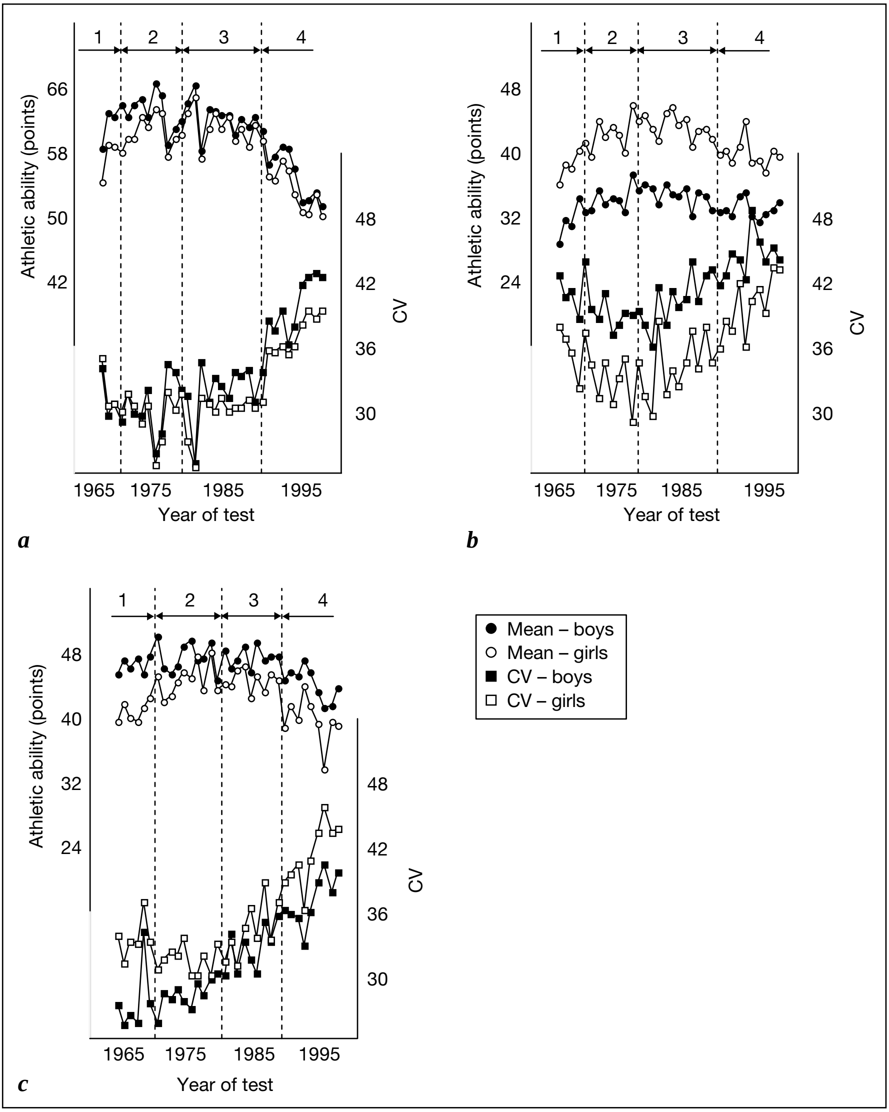


Fig. 4. Secular changes in means (circles) and coefficients of variation (CV, squares) of overall scores of athletic ability for (***a***) 11-year-old, (***b***) 14-year-old, and (***c***) 17-year-old Japanese students. The closed circles indicate the mean scores for boys, the open circles mean scores for girls, the closed squares CVs for boys, and the open squares CVs for girls. The 'Guideline for Teaching' periods are also shown, with (1) indicating the period emphasizing 'systematic athletic exercise', (2) 'physical fitness', (3) 'play', and (4) 'pleasurable play'. Adapted from Noi and Masaki [24] with permission from the Oxford University Press.

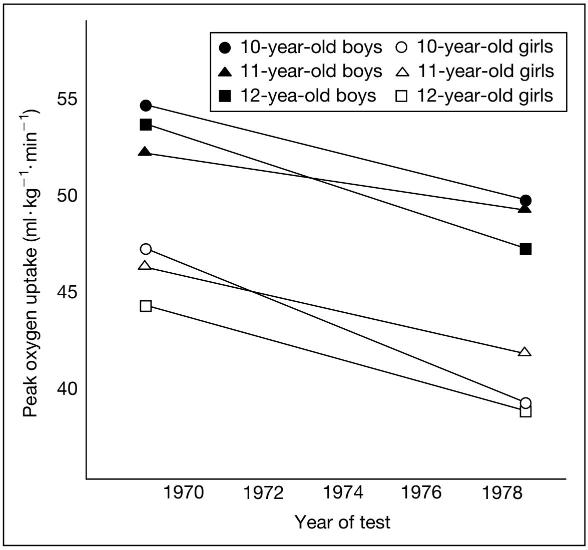


Fig. 5. Comparison of peak aerobic power in Japanese children aged 10–12 years between 1969 and 1978–1979. Adapted from Miyashita and Sadamoto [25] with permission from Edizioni Minerva Medica.

and the 800 m (girls) and 1,000 m (boys) runs (cardiovascular endurance). In general, power and speed test performance improved, while cardiovascular endurance test performance declined. Between 1979 and 1986, there was an improvement in the standing broad jump [+0.16% (CI +0.01 to +0.31%) p.a.] and stability in the 100 m sprint [+0.07% (CI −0.08 to +0.22%) p.a.]. In contrast, performance declines were observed in the distance runs, averaging −0.36% (CI −0.51 to −0.21%) p.a.: −0.44% (CI −0.65 to −0.22%) p.a. for boys (1,000 m) and −0.28% (CI −0.50 to −0.07%) p.a. for girls (800 m).

The Korean Ministry of Culture and Tourism reported the findings of their five national surveys of physical fitness conducted between 1988 and 1998 [27], and whose aims included the examination of secular changes in physical fitness of Korean students. Stratified, proportional samples of Koreans aged 6−17 years from all 15 provinces were tested in 1988, 1989, 1992, 1995 and 1998. A total of 30,227 Koreans were tested over the 10-year period for power (standing broad jump), speed (50 m sprint) and cardiovascular endurance (1,200 m run), in addition to muscular strength and endurance (push-ups and sit-ups) and flexibility (sit-and-reach). Height and mass were also measured. Over the decade, standing broad jump performances declined at an average rate of −0.68% (CI −0.74 to −0.62%) p.a., with running performances also declining, averaging −0.33% (CI −0.39 to −0.27%) p.a. for the 50 m sprint and −1.16% (CI −1.24 to −1.08%) p.a. for the 1,200 m run. Furthermore, Koreans were taller, heavier, less flexible and had improved muscular strength and endurance in 1998 than in 1988.

A study by Tomkinson et al. [28] described the secular changes in the cardiovascular endurance test performances of 22,127,265 6- to 18-year-old Koreans tested between 1968 and 2000 on runs ranging in distance from 600 to 1,200 m. Distance run data from six studies, plus the very large datasets from the Korean Ministry of Education, and Ministry of Culture and Tourism, were collated, with secular changes examined pre- and post-1985 (note, the changes reported here only reflect those of 10- to 17-year-old tested on the 600, 800 and 1,000 m runs). The secular change in fatness (operationalized as BMI) was also investigated. Prior to 1985, the cardiovascular endurance performance of Korean children and adolescents declined slightly, at an average rate of −0.05% (CI −0.05 to −0.05%) p.a. (note, due to very large sample sizes, the estimated standard errors, and hence the confidence intervals, are extremely small). However, after 1985, the rate of decline was much greater, averaging −0.88% (CI −0.89 to −0.87%) p.a. (fig. 6). The post-1985 declines in cardiovascular endurance performance are similar to those reported by the Ministry of Culture and Tourism [27]. The pattern of change in BMI was similar in magnitude, but opposite in direction (i.e. increases in BMI over time).

Singapore

A paper presented by Menon's group in 1993 at the International Sports Science Conference in Singapore [29] provides some insight into the secular changes in fitness test performances of young Singaporeans. This study compared the Singapore Sports Council's National Physical Fitness Award (NAPFA) norms, developed in 1980–1981, to the revised norms generated over a decade later in 1991–1992. The original NAPFA norms involved 1,800 Singaporeans of all ages [30] while the revised norms used a random, cluster sample of 3,263 students aged 12–19 years. Comparisons between 1980–1981 and 1991–1992 were made on fitness tests measuring power (standing broad jump), speed agility (4 × 10 m agility shuttle run) and cardiovascular endurance (2.4 km run), as well as flexibility (sit-and-reach) and muscular strength and endurance (sit-ups, pull-ups and the inclined bent arm hang). Over the 12-year period, the standing broad jump performances improved at an average rate of +0.25% (CI +0.09 to +0.41%) p.a. Improvements were greater in the 4 × 10 m agility shuttle run though, with an average rate of improvement of +0.41% (CI +0.25 to +0.57%) p.a., whilst in the 2.4 km run, the pattern of change was reversed, with performances declining at an average rate of −0.16% (CI −0.32 to 0.00%) p.a. Although the Ministry of Education in Singapore annually updates a superb health-related

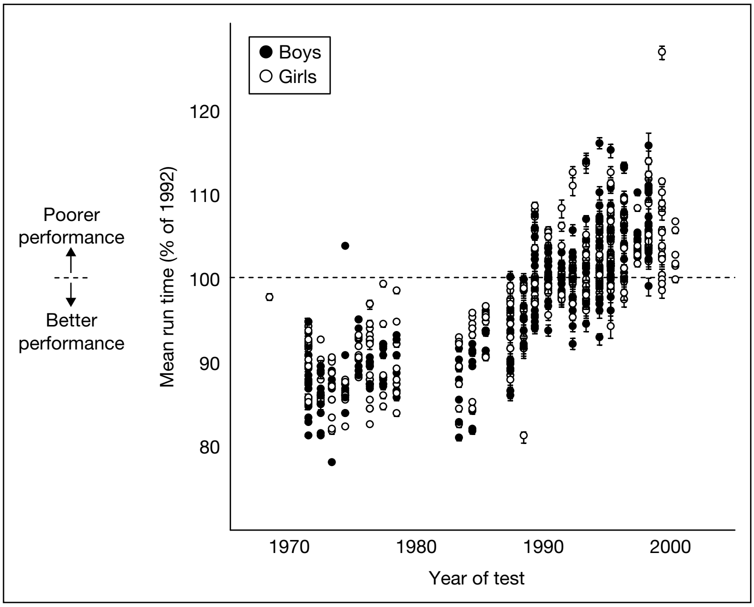


Fig. 6. Scatterplot of mean run times in Korean youths (standardized to 1992 = 100) against year of testing. Each circle represents a single age × sex × year of test × test report. Higher values indicate poorer performance. The closed circles indicate boys and the open circles girls. The error bars are the standard errors. Note that some errors bars are not visible because the standard errors are so small (i.e. sample sizes are very large). Adapted from Tomkinson et al. [28] with permission from Georg Thieme Verlag.

fitness database on its schoolchildren, it was not possible to access these data in order to analyze more recent secular changes.

India

There were no articles that focused on secular fitness changes of Indian children, and only a small number of articles published in English that reported on their cardiovascular fitness levels (as measured by peak aerobic power). Two relatively recent papers [31, 32] reported data collected from Jaeger metabolic equipment, using cycle and treadmill ergometry, respectively. Khanna et al. [32] presented a cross-sectional analysis of 777 children training for high-level sport, together with 209 untrained schoolchildren of 10–16 years of age throughout India. They did not differentiate the results between boys and girls, but provided a comprehensive comparison with a variety of international counterparts. In comparison, Dey and Debray [31] reported data from 394 boys aged 8–14 years from three stages in the Eastern Region and five states in the

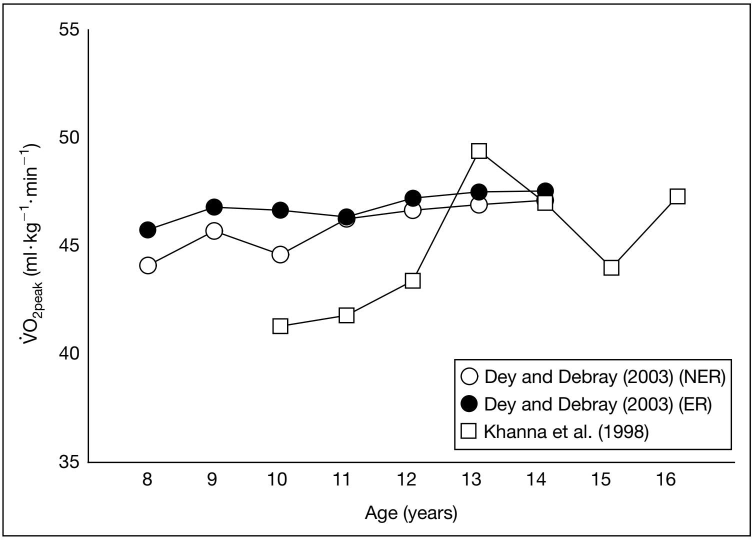


Fig. 7. Comparison of the peak aerobic power data on 209 untrained Indian schoolchildren (boys and girls combined together) [32], and on 394 boys from the Eastern Region (ER) and North-Eastern Region (NER) of India [31].

North-East region, using equipment based at the Sports Authority of India, Kolkata. A similar comprehensive comparison of their data was made with children from 11 other international countries. Figure 7 summarizes the results of these two studies and shows the peak aerobic power of the Indian boys in 2003 was comparable to the 1986 and 1996 data on Chinese boys (fig. 3).

Thailand

As part of his doctoral research into the socio-demographic distribution of health-related fitness of Thai children, Klanarong [33] compared his national survey of 5,970 randomly sampled 6- to 12-year-old tested in 2003 with three previous national surveys of physical fitness of Thai children in 1990 (n = 18,000), 1995 (n = 12,000) and 1997 (n = 12,000). All surveys examined physical fitness using the International Committee for the Standardization of Physical Fitness Tests (ICSPFT) fitness test battery [34]. Secular changes were reported on those aged 8–12 years and across fitness tests measuring power (standing broad jump), speed (50 m sprint), upper body strength (hand-grip strength), and abdominal strength and endurance (sit-ups in 30 s).

Over the 13-year period, power test performance declined at an average rate of −0.81% (CI −0.86 to −0.76%) p.a. A smaller decline was observed in speed test performance, with an average rate of decline of −0.50% (CI −0.55 to −0.45%) p.a. Declines were also observed for abdominal strength and endurance, with improvements in upper body strength. The author noted that an oversampling of private school and urban children, and an undersampling of rural children in the 2003 study, could lead to spurious conclusions regarding secular changes.

Geographic Variability in Fitness Test Performance

There have been few reports that have commented on the geographic variability in the fitness test performance of Asian children. Of the 11 located, only two [35, 36] commented on the variability within Asia, with the remainder making international comparisons. This section will focus primarily on the studies examining the variability within Asia.

Comparisons within Asia

In response to a call for comparisons of fitness test performance among Asian children, pilot data using the eight-item ICSPFT fitness test battery were collected on children aged 7, 12 and 18 years, from seven Asian countries [36]. Data were available from Hong Kong, Japan, Korea, the Philippines, Taiwan, Thailand and Vietnam. A total of 3,200 children were tested between 1969 and 1971, with at least 40 subjects tested in age × sex × test group.

To quantify the variability in fitness test performance of children among the seven Asian countries examined, an overall ‘Performance Index’ was calculated using the procedures outlined in Olds et al. [37]. Briefly, the ‘Performance Index’ is calculated by (a) generating pseudo data from reported means and standard deviations (SDs) using a Monte Carlo simulation, (b) for each fitness test, performances are then expressed as z-scores relative to all children of the same age and sex from all countries, and (c) averaging the age × sex × test-specific z-scores for all children from that country. Note that the overall ‘Performance Index’ was determined using only data from seven of the eight fitness tests, because the protocol for lower trunk flexibility varied among countries.

There was considerable variability in fitness test performance of Asian children. Overall, the best performing country was Japan (table 2). Japanese children were 0.6 SDs above the overall Asian average. They ranked first in five of the seven fitness tests, and second in the remaining two. Children from Hong Kong, Taiwan, Korea and Thailand were middle-ranked, while their counterparts from the Philippines and Vietnam performed the worst. Filipino and Vietnamese children were about 0.3–0.5 SDs below the overall Asian average, with Vietnamese children producing the poorest performances in 5 of the 7 tests.

The magnitude of differences among countries is shown in figure 8, using the relative performances of 18-year-old girls tested on (a) the 800 m distance

Table 2. Performance Index values (mean age × sex × test-specific z-scores) for 7-, 12- and 18-year-olds from seven Asian countries tested in 1969–1971

Country	Performance Index (SE)							
	BAH/PUP	HGR	RUN	SBJ	SHR	SPR	SUP	Z-AVE
Japan	0.19 (0.05)	0.94 (0.04)	0.79 (0.04)	0.76 (0.05)	0.56 (0.04)	0.61 (0.03)	0.47 (0.04)	0.62 (0.02)
Hong Kong	−0.42 (0.08)	0.01 (0.09)	−0.06 (0.04)	0.43 (0.09)	0.74 (0.08)	0.24 (0.08)	−0.08 (0.09)	0.11 (0.03)
Taiwan	0.04 (0.03)	0.13 (0.03)	−0.10 (0.03)	−0.11 (0.03)	−0.05 (0.02)	0.17 (0.02)	0.30 (0.02)	0.05 (0.01)
Korea	−0.07 (0.02)	−0.26 (0.03)	−0.33 (0.02)	0.20 (0.03)	−0.09 (0.03)	−0.25 (0.04)	−0.60 (0.03)	−0.11 (0.01)
Thailand	−0.55 (0.04)	−0.23 (0.05)	−0.53 (0.05)	−0.21 (0.04)	−0.02 (0.06)	−0.21 (0.05)	0.38 (0.05)	−0.17 (0.02)
Philippines	−0.34 (0.04)	NA	0.11 (0.08)	−0.23 (0.07)	−0.04 (0.07)	−0.74 (0.07)	−0.47 (0.06)	−0.30 (0.03)
Vietnam	0.69 (0.09)	−0.94 (0.04)	−0.95 (0.08)	−0.49 (0.04)	−0.23 (0.07)	−0.47 (0.07)	−0.87 (0.06)	−0.46 (0.03)

Data are from Meshizuka and Nakanishi [36]. Performance Indices are shown for the following tests: bent arm hang and pull-up (BAH/PUP); hand-grip strength (HGR); 800 m and 1,000 m distance runs (RUN); standing broad jump (SBJ); 40 m agility shuttle run (SHR); 50 m sprint (SPR); and, sit-ups in 30 s (SUP). The overall Performance Index value (Z-AVE) is also shown. Standard errors (SE) are shown in parentheses.

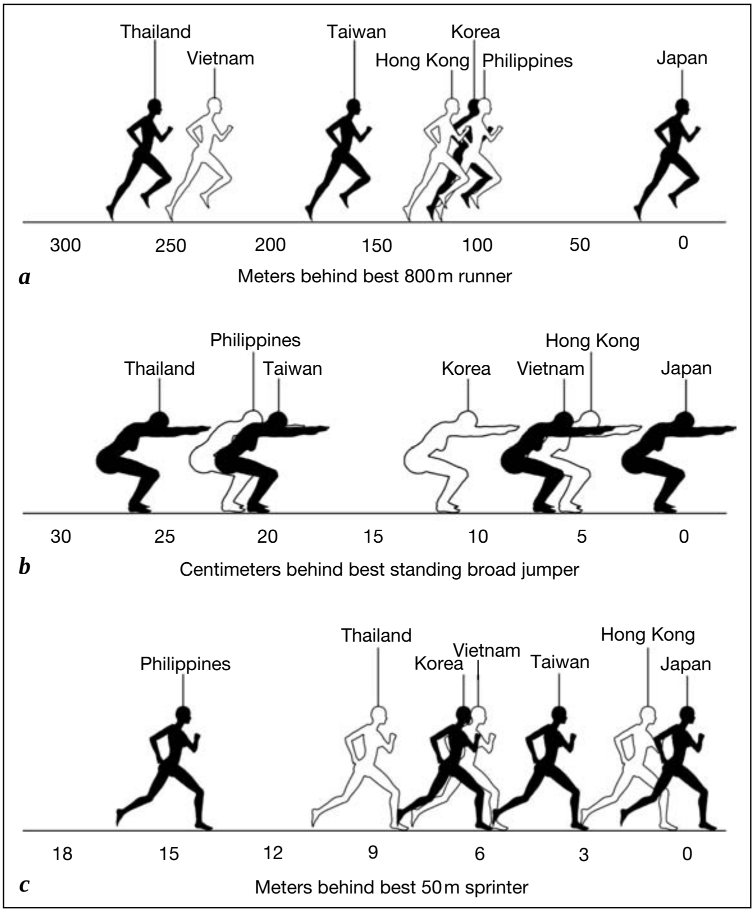


Fig. 8. The magnitude of differences in Asian children's fitness test performance in 1969–1971. Shown are the average values for 18-year-old girls from Hong Kong, Japan, Korea, the Philippines, Taiwan, Thailand and Vietnam. ***a*** Distance (m) the average child from the represented countries would finish behind the fastest 800 m average. ***b*** Distance (cm) behind the best standing broad jump average. ***c*** Distance (m) behind the fastest 50 m sprint average.

run, (b) the standing broad jump, and (c) the 50 m sprint tests. The Japanese were consistently the best performers, varying between 3 and 10% better than their nearest rival.

Twenty-five years after the Meshizuka and Nakanishi [36] study, a second study examining the geographical variability in fitness test performance of Asian children was published. Fitness test data were collected over the period 1991–1995 on 10- to 17-year-old students from Japan (n = 2,149), Mainland

China (n = 3,168), Hong Kong (n = 20,304) and Macau (n = 1,547), using the ICHPER.SD-Asia fitness test battery [35]. Although the primary purpose of developing the ICHPER.SD-Asia tests was to encourage greater interest in health and fitness and not to provide data to compare among countries, this study remains unique in its size and scope. Comparisons were made on tests measuring cardiovascular endurance (distance runs ranging from 800 m to 1,500 m), abdominal and upper body strength and endurance (sit-ups and pull-ups), and lower trunk flexibility (sit-and-reach). The authors concluded that the Mainland Chinese children performed the best overall, with children from Hong Kong and Japan similar and middle-ranked, and children from Macau the poorest performers. The superiority of Mainland Chinese relative to children from Hong Kong has also been highlighted by Hong and Chan [38], who showed that Mainland Chinese children were superior in tests measuring strength and cardiovascular endurance.

International Comparisons

Nine reports using data collected in the 1950s and 1960s (4) and 1990s (5) were located which compared Asian children to their international counterparts. The postgraduate dissertations of Tcheng [39] and Ikeda [40] compared Chinese and Japanese children to United States children, respectively. Relative to United States children, Asian children were stronger and more powerful, faster (in the case of the Japanese) and had superior cardiovascular endurance (in the case of the Chinese). A third postgraduate study of children from Japan, the Philippines and the United States showed similar results [41]. Japanese children had superior strength, power and cardiovascular endurance, however United States children were faster. Overall, United States and Filipino children were similar.

A later comparative study on tests of power showed that relative to European (Belgian, British and Czechoslovakian) and North American (American and Canadian) children, Japanese children came out on top, with Taiwanese and Indonesian children middle-ranked and Thai children at the bottom [42]. In terms of speed, Japanese and Taiwanese children again outperformed the Thai children, and were similar to Eastern European children. Japanese boys outperformed their Taiwanese counterparts on cardiovascular endurance tests, and were similar to Eastern Europeans. The patterns among Asian children observed by this Czechoslovakian-based study [42] are congruent with those of Meshizuka and Nakanishi [36].

Two studies comparing Taiwanese and United States children showed that Taiwanese children in the early 1990s had inferior abdominal strength and endurance [43, 44], yet they presented mixed results on cardiovascular tests. Huang [43] showed that American 12- to 14-year-old outperformed their Taiwanese counterparts in the 1-mile run (1,609 m), while Su [44], using the same test, showed that in general, Taiwanese boys were superior and girls were similar. Another comparison was made with United States children using the median data from a 1989–1990 study of 7,000 Hong Kong children aged 5–12 years [45]. The results indicated the Hong Kong children averaged 32% fewer sit-ups and covered 7.2% less distance in the 9 min run, yet they were slightly more flexible but had higher skinfold thicknesses than their American counterparts.

Two studies have used the 20 m shuttle run test to draw international comparisons in cardiovascular endurance test performance. In a study comparing approximately 500 children, Eston et al. [46] reported that Welsh and Hong Kong children had similar cardiovascular endurance, which when compared to Canadian children, was poorer in young children, but similar in older children. In another comparison using 109 studies of the 20 m shuttle run test in 37 countries (n = 418,026), Olds et al. [37] reported that the best performing children were from Northern Europe (Estonia, Iceland, Finland and Lithuania), with the worst from Southern Europe (Greece, Italy and Spain) and the Pacific Rim (Singapore, United States, Hong Kong and Australia). Japanese children were above average and ranked 12th overall, while Hong Kong and Singaporean children were below average, ranking 30th and 37th, respectively.

Methodological Issues

Extensive attempts were made to gain access to as many databases as possible on the fitness performance of Asian children and adolescents. Although on-line searches were restricted to English publications, this review was not delimited to including only English datasets or studies, as local experts within many countries were contacted and their help solicited in obtaining and translating extensive non-English sourced data. In spite of excellent cooperation in many countries, not all Asian countries were able to provide suitable data for analysis and there remain gaps in our coverage. Although the ICHPER.SD-Asia test has been promoted for over a decade, it has not been widely adopted and considerable inconsistencies remain between Asian countries in the selection of field measures of health-related fitness. Nevertheless, this study provides the most comprehensive summary to date, of the Asian evolution of anaerobic (power and speed) and aerobic fitness test performances in children and adolescents, with secular changes summarized on over 23.5 million 6- to 19-year-olds from seven Asian countries between 1917 and 2003.

Secular changes generated from studies using different sampling procedures (from random national surveys to convenience samples) and testing protocols (e.g. the number of allowed trials, practice, etc.) raise issues of representativeness. Despite that these factors are rarely reported, and without evidence of systematic time-related changes in them, estimates of mean performance changes should not be biased.

As mentioned previously, not all secular changes are linear, so the use of linear regression analysis to estimate secular changes may not have been 'ideal'. Though perhaps not ideal, a consistent method of analysis was needed to estimate performance changes, as each country × age × sex × test change comprised 2–21 country × age × sex × year of test × test reports, spanning 5–52 years.

Conclusions

Obtaining representative data suitable for determining the secular changes and geographical variability in the fitness test performance of Asian children and adolescents is not an easy task. In spite of Asia containing well over half of the world's population, many Asian countries still do not have the infrastructure or resources to collect data that would facilitate systematic analyses of fitness changes and variability. Where data exist, they are sometimes not released for public use or may not be published in the English scientific media. The analysis of secular changes in fitness is important since inadequate fitness, along with physical inactivity and poor dietary habits are inextricably associated with adverse health consequences, especially the emerging epidemic of childhood obesity [3]. Governments need to recognize the risks and costs associated with an increasingly unfit, inactive, and obese population; hence the need for good empirical data as a basis of proactive health policies [47]. It would seem that nutritionists throughout Asia have been much more proactive in providing data on dietary/obesity changes, with numerous regional studies found in the *Asia Pacific Journal of Clinical Nutrition*, including countries like the Philippines, Malaysia, India, and Thailand, where few published fitness data appear to exist. Thus, as can be seen from this review, Asian health and fitness professionals appear to be lagging behind, with relatively few Asian countries being in a position to provide representative data on secular fitness changes and geographical variability.

There have been recent reports of a 'global' decline in the cardiovascular endurance test performance of children in recent decades [48; Tomkinson and Olds, this vol., pp. 46–66]. Performances on cardiovascular endurance tests appear to have been declining at about 4–5% per decade since 1970. This study shows that a similar pattern of change is found in Asia, with Asian children declining at an average rate of −0.44% (CI −0.44 to −0.44%) p.a. since 1970 (fig. 9). In fact, 94% of the country × study × age × sex × test reports on children tested after 1970 were declines. The pattern of decline, however, has not been consistent throughout Asia. Since 1970, Chinese, Japanese and Singaporean children have declined at rates half that of the global decline,

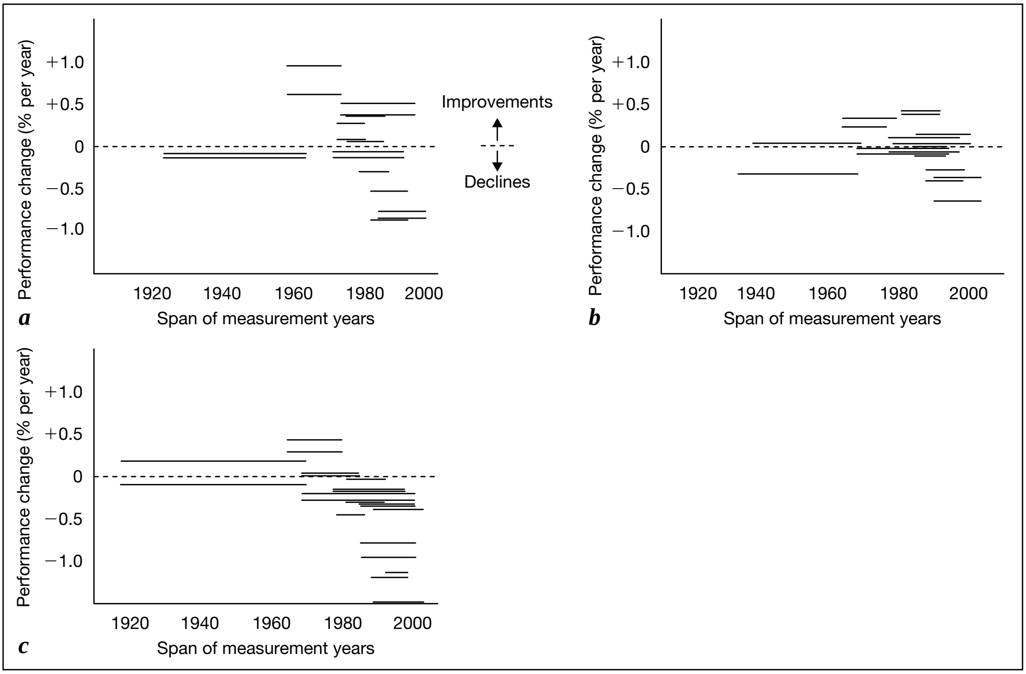


Fig. 9. Bivariate plot showing the span of measurement years (x-axis) and the performance changes (% p.a.; y-axis) for (***a***) power; (***b***) speed, and (***c***) cardiovascular endurance. Each horizontal line represents a single country × study × sex report. The length of the line shows the span of measurement years. Higher values indicate performance improvements.

while Hong Kong and Korean children have declined at rates double the global decline. Given the association between aerobic fitness and numerous degenerative conditions (e.g. diabetes, obesity and metabolic syndrome), particularly in adults, these changes should be an issue of major concern for public health authorities throughout Asia.

Over the same time, there has been very little global change in children's performance on power and speed tests [49]. Changes in power and speed test performances of Asian children are consistent with the global change, with average changes of −0.03% (CI −0.03 to −0.03%) p.a. and 0.00% (CI 0.00 to 0.00%) p.a., respectively. Of the country × study × age × sex × test reports on children tested after 1970, 51% of the power-related reports and 48% of the speed-related reports were declines.

Although comparing geographic variability in children and adolescent fitness may run the risk of fanning the flames of nationalistic pride, it is designed more to provide international comparisons upon which countries can benchmark one component of its nation's health. To these ends, children and adolescents from the Asian powerhouses of China and Japan generally appear to have performed better than their smaller Asian neighbors. However, like most countries around the world, the overall changes towards decreasing cardiovascular fitness levels in young people throughout Asia should be of greatest concern, as these changes may predict future public health catastrophes.

It is beyond the scope of this study to debate the merits of measuring physical fitness or physical activity, yet both are known to be separate heart disease risk factors in adults [50]. Interested readers are referred to a discussion of the relationship between physical activity and physical fitness, the factors that affect physical activity, together with a discussion of secular changes in physical activity, by Salmon and Timperio [this vol., pp. 183–199]. More comprehensive investigations of both physical fitness and physical activity, using simple and inexpensive standardized instruments which can be adapted to each country, would be beneficial. In this respect, the periodic use (e.g. every 3–5 years) of measures such as the Eurofit [51] or Fitnessgram [52] for physical fitness, and questionnaires such as the International Physical Activity Questionnaire (IPAQ [53]) for physical activity, on at least a representative sample of the population, would not only help promote greater awareness of health and fitness in children and adolescents, but would also provide empirical data to aid health professionals formulate and monitor the efficacy and effectiveness of their public health strategies.

References

1 Freedson PS, Cureton KJ, Heath GW: Status of field-based fitness testing in children and youth. Prev Med 2000;31:S77–S85.

2 Macfarlane DJ: Automated metabolic gas analysis systems: a review. Sports Med 2001;31: 841–861.

3 Lobstein T, Baur L, Uauy R: Obesity in children and young people: a crisis in public health. Obes Rev 2004;5(suppl 1):4–85.

4 Florentino RF: The burden of obesity in Asia: challenges in assessment, prevention and management. Asia Pacific J Clin Nutr 2002;11(suppl):S676–S680.

5 Tomkinson GR: Secular trends in fitness performance of Australasian children and adolescents; PhD thesis University of South Australia, Australia, 2004.

6 Sportscience e-mail forum: Sportscience (accessed 23 February 2005, at http://www.sportsci.org/forum/index.html).

7 Chinese Science and Technology Institute: A Report of Scientific Findings: A Study on Morphology and Physical Fitness of Chinese Children and Adolescents (in Chinese). Beijing, Scientific Documents, 1982.

8 Research Team of Students' Physical Fitness and Health in China: A Survey on Students' Physical Fitness and Health in 1985 in China (in Chinese). Beijing, People's Education Press, 1987.

9 Research Team of Students' Physical Fitness and Health in China: A Report on the Physical Fitness and Health Surveillance of Chinese School Children in 1991 (in Chinese). Beijing, Beijing Science and Technology Press, 1993.

10 Research Team of Students' Physical Fitness and Health in China: A Report on Students' Physical Fitness and Health in 1995 in China (in Chinese). Changchun, Jilin Science & Technology Press, 1996.

11 Research Team of Students' Physical Fitness and Health in China: A Longitudinal Study in Han Students' Morphology and Physical Fitness from 1985–2000 in China (in Chinese). Beijing, Higher Education Press, 2002.

12 Lin WS, Ji CY, Zhang YQ, Zivicnjak M, Xin SL, Guan MJ: Maximal aerobic power in children and adolescents of Beijing, China. Am J Hum Biol 1996;8:497–503.

13 Shao L, Lin WS, Yi C, Zhang Y: Maximal aerobic capacity and its relationship with physical growth in Chinese children. Coll Antropol 1997;21:109–116.

14 Qiao JY: Characteristics of maximal oxygen uptake, respiration and heart rate in children and adolescents during the tense muscle action (in Chinese). Sports Sci Information 1964;5:9–12.

15 Zhou MY, Lu S: Age characteristics of maximal oxygen uptake at 12–23 male students from college and high school (in Chinese). Chin J Sports Med 1986;5:211–217.

16 Ding ZY, Yang GF, Li FZ, Zang X: A measurement of constitutional development of healthy children and adolescents by treadmill test (in Chinese). Sch Health 1981;2:35–42.

17 To CY: Physical Fitness of Children in Hong Kong. Hong Kong, Chinese University of Hong Kong School of Education, 1985.

18 Fu FH: Health Fitness Parameters of Hong Kong School Children. Hong Kong, Department of Physical Education, Hong Kong Baptist College, 1994.

19 Fu FH: ICHPER.SD Asia youth health related fitness test: implementation in Hong Kong. J ICHPERSD 1994;30:22–27.

20 Physical Education – Surveys on 'Physical Fitness Status of Hong Kong School Pupils': Education and Manpower Bureau, The Government of the Hong Kong Special Administrative Region (accessed 23 February 2005, at http://www.emb.gov.hk.).

21 Ikai M, Fukunaga T: Imbalance between growth and physical fitness; in Asahina K, Shigiya R (eds): Physiological Adaptability and Nutritional Status of the Japanese. B. Growth, Work Capacity and Nutrition of Japanese. Tokyo, University of Tokyo Press, 1975.

22 Matsuura Y: Annual changing trend of physical fitness of Japanese in the recent 10 years and its present status. Bull Inst Health Sports Sci Univ Tsukuba, 1995;18:11–26.

23 Watanabe T, Yamamoto Y, Miyashita M, Mutoh Y: Secular change in running performance of Japanese adolescents: a longitudinal developmental study. Am J Hum Biol 1998;10:765–779.

24 Noi S, Masaki T: The educational experiments of school health promotion for the youth in Japan: analysis of the 'sport test' over the past 34 years. Health Promot Int 2002;17:147–160.

25 Miyashita M, Sadamoto T: The current problems of physical fitness in Japanese children. J Sports Med 1987;27:217–222.

26 Yang DS: A comparison of the secondary Korean student physical fitness test scores in 1979 and 1986; EdD thesis, University of Houston, 1989.

27 Ministry of Culture and Tourism: National Survey of Physical Fitness. Seoul, Korean Sport Science Institute, 1998.

28 Tomkinson GR, Olds TS, Kang S, Kim D: Secular trends in the aerobic fitness test performance and Body Mass Index of Korean children and adolescents (1968–2000). Int J Sports Med 2007;28: 314–320.

29 Quek JJ, Menon J, Tan S, Wang B: Review of National Physical Fitness Award (NAPFA) Norms. Optimising Performance. Proc Int Sports Science Conf, Singapore, 1993. Singapore, Singapore Sports Council, 1993.

30 Singapore Sports Council: NAPFA Challenge: Your Test of Overall Physical Fitness, ed 6. Singapore, Singapore Sports Council, 1997.

31 Dey SK, Debray P: A comparative study of maximal aerobic power of school boys of east and north-east regions of India. Indian Pediatr 2003;40:105–114.

32 Khanna GL, Majumdar P, Saha M, Mandal M: Cardiorespiratory fitness and body composition in Indian children of 10–16 years; in Parizkova J, Hills AP (eds): Physical Fitness and Nutrition during Growth. Basel, Karger, 1998, pp 132–144.

33 Klanarong S: Socio-demographic distribution of health-related fitness of Thai children; PhD thesis University of South Australia, 2005.

34 International Committee for the Standardization of Physical Fitness Tests: Fitness, Health, and Work Capacity: International Standards for Assessment. New York, Macmillan, 1974.
35 Hatano Y, Hua ZD, Jiang LD, Fu FH, Zhi CJ, Wei SD: Comparative study of physical fitness of the youth in Asia and their attitude towards sports. J Phys Ed Rec (Hong Kong) 1997;3:4–11.
36 Meshizuka T, Nakanishi M: A report on the results of the ICSPFT performance test applied to the people in Asian countries; in Simri U (ed): Proceedings of the ACSPFT and the ICSPFT – 1972. Israel, Wingate Institute for Physical Education in Sport, 1972, pp 7–23.
37 Olds TS, Tomkinson GR, Léger LA, Cazorla G: Worldwide variation in the performance of children and adolescents: an analysis of 109 studies of the 20 m shuttle run test in 37 countries. J Sports Sci 2006;24:1025–1038.
38 Hong Y, Chan KM: Comparison of health-related physical fitness of school children between Hong Kong and Mainland cities. HK J Sports Med Sports Sci 1997;5:34–41.
39 Tcheng TK: Physical fitness of Chinese and American boys and girls ten to eighteen years of age; Masters thesis, State University of Iowa, 1961.
40 Ikeda N: A comparison of physical fitness of children in Iowa, USA and Tokyo, Japan; PhD thesis, State University of Iowa, 1961.
41 Mequi AH: Comparison of performances in the AAHPER Youth Fitness Test between University of the Philippines entering freshman students and American and Japanese boys; Masters thesis, University of Oregon, 1965.
42 Unknown author: Physical fitness of Czechoslovak children at 12 and 15 years of age: International Biological Programme results of investigations 1968–1969. Acta Universitatis Carolinae: Gymnica, 5(2). Prague, Universita Karlova, 1970.
43 Huang YC: Relationship of sociodemographic and physical activity variables to physical fitness of Taiwanese junior high school students; PhD thesis, University of Texas, 1994.
44 Su CH: Development of fitness norms for school-aged children in Hsinchu, Taiwan; PhD thesis, University of Northern Colorado, 1993.
45 Ip MHH: Physical fitness in Hong Kong children. HK Assoc Sports Med Sports Sci Newslett 1991;3:19–23.
46 Eston RG, Ingledew DK, Fu FH, Rowlands A: Comparison of health-related fitness measures in 7- to 15-year-old in Hong Kong and North Wales; in Chan KM, Michelli LJ (eds): Sports and Children. Hong Kong, Williams & Wilkins, 1998, pp 119–130.
47 Adab P, Macfarlane DJ: Exercise and health – new imperatives for public health policy in Hong Kong. HK Med J 1998;4:389–393.
48 Tomkinson GR, Léger LA, Olds TS, Cazorla G: Secular trends in the performance of children and adolescents (1980–2000): an analysis of 55 studies of the 20 m shuttle run in 11 countries. Sports Med 2003;33:285–300.
49 Tomkinson GR: Global changes in anaerobic fitness test performance of children and adolescents (1958–2003). Scand J Med Sci Sports. In press.
50 Williams PT: Physical fitness and activity as separate heart disease risk factors: a meta-analysis. Med Sci Sports Exerc 2001;33:754–761.
51 Council of Europe: Eurofit: Handbook for the Eurofit Tests of Physical Fitness. Rome, Council of Europe, 1988.
52 Cooper Institute: Fitnessgram 6.0 CD/Test Administration Manual-Updated. Dallas, Cooper Institute for Aerobic Research, 2004.
53 Craig CL, Marshall AL, Sjöström M, Bauman AE, Booth ML, Ainsworth BE, Pratt M, Ekelund U, Yngve A, Sallis JF, Oja P: International Physical Activity Questionnaire (IPAQ): 12-country reliability and validity. Med Sci Sports Exerc 2003;35:1381–1395.

Duncan J. Macfarlane, PhD
Institute of Human Performance, University of Hong Kong
111–113 Pokfulam Road
Pokfulam (Hong Kong)
Tel. +852 2817 9451, Fax +852 2818 8042, E-Mail djmac@hku.hk

Tomkinson GR, Olds TS (eds): Pediatric Fitness. Secular Trends and Geographic Variability.
Med Sport Sci. Basel, Karger, 2007, vol 50, pp 168–182

Secular Changes in Aerobic Fitness Test Performance of Australasian Children and Adolescents

Grant R. Tomkinson[a], *Timothy S. Olds*[b]

[a]Centre for Applied Anthropometry and [b]Nutritional Physiology Research Centre,
School of Health Sciences, University of South Australia, Adelaide, Australia

Abstract

Introduction: There have been an increasing number of reports in recent years which have highlighted that the aerobic fitness test performances of Australian and New Zealand children and adolescents are declining. Some researchers have previously commented on secular changes in performance, but have used data dating back only to 1985. Using a meta-analytical approach, this study aimed to quantify the secular changes in the aerobic fitness test performances of Australasian (Australian and New Zealand) children and adolescents over the past half a century. **Methods:** Forty-six studies reporting on the aerobic fitness test performances of healthy Australasian children and adolescents were included in the analysis. Corrections for methodological variation were made where possible, and data for each aerobic fitness test were expressed in a common metric. Raw data were merged with pseudo data generated from reported means and standard deviations using Monte Carlo simulation. Changes in aerobic test performance were calculated at the country × age × sex × test level using least squares linear regression. **Results:** Secular changes were calculated for 161,419 6–17-year-old tested on five different maximal field-running tests of aerobic fitness between 1961 and 2002. Overall, the aerobic performance of young Australasians declined at an average rate of −0.24% per annum (95% confidence interval −0.22 to −0.26% per annum). The pattern of change, however, was not consistent over time. Early in the 1960s, changes in performance shifted from improvements to declines, with the rate of decline accelerating until about 1990, and slowing thereafter. Secular changes were reasonably similar for boys and girls, but quite different for children and adolescents. **Discussion/Conclusion:** There has been a marked decline in aerobic fitness test performances of Australasian children and adolescents in recent decades. It is likely that this secular decline is caused by a network of social, behavioral, physical, psychosocial and physiological factors.

It is commonly believed in Australia and New Zealand (henceforth collectively termed 'Australasia') that today's children and adolescents have lower aerobic fitness than their peers from decades past. Though there have been few scientific studies which have explicitly commented on secular changes in Australasian children's aerobic fitness (operationalized as performances on maximal field-running tests), available evidence is consistent and supportive of popular belief. In 1996, McNaughton et al. [1] compared a statewide health and fitness survey of 2,450 7- to 10-year-old Tasmanian children in 1995 to a national survey of 8,484 young Australians in 1985 [2]. Over the 10-year period, 1,600 m running performance declined at an average rate of −0.24% per annum (p.a.) (range −0.01 to −0.37% p.a.). A similar study of 1,463 10- to 11-year-old South Australian children found a decline of −0.64% p.a. (range −0.52 to −0.75% p.a.) in 1,600 m running performance between 1985 and 1997 [3]. In a review of 55 studies of the 20 m shuttle run test (20 mSRT) in 11 countries, Tomkinson et al. [4] reported an average decline of −0.31% p.a. in 20 mSRT performances of 38,380 Australian youths tested between 1990 and 2000. The pattern of change has been more marked in New Zealand children however. In a study of 5,579 10- to 14-year-old New Zealand children tested from 1991 to 2000, Dawson et al. [5] reported an average decline of −1.83% p.a. in 550 m run performance. A year later, Hamlin et al. [6] compared the 550 m run performances of 2,296 10- and 12-year-old children tested between 1984–1985 and 2000, reporting declines of −1.12% p.a. (range −0.65 to −1.43% p.a.).

These snapshots, when pieced together, paint a very consistent picture – they all show declines in aerobic performance of young Australasians, ranging on average from −0.24 to −1.83% p.a. However, these data are typically limited to children from narrow age bands, compared over relatively short periods of time, and extend only as far back as the mid-1980s. However, field-testing for fitness has been very popular in Australasia since the early 1960s, with performances on maximal field-running tests commonly used to index aerobic fitness. With a wealth of data available from both the lay and scientific literature, and available scientific evidence on secular changes limited in scope, the aim of this study, therefore, was to quantify the secular changes in aerobic fitness test performance of Australasian children and adolescents.

Methods

Data Sources

An extensive review of literature was undertaken to locate studies which reported on the fitness test performance of Australasian children and adolescents. Studies were identified in four main ways. First, a computer search of online and CD-ROM bibliographic databases (Australian Sport, CINAHL, Current Contents, Digital Dissertations, ERIC, Medline, and Sports Discus), and the University of South Australia's library catalogue, was undertaken.

Numerous key words (fitness, performance, power, speed, agility, endurance, cardiovascular, run, jump, sprint, anaerobic and aerobic) and modifiers (child, adolescent, boy, girl, youth, young and infant) were used for the computer searches. Second, all hard copy scientific journals and books (the 150, 570, 610 and 790 Dewey decimal classification ranges), and bibliographic indexes, held at the University of South Australia Library, were manually searched. Third, the reference lists of all located reports were examined and cross-referenced, and followed up where appropriate. Lastly, attempts were made to personally contact the authors of each study to clarify details of their own study, to request raw data, and to ask if they knew of further studies which could be of use.

Seventy-one candidate studies were located. Twenty-five of these were excluded from the analysis because data were reported for: (a) individuals not aged between 6 and 17 years; (b) large, undifferentiated age ranges spanning 3 or more years (e.g. 10–12-year-olds); (c) a sample not distinguished by sex; (d) unhealthy or non-normal individuals (e.g. asthmatics or elite young athletes); (e) a sample previously reported in other located studies, or (f) individuals not tested on maximal field-running tests of aerobic fitness (e.g. distance-runs, timed-runs and endurance shuttle runs).

Forty-six studies were included in the analysis, 34 from Australia and 12 from New Zealand. Of these, 57% (26 of 46) were peer-reviewed scientific journal articles, 3% (1 of 46) published book chapters, 7% (3 of 46) published conference papers or abstracts, 7% (3 of 46) post- and under-graduate theses, and 28% (13 of 46) unpublished raw datasets. Studies were published between 1962 and 2003. Most studies employed a cross-sectional design (91% or 42 of 46) using a mixed sample of boys and girls (76% or 35 of 46). The majority of studies (54% or 25 of 46) used convenience samples, with 22% (10 of 46) using randomized-stratified samples on a regional or national basis, 4% (2 of 46) stratified-uniform samples and 20% (9 of 46) stratified-proportional samples based on education systems or geographical areas. Table 1 summarizes the studies used in this analysis.

Data Entry

A lineage covering a good span of years was available for five maximal field-running tests of aerobic fitness: the 550 and 1,600 m distance-runs, the 10- and 12-minute timed-runs, and the 20 m SRT. Fifty-four percent of all studies reported data as descriptive summary statistics, with 37 and 9% available as soft- and hard-copy raw data, respectively. All hard copy data (descriptive and raw) were manually entered into a spreadsheet and checked for transcription errors, with corrections made where appropriate. All raw data (constituting 62% of all data points) were checked for outliers by running automated range checks, with anomalous data eliminated if they fell more than three standard deviations (SDs) from the mean. Age and measurement year were recorded using procedures described by Tomkinson et al. [4]. Sample size statistics were not reported at the age × sex × test level in three studies (8% of all data points), and were derived from available data or through personal contact with the study authors.

Data Treatment

While it is recognized that fitness test performances can be affected by factors such as the environment, clothing, practice, motivation, test administration and instructions, such factors were rarely reported, and therefore could not be controlled for. Furthermore, there is no evidence of a systematic, time-related bias in these factors. Nonetheless, primary data

Table 1. Summary of the studies used in this analysis

Study	Country	Years	Sex	Age range, years	Sample No.	Test(s)
ACHPER [7]	Australia	1994	M, F	9–18	35–104	1,600 m, 20 m SRT
ASC [8]	Australia	1993	M, F	12–17	301–542	20 m SRT
Birchall [9]	Australia	1990–91	M, F	6–12	4–185	1,600 m
Booth et al. [10]	Australia	1997	M, F	9, 11, 13, 15	399–634	20 m SRT
Brewer et al. [11]	Australia	1991	M, F	11–14	57–256	20 m SRT
Brown [12]	New Zealand	1961	M, F	11–17	21–600	550 m
Carter [13]	Australia	1972	M	13–15	117–139	550 m
Cooley and McNaughton [14]	Australia	1998	M, F	11–16	339–636	20 m SRT
Coonan [15]	Australia	1982	M, F	10.2 ± 0.6	9–207	1,600 m
Corkill et al. [16]	New Zealand	1974	M, F	12–16	10–193	12 min
Dawson et al. [5]	New Zealand	1991–2000	M, F	11–13	2–79	550 m
Dollman et al. [3]	Australia	1997	M, F	10–12	101–447	1,600 m
Gibbs et al. [17]	Australia	1995	F	9.5 ± 0.7	36–38	20 m SRT
Hage [pers. commun.]	Australia	1999	F	13, 14, 16, 17	3–126	20 m SRT
Hamlin [pers. commun.]	New Zealand	2002	M, F	6–11	1–20	550 m
Hamlin et al. [6]	New Zealand	2000	M, F	6–12	9–95	550 m
Hands [18]	Australia	1999	M, F	6–13	1–37	20 m SRT
HDF [unpubl. data]	Australia	1991–95	M, F	9–12	154–1, 198	1,600 m
Jenner et al. [19]	Australia	1988	M, F	12.0 ± 0.4	527–565	20 m SRT
Lindquist [pers. commun.]	Australia	1998–99	F	7–15	1–40	20 m SRT
Lloyd and Antonas [20]	Australia	1999	M, F	11–12	35–53	20 m SRT
Masson [pers. commun.]	Australia	1999	M, F	14,16	4–15	20 m SRT
McNaughton et al. [1]	Australia	1995	M, F	7–10	30–327	20 m SRT
Miller [21]	Australia	1969	M	14.5 ± 0.5	84	550 m
Mulkearns [pers. commun.]	Australia	1996–98	F	7–10	3–79	20 m SRT
NZDE [22]	New Zealand	1966	M, F	9–13	239–796	550 m

Table 1. (continued)

Study	Country	Years	Sex	Age range, years	Sample No.	Test(s)
NZDE [23]	New Zealand	1968	M	13–16	589–1,106	550 m
NZDE [24]	New Zealand	1969	F	13–17	329–1,106	550 m
NZDE [25]	New Zealand	1971	M, F	9–13	239–796	550 m
Okely et al. [26]	Australia	1996	M	14.3	51	20 m SRT
Pavy [27]	Australia	1963	M, F	13–17	200	550 m
Pyke [2]	Australia	1985	M, F	7–15	361–520	1,600 m
Robertson [pers. commun.]	Australia	1969	M, F	12–17	2–160	550 m
Russell et al. [28]	New Zealand	1985	M, F	10, 12, 14	367–415	12 min
SASI [unpubl. data]	Australia	1995–01	M, F	11–15	7–1,473	20 m SRT
TIS [unpubl. data]	Australia	1996–01	M, F	12–15	47–833	20 m SRT
WAIS [unpubl. data]	Australia	1999–01	M, F	12–15	213–1,473	20 m SRT
Tilbrook [pers. commun.]	Australia	1984,00	M, F	6–12	8–31	10 min
Vandongen et al. [29]	Australia	1990	M, F	10–12	485–486	1,600 m, 20 m SRT
Walker [pers. commun.]	Australia	1993–02	M, F	13, 16	3–100	1,600 m, 20 m SRT
Whitebrook [30]	Australia	1961	M, F	10–16	560	550 m
Willee [31]	Australia	1969–70	M, F	13–17	173–1,217	550 m
Williams [32]	New Zealand	1967	M	13–16	27–121	550 m
Wilson and Russell [33]	New Zealand	1982	M, F	12.0, 15.8	38–45	12 min
Woolard [pers. commun.]	Australia	1999	F	8–13	1–7	20 m SRT
Wooller et al. [34]	Australia	1981–83	M, F	10, 13	300–350	1600 m

Shown are country, year(s) of measurement, sex (F = female, M = male), age range, range of sample sizes (at the country × age × sex × test × year of test), and the test(s) for which data were available.

ACHPER = Australian Council for Health, Physical Education and Recreation; ASC = Australian Sports Commission; HDF = Health Development Foundation; NZDE = New Zealand Department of Education; SASI = South Australian Sports Institute; TIS = Tasmanian Institute of Sport; WAIS = Western Australian Institute of Sport.

10 min = 10 min timed run; 12 min = 12 min timed run; 550 m = 550 m distance run; 1,600 m = 1,600 m distance run; 20 m SRT = 20 m shuttle run test.

treatment procedures were adopted prior to combining studies and calculating secular changes, in order to systematically control for any identified, controllable biases (e.g. differences in 20 m SRT protocols) (for more details, see Tomkinson et al. [4]).

The results of all studies reporting on the same fitness test were expressed in a common metric: time in seconds for the 550 and 1,600 m distance-runs, distance in metres for the 10- and 12-minute timed-runs, and speed in $km \cdot h^{-1}$ for the 20 m SRT (for precise details regarding expressing 20 m SRT performances in speed at the last completed stage, see Tomkinson et al. [4]). For studies not reporting descriptive summary statistics as means (seven studies constituting 15% of all data points) and SDs (12 studies constituting 23% of all data points), the means and SDs were estimated. Means were estimated using simple linear regression equations relating mean and median values using studies where both were reported, and SDs were estimated using sex × test specific sample-weighted mean coefficients of variation.

Statistical Analysis

Changes in aerobic fitness test performance were calculated using a combined dataset comprising both raw and descriptive summary data. Datasets were combined using the procedures described in Tomkinson et al. [35]. All fitness test results were adjusted such that higher scores indicated better performance. Secular changes were calculated at the country × age × sex × test level using simple linear regression, with year of test as the predictor variable and fitness test performance as the response variable. Only country × age × sex × test groups spanning a minimum measurement year range of 5 years were analyzed. Secular changes were expressed in relative terms by expressing the slope of the regression line (the absolute change) as a percentage of the mean value for all data points in the regression. Negative values indicated performance declines, and positive values improvements. Sample-weighted mean changes were calculated to compare between groups [e.g. children ($<$13 years) and adolescents ($\geq$13 years)] and to estimate whether groups differed significantly from zero. The standard error of a sample-weighted mean change was approximated using equations reported in Tomkinson [36], with the 95% confidence interval (CI) calculated as ±1.96 standard errors about the sample-weighted mean. A sample-weighted mean change was considered significantly different from zero when the CI did not include zero. The time-related patterns of change and time-related patterns of performance were summarized using the procedures of Tomkinson and Olds [this vol., pp. 46–66].

Results

Changes in aerobic fitness test performance were calculated in 161,419 6- to 17-year-old Australasians tested between 1961 and 2002, with 135,990 from Australia (61 age × sex × test groups) and 25,429 from New Zealand (23 age × sex × test groups) (table 2). The secular changes spanned an average of 14 years (range 5–41 years), and involved an average of seven country × age × sex × test × year of test reports (range 2–27). Three quarters (62 of 84) of the individual changes were negative (declines in performance).

Table 2. Summary of the country × age × sex × test groups for which changes in aerobic fitness test performance were calculated

Test	Australia		New Zealand	
	k	n	k	n
550 m	10	14,869	17	23,005
1,600 m	20	39,239		
20 m SRT	17	81,353		
10 min	14	529		
12 min			6	2,424
Total	61	135,990	23	25,429

Shown are the number of country × age × sex × test groups (k) and sample sizes (n).

Over the 41-year period from 1961 to 2002, the aerobic performances of Australasian children and adolescents declined at an average rate of −0.24% p.a. (CI = −0.22 to −0.26% p.a.). This overall decline increased slightly to −0.28% p.a. (CI = −0.26 to −0.30% p.a.) when only the statistically significant changes (74% of all changes at the country × age × sex × test level) were considered. When secular changes were calculated using only raw data, the results were strikingly similar. Using 20 m SRT test data collected on 13- to 15-year-old Australians as an example, declines in the raw dataset ranged from 0.00 to −0.19% p.a. and in the combined dataset from −0.07 to −0.16% p.a., both averaging −0.11% p.a.

The differences in sample-weighted mean changes among country × test groups are shown in figure 1. Sample-weighted mean changes ranged from a decline of −0.89% p.a. for Australians tested on the 10 min run (1984–2000) to an improvement of +0.33% p.a. for Australians tested on the 550 m run (1961–1972). All groups, except Australians tested on the 550 m run, showed a decline in performance over time. All sample-weighted mean changes were significantly different from zero.

Overall, secular changes were somewhat greater for boys [−0.32% p.a. (CI = −0.36 to −0.28% p.a.)] than for girls [−0.15% p.a. (CI = −0.19 to −0.11% p.a.)]. In contrast, performances declined in children at the average rate of [−0.62% p.a. (CI = −0.66 to −0.58% p.a.)], and remained stable in adolescents [+0.01% p.a. (CI = −0.01 to +0.03% p.a.)].

There was a fair degree of lability in the individual secular changes when sample sizes and the span of measurement years were small, with individual

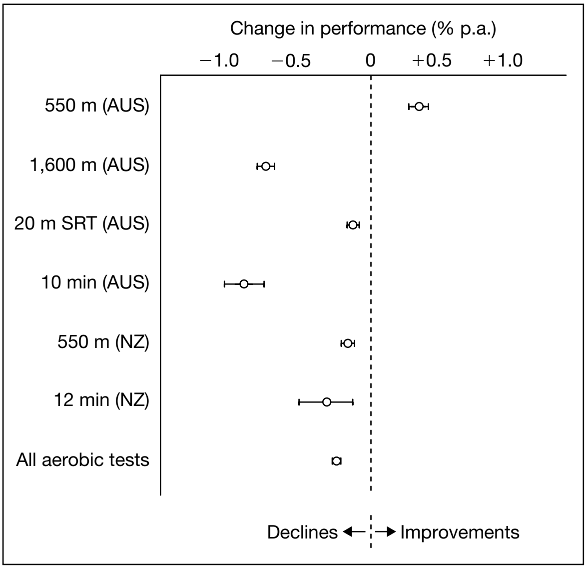


Fig. 1. Sample-weighted mean changes (% p.a.) in Australasian children tested on five maximal field-running tests of aerobic fitness. Shown are the sample-weighted mean changes for Australians tested on the 550 m run [550 m (AUS)], 1,600 m run [1,600 m (AUS)], 20 m SRT [20 m SRT (AUS)] and 10 min run [10 min (AUS)], New Zealanders tested on the 550 m run [550 m (NZ)] and 12 min run [12 min (NZ)], and all Australasian children and adolescents. The error bars are the 95% confidence intervals about the sample-weighted mean changes. Higher values (i.e. those to the right) indicate performance improvements.

changes tending to stabilize near the overall sample-weighted mean change of −0.24% p.a. as both increased. Secular changes also varied considerably with the mid-year of the measurement periods over which they were calculated, with positive changes constituting 64% of all changes in the 1960s, 50% in the 1970s, zero in the 1980s, and 16% in the 1990s. This helps explain why the sample-weighted mean change for Australians tested on the 550 m run shown in figure 1 is unique – the mean mid-year for these changes was 1966 (range 1961–1972).

Figure 2 shows the time-related pattern of change (fig. 2a) and the time-related patterns of performance (fig. 2b) over the period 1961–2002. Using data from Tomkinson and Olds [this vol., pp. 46–66], the global pattern is also shown. Because Tomkinson and Olds [this vol., pp. 46–66] used unweighted average annual changes to describe the global time-related pattern of change, unweighted values were used here to show the Australasian pattern. The use of weighted rather than unweighted average annual changes had little effect on the overall pattern. Consider first the time-related pattern of change (fig. 2a). In the early 1960s,

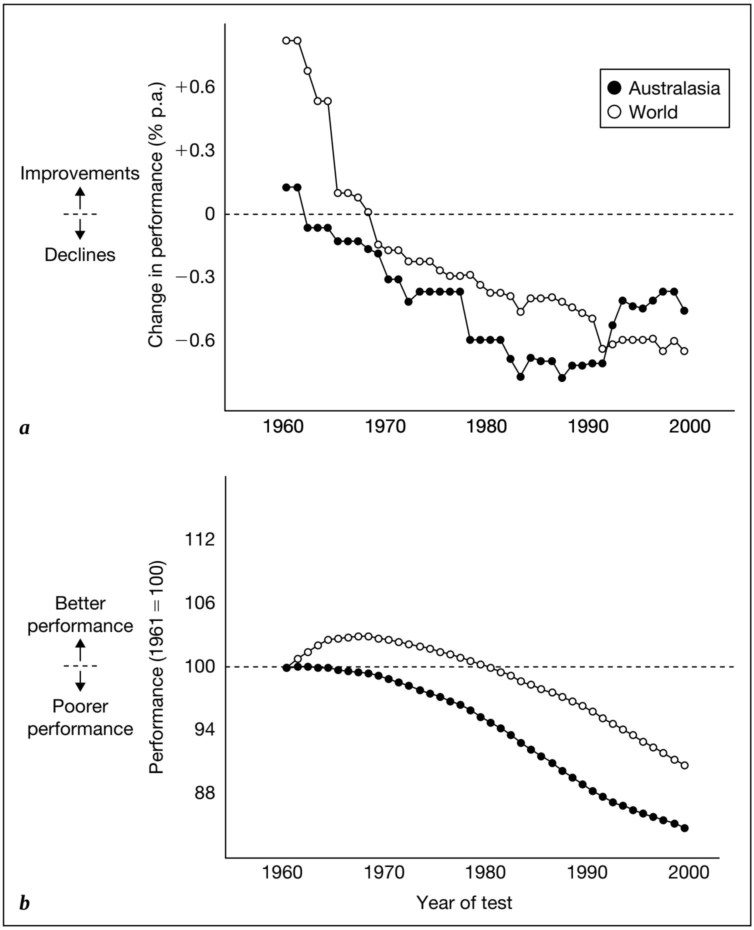


Fig. 2. Time-related patterns of (***a***) change and (***b***) performance for Australasia and the World (1961–2002). The World data are from the chapter by Tomkinson and Olds [this vol., pp. 46–66]. In (***a***), higher values (i.e. those greater than zero) indicate improvements in performance, while in (***b***), higher values (i.e. those greater than 100) indicate better performance.

changes in Australasians shifted from improvements to declines, with the rate of decline accelerating until about 1990, and slowing thereafter. Over the past three decades, the Australasian and global rates of decline have been remarkably similar, averaging about −0.5% p.a. The Australasian and global patterns of change differed in two distinct ways. First, the crossover point from improvements to declines came earlier in Australasia (1963 vs. 1968), and second, there has been deceleration in the Australasian decline and stability in the global decline in recent years.

Consider now the time-related pattern of performance (fig. 2b). Globally, performances improved in the early 1960s, plateauing from the mid-1960s until the mid-1970s, followed by a 28-year decline. In Australasia, aerobic performances plateaued throughout the 1960s, and declined thereafter, at a rate similar to that observed globally.

Discussion

There have been declines in aerobic fitness test performances in Australasian children and adolescents since the early 1960s, with declines accelerating until about 1990, and slowing thereafter. The Australasian decline is similar to the global decline. However, the recent slowing of the decline in Australasia appears to be a local, rather than a global, pattern. Secular changes differed among aerobic fitness tests, itself underscoring the value of a universal test battery for tracking secular changes, yet were reasonably similar for boys and girls (declines were observed for both and were somewhat higher for boys), and quite dissimilar for children and adolescents (there were decline in children and no change in adolescents). The somewhat greater declines in boys relative to girls could reflect secular differences in increases in fat mass. Using the Pyke [2] and Dollman et al. [3] datasets, the secular increase in fat mass (calculated using the triceps and subscapular skinfolds as inputs into the Slaughter equations to estimate percentage body fat, and hence fat mass by calculating the percentage of body mass comprised of fat) between 1985 and 1997 was greater for boys (+3.1% p.a.) than for girls (+2.2% p.a.). Mechanistically, increased fat mass should impair weight-bearing distance-running performance, as ‘fat constitutes an extra load to carry and reduces mass-specific aerobic power approximately on a pro rata basis’ [chapter by Olds et al., this vol., pp. 226–240]. The differences between children and adolescents are probably because secular changes varied with the mid-year of the measurement periods over which they were calculated. The majority of the changes for adolescents (55%) spanned only the 1960s and 1970s, a time when most of the changes were positive, with only 5% of changes for children falling in the same period. This temporal variability is likely the reason for the polarized results in children and adolescents.

A major strength of this study is that it provides the most comprehensive picture to date of the secular changes in aerobic fitness test performance of Australasian children and adolescents, by describing secular changes in 161,419 6- to 17-year-old Australasians between 1961 and 2002. This study applied a strict set of inclusion and exclusion criteria, and rigorous primary data treatment procedures to systematically control for identified, controllable biases which might have lead to spurious conclusions when estimating secular changes.

For example, it used a novel simulation procedure to ‘recreate’ pseudodata [35] in order to minimize the effect of skew on estimates of secular changes and to expand the secular coverage (raw data were only available post-1984).

However, like other meta-analyses, this study is not without its limitations. First, there were differences in sampling protocols. Ideally, large raw data sets from nationally representative samples taken at regular time-intervals should have only been used, however such data are rare. Only eight national fitness surveys of Australasian children and adolescents have been conducted, with these data constituting only 23% of all data points and spanning only the period 1961–1985. In addition, data were not always collected under precisely the same test conditions, due to uncontrollable and largely unreported factors such as environmental conditions, practice and running surfaces. However, without evidence of a systematic, time-related bias in sampling procedures or test conditions, estimates of mean changes should not have been biased, although our confidence in such estimates will be somewhat reduced. Third, it is acknowledged that not all secular changes are linear, and the use of linear regression analysis to estimate secular changes may not have always been the most appropriate. However, linear regression analysis did at least provide a consistent method of analysis, which was needed because of the diversity in the number of country × age × sex × test × year of test reports (range 2–27) and the span of measurement years within country × age × sex × test groups (range 5–41).

Comparisons with Other Australasian and Overseas Studies

Even though previous studies examining secular changes in aerobic fitness test performance of Australasian children and adolescents are limited in scope, the results of this study are strikingly similar. Previous Australasian studies examining secular changes show a decline in aerobic performances of about −0.50% p.a. since 1985. Over the same period, the rate of decline in this study was −0.56% p.a. The secular changes reported in this study are also consistent with global changes. This is best illustrated by comparing the results of this study to those of Tomkinson and Olds [this vol., pp. 46–66], who report on the secular changes in maximal field-running test performance of over 25 million children and adolescents from 27 countries between 1958 and 2003 (fig. 2). Since 1970, aerobic performances have been declining at a global rate of −0.51% p.a. – a rate identical to that observed in this study over the same period. This suggests that Australasia is part of the global change.

What Is Causing the Observed Decline in Performance on Maximal Field-Running Tests of Aerobic Fitness?

Tomkinson and Olds [this vol., pp. 46–66] described a model which suggests that the secular declines in aerobic performance are caused by a network of social, behavioral, physical, psychosocial and physiological factors (see Tomkinson [36] for more detail). The model argues that proximate causes of declines in maximal field-running performance are essentially changes in maximal oxygen uptake, mechanical efficiency and the sustainable fraction of maximal oxygen uptake. In addition, a reduction in affective (e.g. motivation) and/or cognitive (e.g. pacing) aspects of maximal performance may also be important. These physiological changes are in turn affected by physical changes such as increased fat mass and reduced cardiovascular function. These physical changes are the result of behavioral changes such as excessive energy intake relative to expenditure, reduced energy expenditure, and reduced vigorous physical activity. These behaviors, in turn, are driven to some extent by large social changes, such as a changing family profile, advancing technology and a shift towards suburbanization. Though this model describes plausible underlying causal mechanisms, it is the changes in aerobic performances which are of primary interest in this study. It is the ability to play harder and longer which is important for children's physical activity levels, irrespective of the underlying causal mechanisms.

It could also be argued that the time-related patterns of change are a function of differences in the distribution of aerobic tests over time. In the 1960s and 1970s in Australia, the most popular aerobic test for children and adolescents was the 550 m run, in the 1980s it was the 1,600 m run, and in the 1990s it was the 20 m SRT. It is therefore possible that the time-related changes reflect differences in the physiological and psychosocial demands of the tests. For example, factors such as oxygen uptake kinetics and anaerobic capacity will be relatively more important for performances over shorter distances, though the effect will be very small over distances of more than several hundred meters [37]. Given that there has been little secular change in the anaerobic performances of young Australasians [38], this could help explain the improvements in 550 m run performances of young Australians between 1961 and 1972. However, secular data on New Zealand children and adolescents tested on the 550 m run, which span the period 1961–2002, show initial improvements followed by more recent declines.

Comparison of Secular Changes in Aerobic and Anaerobic Performance

Tomkinson et al. [38] reported in their meta-analysis of 39 Australasian studies, that the power and speed test performances of 232,564 6- to 17-year-old Australasians have remained relatively stable since 1960, with mean improvements of +0.05% p.a. (CI = +0.01 to +0.09% p.a.) and +0.04% p.a. (CI = +0.02 to +0.06% p.a.) for power and speed, respectively. This study has shown that the secular change in maximal field-tests of aerobic fitness is much larger, with an overall decline of −0.24% p.a. (CI = −0.22 to −0.26% p.a.) observed over the 1961–2002 period. It is not obvious why we see declines in aerobic performance and relative stability in anaerobic performance. It is possible that the secular differences in aerobic and anaerobic performance may be due to the differential effects of fat mass and fat-free mass. Mechanistically, additional fat mass should impair weight-bearing performance more so in distance-running than in sprint-running or jumping, and additional fat-free mass should assist performances requiring explosive power, such as sprint-running and jumping, as opposed to distance-running. There is evidence that (a) there is a stronger negative relationship between fat mass and distance-running, than between fat mass and sprint-running and jumping, and (b) there is a stronger positive relationship between fat-free mass and jumping and sprint-running, than between fat-free mass and distance-running [38]. With recent increases in both fat mass and fat-free mass in Australian children [38], it is possible that the positive effect of increasing fat-free mass counteracts the negative effect of increasing fat mass for jumping and sprint-running (hence the secular stability), but is not enough to counteract the negative effect of increasing fat mass for distance-running (hence the secular decline). Though not complete, this does at least suggest a reason for the secular differences in aerobic and anaerobic performances (see also Tomkinson and Olds, in this volume, for a discussion on other possible reasons for these secular differences).

Conclusion

This study shows that there has been a sharp decline in the aerobic fitness test performance of Australasian children and adolescents in recent decades. The etiology of this secular change is difficult to pinpoint, although it is likely caused by a network of social, behavioral, physical, psychosocial and physiological factors. There is at least some room for optimism, as the secular decline in aerobic performance appears to be slowing.

Acknowledgements

We would like to thank the following organizations for their support: the Australian Council for Health, Physical Education and Recreation; the Children's Health Development Foundation; the South Australian Institute of Sport; the Tasmanian Institute of Sport; and the Western Australian Institute of Sport. We also thank the following individuals for allowing them access to their data: John Birchall, Jim Dollman, Jill Hage, Beth Hands, A. Lindquist, Shane Masson, Sara Mulkearns, David Tilbrook, Colin Walker and Sue Woolard. Thanks also to the following for their kindness in providing extra information about their studies: Scott Baker, Michael Booth, Valerie Burke, Dean Cooley, Wayne Coonan, Morag Croser, Tammy Ebert, Jeff Emmel, Jason Gulbin, Christine Hamlyn, Deb Hoare, Evie Ledger, Lars McNaughton, Geraldine Naughton, Tony Okely, David Russell, Jeff Walkey and Peter Wooller.

References

1 McNaughton L, Morgan R, Smith P, Hannan G: An investigation into the fitness levels of Tasmanian primary schoolchildren. ACHPER Healthy Lifestyles J 1996;43:4–10.

2 Pyke JE: Australian Health and Fitness Survey 1985. Adelaide, Australian Council for Health, Physical Education and Recreation, 1987.

3 Dollman J, Olds T, Norton K, Stuart D: The evolution of fitness and fatness in 10- to 11-year-old Australian schoolchildren: changes in distributional characteristics between 1985 and 1997. Pediatr Exerc Sci 1999;11:108–121.

4 Tomkinson GR, Léger LA, Olds TS, Cazorla G: Secular changes in the performance of children and adolescents (1980–2000): an analysis of 55 studies of the 20 m shuttle run in 11 countries. Sports Med 2003;33:285–300.

5 Dawson K, Hamlin M, Ross J, Duffy D: Changes in the health-related physical fitness of 10–14 year old New Zealand children. J Phys Ed NZ 2001;34:26–39.

6 Hamlin MJ, Ross JJ, Hong S-W: Health-related fitness changes and gender differences in 6–12 year old New Zealand children. NZ J Sports Med 2002;30:4–11.

7 Australian Council for Health, Physical Education and Recreation: Australian Fitness Education Award: User's Manual and Curriculum Ideas. Adelaide, Author, 1996.

8 Australian Sports Commission: Sport search: Norms for Sport Related Fitness Tests in Australian Students Aged 12–17 years. Belconnen, Author, 1994.

9 Birchall J: Health-related fitness testing; in Went S (ed): A Healthy Start: Holistic Approaches to Health Promotion in School Communities. Melbourne, Monash University, 1991, pp 251–265.

10 Booth M, Macaskill P, McLellan L, Phongsavan P, Okely T, Patterson J, et al: NSW Schools Fitness and Physical Activity Survey 1997. Sydney, NSW Department of Education and Training, 1997.

11 Brewer J, Ramsbottom R, Williams C: Multistage Fitness Test: A Progressive Shuttle-Run Test for the Prediction of Maximum Oxygen Uptake. Belconnen, Australian Coaching Council, 1988.

12 Brown SR: AAHPER Youth Fitness Test: Average scores of 1961 NZ school children compared with 1964–65 US norms. NZ J Phys Ed 1967;41:31–34.

13 Carter PT: A comparison of certain physical fitness components among selected junior high school males; unpubl Masters thesis, California State University, 1975.

14 Cooley D, McNaughton L: Aerobic fitness of Tasmanian secondary school children using the 20-m shuttle run test. Percept Motor Skills 1999;88:188–198.

15 Coonan WE: The effectiveness of physical education programs in reducing cardio-vascular disease risk factors in selected ten year old Australian school children; unpubl PhD thesis, Adelaide, Flinders University of South Australia, 1984.

16 Corkill J, Williams LRT, Roberts K: Twelve-minute run standards for New Zealand secondary schools. NZ J Health Phys Ed Rec 1975;8:67–71.

17 Gibbs JL, Naughton GA, Carlson JS, Wark J, Morris F: The effects of an exercise intervention program on the bone health and physical fitness of pre-adolescent females. Abstracts, Australian Conference of Science and Medicine in Sport, Hobart, 1995. Canberra, Sports Medicine Australia, 1995.

18 Hands B: Fitness and Motor Skill Levels of Western Australian Primary School Children. Perth, University of Western Australia, 2000.

19 Jenner DA, Vandongen R, Beilin L: Relationships between blood pressure and measures of dietary energy intake, physical fitness, and physical activity in Australian children aged 11–12 years. J Epidemiol Commun Health 1992;46:108–113.

20 Lloyd KC, Antonas KN: Nutritional habits and fitness levels of schoolchildren. Proceedings of the Nutrition Society of Australia – Twenty-fourth Annual Scientific Meeting, Fremantle, 2000. Adelaide, Nutrition Society of Australia, 2000, p 138.

21 Miller JO: Personality and perceptual factors in motor performance. Thirteenth International Congress of the International Council on Health, Physical Education and Recreation, Sydney, 30–3 July/August, 1970. Washington, International Council on Health, Physical Education and Recreation, 1971, pp 46–61.

22 New Zealand Department of Education: Fitness Performance Tests – Primary Schools. Wellington, Author, 1967.
23 New Zealand Department of Education: Fitness Performance Tests – Secondary Boys. Wellington, Author, 1969.
24 New Zealand Department of Education: Fitness Performance Tests – Secondary Girls. Wellington, Author, 1970.
25 New Zealand Department of Education: Fitness Performance Tests – Primary Schools (1972 revision). Wellington, Author, 1972.
26 Okely AD, Gray T, Cotton WG: Effect of an extended stay outdoor education program on aerobic fitness; in Gray T, Hayllar B (eds): Catalysts for Change: Proceedings from the 10th National Outdoor Education Conference, Collaroy Beach, 1997. Sydney, The Outdoor Education Council, 1997, pp 206–210.
27 Pavy L: An investigation of the physical fitness of children in Perth metropolitan secondary schools based on the AAHPER Youth Fitness Test including a comparative study of the fitness of children of secondary schools of Perth, Sydney, and the USA; unpubl Masters thesis, University of Western Australia, Perth, 1967.
28 Russell DG, Isaac A, Wilson PG: The New Zealand Fitness Test Handbook: A Test of Health-Related Fitness. Wellington, New Zealand Department of Education, 1989.
29 Vandongen R, Jenner DA, Thompson C, Taggart AC, Spickett EE, Burke V: A controlled evaluation of a fitness and nutrition intervention program on cardiovascular health in 10- to 12-year-old children. Prev Med 1995;24:9–22.
30 Whitebrook FC: The physical fitness of Sydney's metropolitan school children. Aust J Phys Ed 1962;26:17–44.
31 Willee AW: Australian Youth Fitness Survey 1971. Canberra, Australian Government Publishing Service, 1973.
32 Williams LRT: New Zealand norms for the Brouha test, heights and weights. NZ J Health Phys Ed Rec 1962;2:30–34.
33 Wilson PG, Russell DG: The national fitness survey: the pilot study. NZ J Health Phys Ed Rec 1985;18:15–22.
34 Wooller P, Whittle R, McLeod J: Measuring Up: A Teachers' Handbook for Health-Related Fitness Tests. Adelaide, Health Development Unit, 1985.
35 Tomkinson GR: Global changes in anaerobic fitness test performance of children and adolescents (1958–2003). Scand J Med Sci Sports. In press.
36 Tomkinson GR: Secular changes in fitness performance of Australasian children and adolescents; unpubl PhD thesis, University of South Australia, Adelaide, 2004.
37 Péronnet F, Thibault G: Mathematical analysis of running performance and world records. J Applied Phys 1989;67:453–465.
38 Tomkinson GR, Hamlin MJ, Olds TS: Secular changes in anaerobic test performance in Australasian children and adolescents. Pediatr Exerc Sci 2006;18:314–328.

Grant R. Tomkinson, PhD
Centre for Applied Anthropometry, School of Health Sciences
University of South Australia, City East Campus, GPO Box 2471
Adelaide SA 5001 (Australia)
Tel. +61 8 8302 1407, Fax +61 8 8302 2766, E-Mail grant.tomkinson@unisa.edu.au

Tomkinson GR, Olds TS (eds): Pediatric Fitness. Secular Trends and Geographic Variability.
Med Sport Sci. Basel, Karger, 2007, vol 50, pp 183–199

Prevalence, Trends and Environmental Influences on Child and Youth Physical Activity

Jo Salmon, Anna Timperio

Centre for Physical Activity and Nutrition Research, School of Exercise and Nutrition Sciences, Deakin University, Burwood, Vic., Australia

Abstract

The purpose of this chapter was to describe prevalence and trends in children's physical activity (PA) and to overview the evidence of relationships between the broader neighborhood social and physical environment and child and youth PA. PA typically declines throughout childhood and adolescence. Few countries describe prevalence estimates of the proportion of children and youth meeting current PA recommendations; however, trends suggest declines in population level PA among children, in particular declines in active transport and school physical education. While reasons for these changes are not well-understood, there is an increasing research focus on the influence of the neighborhood social and physical environment as possible determinants of these declines. Literature examining associations between the broader social and physical environment and child and youth PA identified factors such as safety concerns (e.g. road safety, crime and concerns about strangers), social interaction (e.g. child visits with peers, neighborhood relationships, other children live in neighborhood close by), and urban design (e.g. connectivity of streets, access and availability of public open spaces and sports facilities) as important influences. However, much of the evidence is preliminary and context specific. That is, studies that reported null associations with children's PA used global rather than context-specific measures of PA (e.g. walking in the neighborhood). Future research requires better conceptualization of the social and physical environment in which children live and consideration of context-specific behaviors and behavior-specific aspects of the environment relevant to children and youth. Prospective studies are needed to establish temporal relationships between the social and physical environment and child and youth PA.

Regular physical activity is critical for children's healthy growth and also for their physical, mental, and social health. The purpose of this chapter is to describe the prevalence, trends and environmental influences on child and youth physical activity. While there are many ways in which the 'environment' is conceptualized, this chapter focuses on the broader neighborhood social and physical environments and does not review evidence of other potentially important environmental influences on children's physical activity such as peers and family, the home, school, and policy environments.

Delineating Physical Fitness and Physical Activity

It is important at the outset to clearly delineate the terms physical activity and physical fitness. Among adults, physical activity is typically defined as movement of large skeletal muscles that results in energy expenditure, whereas physical fitness is a set of attributes that are a product of being active and that also contribute to people's ability to perform activity [1]. Physical fitness consists of cardiorespiratory fitness along with other health- and skill-related fitness components such as endurance, strength and flexibility. Among adults there is reasonably consistent evidence that, in addition to having a genetic basis, optimal physical fitness is a product of physical activity. Children, however, are not simply miniature adults. Their movement and physical activity behavioral patterns differ markedly from those of adults. For example, children rarely engage in lengthy sustained bouts of activity, but typically participate in intermittent and spontaneous activity [2]. Children's physical activity consists of active play, organized and non-organized sports, school physical education, transport-related activity (e.g. walking and cycling), chores, and other incidental activities. With physical development, independence and social changes, the types of physical activity in which young children engage shifts from informal active play and begins to mirror the types of physical activity performed by adults. The association between children's physical activity and cardiorespiratory fitness is complex and will be briefly explored.

Links between Physical Activity and Cardiorespiratory Fitness

Among children the relationship between cardiorespiratory fitness and physical activity is varied [3]. Many studies have reported low to moderate positive correlations between physical activity and fitness [4]. It has been argued, however, that this relationship is largely mediated by adiposity [3]. The lack of a strong and consistent relationship between physical activity and cardiorespiratory fitness may be attributed to the challenges of assessing children's physical activity, different rates of maturation, and genetically predetermined fitness [3]. However, most of the evidence is derived from cross-sectional relationships and these do not always reflect secular relationships [5]. Therefore, it is important to consider that although there may be a weak positive relationship between physical activity and fitness, the terms should not be used interchangeably. While it is important to identify the physiological health outcomes of physical activity in young people, designing interventions to affect such outcomes in children and youth can be difficult. Furthermore, an important benefit of focusing on physical activity in health promotion initiatives is that it consists of a group of behaviors that can themselves be directly promoted [6]. In addition, children may feel they have more 'control' over their physical activity than their physical fitness, and they are able to self-monitor and note changes in their behavior more easily.

Children's Physical Activity: Health, Tracking, and Recommendations

Links between Physical Activity and Health

There is consistent epidemiological evidence that physical inactivity (i.e. an absence of physical activity) is associated with increased risk of cardiovascular disease, osteoporosis, some cancers, obesity, and type II diabetes among adults [7]. However, much less is known about the health effects of physical inactivity on child health. There is some evidence of links between physical inactivity and risk factors for cardiovascular disease (CVD), overweight/obesity, type II diabetes, and positive associations between physical activity and psychosocial outcomes and bone health among children [8]. Risk factors for CVD, such as poor blood lipid profiles, are weakly associated with physical inactivity in childhood [3]. There is more consistent evidence of links between physical inactivity and various indices of adiposity among children and youth [9]. Little is known, however, about dose-response relationships between physical activity and adiposity or other health outcomes among children or adolescents.

Although the evidence of relationships between physical activity and health among children and adolescents is not as strong as it is for adults, intuitively physical activity is likely to be important for children's growth and development as well as for their health. Furthermore, there is emerging evidence that weight bearing physical activity during childhood is important for adult skeletal health and reduced risk of osteoporosis later in life [10], and that CVD risk factors and obesity track from childhood to adulthood [11]. Given the benefits of physical activity, it is important for children to remain physically active throughout childhood and adolescence. Evidence of tracking of physical activity from childhood to adulthood will be briefly explored in the following section.

Tracking of Physical Activity

In the absence of consistent evidence of relationships between physical activity and health during childhood, a common rationale for focusing health promotion efforts on increasing children's physical activity is that physical activity tracks from childhood into adulthood. A small number of cohort studies have examined this issue. Collectively, these studies have found that physical activity appears to track over 3–5 year periods, but that there is little evidence that physical activity tracks over longer periods [12]. However, a recent tracking study of more than 1,500 Finnish children and adolescents [13] found that over a 21-year period physical activity declined but those who were persistently active (defined as being in the upper tertile for physical activity over 2–3 consecutive measurements) were significantly more likely to be physically active as adults. There is evidence that physical inactivity tracks from childhood to adulthood [14]. Although most of these studies demonstrate overall decreases in physical activity with age, evidence from animal studies of declines in energy expenditure with age suggests a possible biological basis for this phenomenon [15]. These tracking studies indicate that it is important to promote physical activity throughout the lifespan. Focusing physical activity promotion efforts solely on children may not be sufficient to maintain an active population through to adulthood. It is therefore important that physical activity is promoted and encouraged throughout childhood and adolescence and that children, parents, teachers, and public health practitioners are provided with guidelines regarding how much activity children and youth should be doing for their health.

Physical Activity Recommendations for Children and Youth

Ideally, physical activity recommendations for children and youth should be based on evidence regarding how much activity is important for health gains. However, it is important to develop and implement such recommendations even in the absence of such evidence [16]. Guidelines have been developed in several countries (UK, US, Canada, Australia) and are reasonably consistent in the dose and intensity of physical activity recommended [17–21]. Most recommend at least 60 min of moderate- to vigorous-intensity physical activity (MVPA) every day. The Canadian guidelines are less prescriptive, however, recommending a global increase of 30 min of MVPA per day and a corresponding 30-minute per day decrease in the use of electronic media (e.g. television viewing, computer games, Internet), regardless of current levels [20]. Other guidelines also recommend participation in activities that promote bone health [19] and recommend spending less than 2 h per day using electronic media for entertainment [17, 21]. In addition to informing young people, parents, teachers, and health practitioners about the duration, frequency, intensity, and type of physical activity recommended for children's health, one of the main objectives of developing physical activity guidelines is to establish a benchmark level of physical activity for monitoring purposes. The following section will provide an overview of the prevalence of physical activity among children and youth across the population, and trends in physical activity participation over time.

Prevalence and Trends in Child and Youth Physical Activity

As described earlier, the physical activity of both children and youth occurs in various domains. Most of the evidence on trends in children's physical activity is derived from specific domains such as transport and organized sport; much less evidence is available on population changes in overall levels of children's physical activity over time.

Active Transport

In the US, transportation surveys have shown declines of 40% in the proportion of 5- to 15-year-old children and adolescents walking and cycling to school between 1977 and 1995 [22]. However, a more recent analysis reported that of the 36% of 5- to 15-year-old children who travel 1 mile or less to school, the proportion walking to school increased from 31% in 1995 to 36% in 2001 [23]. A study of physical activity trends among 10- to 12-year-old Melbourne school children between 1985 and 2001 found evidence of declines in the frequency of walking (4.4 trips to 3.6 trips per week) and cycling (1.2 trips to 0.4 trips per week) to/from school [24]. Using a measure of habitual active transport, estimates from that survey suggest that in 2001, 38% of children reported never walking to school and 92% reported never cycling to school during a typical week. A recent study of 11- to 12-year-old children (n = 136) in South Australia found that 6% cycled to/from school on the previous day and 26% walked to school [25]. These estimates are consistent with a 1994 survey of travel to school among 6- and 9-year-old children conducted in Melbourne and Perth, which found that 3% cycled to/from school, 30% walked to school and 35% walked from school, on the day of the survey [26].

Using a similar measure, in 2003 the Western Australian (WA) Child and Adolescent Physical Activity and Nutrition Survey (CAPANS) found that approximately one-quarter of children in school year 3, more than 35% of children in school years 5 and 7, and 41% of children in years 8, 10 and 11 walked to school on the day of the survey [27]. A higher percentage of children (approximately 4% more across all age groups) walked home from school. Although variations in assessment of active transport between surveys make it difficult to accurately determine the current prevalence of walking and cycling to/from school among children, there appears to have been some declines in these physical activity opportunities, and current estimates suggest that this is a potentially important domain for intervention.

Physical Education and School Sport

The school setting provides important opportunities for children to be active informally through play during school breaks and formally through physical education (PE) and school sport. In Australia, school sport is distinct from PE in that 'PE is defined as the process through which sport, outdoor education, dance, gymnastics, aquatics and games are used by physical educators to teach students motor skills and fitness skills', whereas school sport is defined as involving competition [24, p. 338]. Children generally participate in team or individual organized sports against each other or against children from other schools.

The study of physical activity trends among 10- to 12-year-old Melbourne school children between 1985 and 2001 described earlier [24], identified declines in the frequency of school PE, from 1.6 lessons per week to 1.2 lessons per week. The proportion of children receiving two or more PE lessons per week declined from 52% in 1985 to 22% in 2001. It is of note that these declines were relatively greater among children attending schools in low socioeconomic status (SES) areas (50–8%) compared with children attending schools in high SES areas (53–31%). However, the declines appeared to be off-set by increases in school sport over this 15-year period (from 0.9 lessons · week^{-1} to 1.2 lessons · week^{-1}) among children attending schools in both high and low SES areas. In 1985, almost half the children in the survey did no school sport; however, in 2001 only 8% of children reported no school sport. This increase in school sport is most likely attributable to the introduction of a school PE/sport mandate in that state in 1993.

The 2003 CAPANS study in WA found that 12% of boys and 8% of girls in primary school, and 10% of adolescent boys and 17% of adolescent girls did no school PE, or reported that they were rarely active during PE lessons [27]. In the US, a study examining PE data from the school-based Youth Risk Behavior Surveillance System (YRBSS) that was collected every 2 years from 1991 to 1997 found that although enrolment in PE classes did not decline (49% enrolment), there were decreases in the proportion of youth who attended PE classes daily and there was a significant decline in the proportion of youth reporting more than 20 min of physical activity per PE lesson (from 34% in 1991 to 22% in 1997) [28].

In 1994, 85% of young people in school years 2–11 in the UK participated in school sport regularly (at least 10 times per year), which declined slightly to 83% in 1999, and to 82% in 2002 [29]. Although the proportion of young people spending 2 h or more in school PE declined between 1994 and 1999 (from 46 to 33%), in 2002 the proportion had increased to 49%, which means that more than half the children and adolescents in the UK are not receiving two or more hours of PE per week at school. Findings from the studies reviewed here highlight the importance of the quality of PE classes, and equity in access among children attending schools in low SES areas. In addition, there appears to be substantial fluctuation in the quantity of PE delivered in schools over the years. School PE and sport should be the focus of strategies for promoting children's physical activity, particularly those attending schools in low SES areas.

Organized Sport

In 2000, 59% of Australian children aged 5–14 years were reported to have participated in sport that had been organized by a school, club or association outside of school hours in the previous 12 months [30], with a higher participation rate for boys (66%) than girls (52%). Participation rates also varied by age, ranging from 32% at 5 years of age to a peak of 69% at 11 years of age followed by a decline to 58% at 14 years of age. Overall, there was a small increase in participation to 62% in 2003 [31], however, these estimates were based on a proxy-report instrument that asked parents whether their child participated in organized sport on at least one occasion in the last 12 months, and therefore it is difficult to differentiate between children who participate frequently and those who participate infrequently. Longer-term trends in sports and recreational activities among 9- to 15-year-old children were compared from the 1985 Australian Health and Fitness Survey, a 1991 Australian Sports Commission survey, a 1997 South Australian survey, and the 2000 Australian Bureau of Statistics leisure activities survey [32]. Participation in at least one organized sport declined from 83% in 1985 to 60–64% in the latter surveys, and even greater declines in the proportion of children performing three or more sports (~40% in 1985 and 11% in 2000) were noted.

In 1995, 50% of US youth in school years 9–12 participated in school sports teams (an increase from 43% in 1991) and 37% participated in sports teams run by other organizations [7]. A 2002 telephone survey of more than 3,000 US parents and their children (aged 9–13 years), asking about their child's participation in organized physical activity during the previous week, found that 39% reported engaging in organized sports and 77% reported free-time physical activity in the week preceding the survey [33]. In New Zealand, there has been a decline in sport and active leisure from 93% in 1997 to 89% in 2001 [34]. The greatest declines in participation appeared to be among the 13- to 15-year-olds (from 94% in 1997 to 88% in 2001) and 16- to 17-year-olds (from 81% in 1997 to 74% in 2001). Although it was reported that the sport and active leisure rates were based on a 2-week recall proxy-report instrument, the definition of participation was unclear in the report [34]. In the UK, trends in out-of-school organized sport participation among children and adolescents from school years 2–11 over three population-based surveys (in 1994, 1999 and 2002) remain stable with a high proportion of young people (98%) participating at least once per year in one sport [29]. However, when frequency was taken into consideration a much lower proportion of young people 'regularly' (defined as at least 10 times per year) participated in organized sport (13% in 1994 and 1999 and 14% in 2002).

In summary, organized sport participation rates vary from between 50–60% in Australia and the US to approximately 90–98% in the UK and New Zealand. While some surveys reported no change [29] or a small increase in participation rates [31], other surveys reported a decline [32]. These estimates are likely to vary according to the definition of participation (e.g. assessment of frequency) and also the methodology and instrument used. The latter is important as self-report surveys or child-assisted proxy-report surveys may result in over-estimates of participation and unassisted proxy-reports may result in underestimates, particularly if parents are not fully aware of all of their child's activities (although this may be less likely with organized sport participation than with unstructured free-play). In addition to data on prevalence of children's physical activity in specific domains, a small number of studies have reported on the prevalence of children's overall physical activity.

Overall Physical Activity

With many of the current physical activity recommendations only recently being endorsed, most countries are yet to monitor the proportions of children meeting these recommendations. In the UK, survey estimates suggest that 3 of 10 boys and 4 of 10 girls fail to meet physical activity recommendations for children [19]. In New Zealand, proxy-reported physical activity levels across all young people have marginally declined from 69% being active (defined as spending more than 2.5 h in sport and active recreation in last 7 days) in 1997 to 67% in 2001, and there was also a significant increase in the proportion reporting no activity in the past week from 8 to 13% over this period [34]. Self-report data on Australian adolescents showed that 20–25% failed to meet adult physical activity recommendations of 30 min in MVPA on 5 days per week [35]. The US Surgeon General's Report on physical activity identified that almost half of American youth did not regularly engage in vigorous-intensity physical activity [7]. Of more concern, 14% were not participating in even light- to moderate-intensity physical activity. More recent US population data suggest that one in three youth in school grades 9–12 reported no regular vigorous-intensity physical activity [33]. It has been argued, however, that current national estimates in the US are inaccurate for children and youth due to inadequate measures of physical activity [36]. One of the key challenges of monitoring children's physical activity is the assessment of this complex, multifaceted health behavior [37]. Pratt et al. [36] argue that wherever possible objective measures should be used to monitor children's physical activity in populations.

Studies that have used more objective measures of children's physical activity have been reviewed; 26 international studies (n = 1883) using heart-rate monitoring to measure physical activity in children and adolescents (aged 3–17 years) classified participation into different intensities based on the time spent at or above a particular percentage of heart rate reserve (HRR) [38]. It was identified that children and adolescents participated in an average of $47\,\text{min}\cdot\text{day}^{-1}$ of moderate-intensity activity (40–50% of HRR) and an average of $15\,\text{min}\cdot\text{day}^{-1}$ of vigorous-intensity activity (60–70% of HRR). When these results are interpreted according to youth physical activity guidelines, it appears that many children may be meeting the minimum recommendation of $60\,\text{min}\cdot\text{day}^{-1}$ of MVPA. A limitation of using HRR to estimate children's participation in physical activity, however, is that HR is also influenced by cardiorespiratory fitness, psychological state, and temperature.

Nevertheless, these findings are consistent with studies using accelerometers to assess children's activity. For example, a US study of more than 350 children (aged 7–16 years) was the first to use objective assessment of physical activity to determine the proportions of children meeting physical activity recommendations [39]. More than 90% of youth met the Healthy People 2010 objective of more than 30 min of moderate-intensity physical activity on five or more days per week, and more than two-thirds met the more recent US recommendations of more than 60 min of moderate-intensity physical activity on at least 5 days per week. In contrast, less than 3% met the objective of more than 20 min of vigorous-intensity physical activity on three or more days per week [39]. The European Youth Heart Study [40] reported the physical activity levels of more than 2,000 children (aged 9 and 15 years) from Denmark, Portugal, Estonia, and Norway assessed by the Actigraph accelerometer. That study found that almost 98% of younger children met the guidelines; however, there were significant cross-sectional declines among the older children (89% of boys and 62% of girls met recommendations).

A study of children's physical activity among approximately 1,200 children aged 5–6 and 10–12 years in Melbourne, Australia also used the Actigraph accelerometer [41] and found very similar patterns of physical activity by age and sex to the European study. Physical activity levels of children in the Australian study appeared to be quite similar to those in the European study, particularly the younger children (99%). However, a higher percentage (97%) of 10- to 12-year-olds met recommendations in the Australian study compared to 15-year-olds in the European study. These variations may be attributable to age differences between the samples, lack of representativeness of the Australian sample, and methodological differences in management of the accelerometry data. Nevertheless, the data from both studies are consistent in showing cross-sectional declines in physical activity by age and that girls are significantly less active than boys, even at a very young age. However, accuracy of these measures is also limited in that accelerometry does not capture load (e.g. carrying heavy objects, walking/running uphill), water-based activities (although the Mini Mitter® and the new version of the Actigraph® are waterproof), or other activities such as cycling, or activities involving predominantly upper body movements.

In summary, accurate assessment of children's physical activity is hindered in varying degrees, by limitations with all currently available measures. Issues around measurement continue to provide a challenge for countries that have invested in or are intending to establish regular monitoring and surveillance of children's physical activity. Therefore, evidence of trends in children's physical activity is primarily derived from studies of children's active transport, school-based physical activity, and organized sport. No published data on trends in children's overall physical activity, particularly in relation to current recommendations were located. The following section considers changes in the social and physical environment that may relate to population level declines in children's physical activity over time, and where possible describes evidence of relationships to children's physical activity.

Social and Environmental Changes and Children's Physical Activity

There is widespread commentary that declining levels of physical activity are largely the result of a changing environment that discourages physical activity [42]. Although there are some ecological-level data documenting changes in the environment over recent decades that have occurred alongside shifts in physical activity [42, 43], there is a need for empirical data linking both the neighborhood social and physical environment to physical activity [44]. While there are many aspects of the 'environment' in which children live their lives, this section focuses only on the broader social and physical environments within children's immediate neighborhoods.

Safety Concerns

It has been argued that compared to previous generations, children now have greater restrictions placed on their ability to travel without an adult (decreased independent mobility) [45]. Fears for the safety of children have led to increased surveillance of children's activities, a shift from unstructured to structured play activities, and greater levels of ‘chauffeuring’ to destinations [46], all of which may contribute to declines in overall physical activity. It is argued that these changes have been driven by fears for children’s safety from strangers and traffic, and potentially by changing notions of parenting where chauffeuring and supervision of activities is considered a symbol of a ‘good mother’ among some groups [46, 47]. Indeed, there has been a dramatic increase in car ownership [43] and reliance on private transport [42, 47] over the past five decades that has fuelled greater levels of traffic.

Road Safety

Empirical research examining traffic or road safety and children’s physical activity has produced mixed results. For example, an Italian study of 7- to 12-year-old children found no association between perceived level of danger regarding traffic in the area and children’s independent mobility [48], while an Australian study [49] reported that parental perceptions of heavy traffic were positively associated with 5- to 6-year-old children’s walking or cycling to destinations in their neighborhood, and reported no association with perceptions of road safety among 5–6 or 10–12 year olds. Nevertheless, among 10- to 12-year-old girls, a perceived need to cross several roads to reach play areas was negatively associated with children’s walking and cycling in the neighborhood [49], and 5- to 6- and 10- to 12-year-old children whose shortest possible route to school crossed a ‘busy’ road have been shown to be less likely to walk or cycle to school [50]. In addition, a study of Australian adolescents found that those who perceived there was so much traffic in their neighborhood that it is difficult/unpleasant to walk, and those who had concerns about road safety were less likely to cycle or walk in their neighborhood [51]. Thus, the evidence regarding traffic safety is mixed and may vary according to age and the type of activity being assessed. However, infrastructure for dealing with traffic-related issues, such as traffic lights and pedestrian crossings, have been related to local walking or cycling trips [49] and active transport to school [50].

Crime and Concerns about Strangers

While concern about strangers is commonplace [49], empirical evidence of associations between crime or personal safety and children’s physical activity is also equivocal. Parental concern about stranger danger and youth anxiety about strangers, respectively, have not been found to be associated with Australian children’s [49] or adolescents’ [51] walking or cycling in the neighborhood, or with active transport to or from school [50]. Further, no associations have been found between general child perceptions of the neighborhood being a safe place to play, or walk or ride a bicycle and 8–10 year olds African-American girls’ objectively assessed physical activity [52] or Australian adolescents’ self-reported walking or cycling in the neighborhood [51]. However, Romero [53] found a positive association between perceptions of safe adults at facilities and frequency of vigorous physical activity among 10- to 16-year-old youth in the US.

Also in the US, incidents of serious crime have been inversely associated with self-reported physical activity among adolescents [54], and adolescents' self-reported physical activities outside of school [55], while fear of crime was not associated with children's proxy-reported independent mobility among 7- to 12-year-old Italian children [48]. When broader measures of social disorder (e.g. litter, traffic, crime, noise) are considered, empirical findings have been equally mixed [53, 56, 57].

Social Interaction in the Neighborhood

Conversely, positive social interactions may be conducive to children's physical activity. Various aspects of social connectedness (e.g. child visits with peers, neighborhood relationships, other children live in neighborhood close by) have been shown to be associated with Italian children's independent mobility [48] and Australian youth walking and cycling in the neighborhood [51]. Further, an Australian study found that children were less likely to actively commute to school if their parents perceived that there were few other children nearby [50]. It may be that parents' concerns about safety and traffic may be moderated when their child is with other children or adults, when there are other children in their neighborhood, or when they live in an environment where there is a certain level of trust or familiarity between neighbors.

Urban Design

Over the past few decades, there has also been a shift towards suburban living and increasing urban sprawl, characterized by low-density housing, segregated land use (such as separate areas for housing, stores, businesses, utilities and schools) [43] and poorly connected road and pedestrian networks that promote dependence on private transport to reach services and employment [58]. Studies of adults have consistently shown that high population or residential density, better connected streets and mixed land use are associated with higher levels of active travel [58]. Such aspects of urban design have been infrequently examined among children. A US study found higher rates of walking or cycling to school among 5th grade children from larger schools and schools located in areas with higher residential density, but no association with street connectivity [59]. In contrast, a study of Australian primary (elementary) school children found a negative association between potentially direct routes to school (i.e. better connectivity) and actively commuting there [50]. Further, a qualitative study of parents in Australia found that families who lived in or near a court or cul-de-sac considered this to be a positive influence on their child spending time outside playing [60]. It may be that poor connectivity is indicative of lower traffic exposure [50] and may be supportive of other aspects of children's physical activity such as active free-play.

Several studies have examined access and availability of facilities or spaces where children can participate in structured or unstructured physical activity. The accessibility of destinations or physical activity spaces is often a function of urban form. Empirical evidence supports the impact of distance, with children in an Australian study being more than 10 times as likely to walk or cycle to school if their school is within 800 m of home [50]. Furthermore, 10- to 12-year-old girls who perceive that there are no parks near where they live were half as likely as other girls to make regular walking or cycling trips within their neighborhood [49], and the number of open spaces and sports pitches in a local area have been positively associated with frequency of vigorous activity among 11- to 12-year-old children from South London [61]. However, US studies of total physical activity among 8- to 10-year-old African-American girls [52] and 10- to 16-year-olds [53] have reported no relationships between access to and availability of facilities and overall physical activity.

Conclusions and Future Directions

This chapter aimed to provide an overview of the trends and prevalence of child and youth physical activity, and to discuss possible environmental changes that may be related to such trends. The limited evidence available suggests that children's active transport and school PE may have declined, however, participation in organized sport appears to be more stable (although this varied by country and by survey within country). However, the quality of trend data is insufficient to conclude ecological associations between changes in the environment and trends in children's physical activity.

Very little is currently known about why some children are more active than others, and why some types of physical activity, such as active commuting to school, appear to have declined over recent decades. The evidence summarized here relates only to the neighborhood social and physical environments and is equivocal, with different relationships for different age groups and for different domains of physical activity. However, this was not intended to be a comprehensive review of the literature and other aspects of the environment (such as the home and school environment and broader societal rules and regulations) were not examined. For example, it is possible that changes in teacher training, making room for PE and school sport within a crowded school curriculum and the overall perceived value of physical activity within schools may have contributed to reductions in physical activity in that setting.

Furthermore, consistent with ecological theories [44], individual factors (such as motivation, self-efficacy, enjoyment) may interact with the environment, changes to family circumstance (such as increases in single-parent families, divorce rates and the number of families with two working parents) and broader changes in the school and neighborhood environment to influence physical activity participation. Physical activity is a complex behavior comprised of several domains of activity and each domain is subject to many influences at various levels. Thus, there is a need for conceptual models that take such complexities into account, and a need for multilevel study designs that incorporate individual-level influences, proximal social influences and influences within the broader environment in order to better understand (and thus promote) physical activity behavior.

As described in this chapter, there is a clear lack of quality data on the physical activity behaviors of children and youth and how these behaviors have changed over time. There is, therefore, an urgent need to establish child and youth physical activity monitoring and surveillance systems that use valid and reliable estimates of physical activity prevalence and trends, as well as monitoring environmental and other factors that may explain changes in physical activity within populations. There is also a need for prospective studies that establish temporal relationships between key aspects of the environment and child and youth physical activity.

Acknowledgements

Jo Salmon and Anna Timperio are both recipients of Public Health Research Fellowships from the Victorian Health Promotion Foundation (VicHealth).

References

1 Caspersen C, Powell K, Christensen G: Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. Publ Health Rep 1985;100:126–131.
2 Pangrazi P, Corbin C, Welk G: Physical activity for children and youth. CAHPERD J 1997; Summer:4–7.
3 Boreham C, Riddoch C: The physical activity, fitness and health of children. J Sports Sci 2001;19: 915–929.
4 Morrow JR, Freedson PS: Relationship between habitual physical activity and ærobic fitness in adolescents. Pediatr Exerc Sci 1994;6:315–329.
5 Tomkinson GR, Leger LA, Olds TS, Cazorla GC: Secular trends in the performance of children and adolescents (1980–2000). Sports Med 2003;33:285–300.
6 Kohl HW, Hobbs KE: Development of physical activity behaviors among children and adolescents. Pediatrics 1998;101:549–554.
7 US Department of Health and Human Services: Physical Activity and Health: A Report of the Surgeon General. Atlanta, Department of Health and Human Services, Centers for Disease

Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion, 1996.

8 Biddle SJ, Gorely T, Stensel DJ: Health-enhancing physical activity and sedentary behaviour in children and adolescents. J Sports Sci 2004;22:679–701.

9 Davison K, Birch L: Childhood overweight: a contextual model and recommendations for future research. Obes Res 2001;2:159–171.

10 Bass S, Pearce G, Hendrich E, Delmas P, Bradney M, Harding A, Seeman E: Exercise before puberty may confer residual benefits in bone density in adulthood: studies in active prepubertal and retired gymnasts. J Bone Miner Res 1998;13:500–507.

11 Biddle SJ, Cavill N, Sallis JF: Policy framework for young people and health-enhancing physical activity; in Biddle SJ, Sallis JF, Cavill N (eds): Policy Framework for Young People and Health-Enhancing Physical Activity. London, Health Education Authority, 1998.

12 Trost SG, Pate RR: Physical activity in children and youth; in Rippe JM (ed): Physical Activity in Children and Youth. Massachusetts, Blackwell Science, 1999.

13 Telama R, Yang X, Viikari J, Välimäki I, Wanne O, Raitakari O: Physical activity from childhood to adulthood: a 21-year tracking study. Am J Prev Med 2005;28:267–273.

14 Telama R, Yang X, Laakso L, Viikari J: Physical activity in childhood and adolescence as predictor of physical activity in young adulthood. Am J Prev Med 1997;13:317–323.

15 Sallis JF: Age-related decline in physical activity: a synthesis of human and animal studies. Med Sci Sports Exerc 1998;32:1598–1600.

16 Salmon J, Shilton T: Endorsement of physical activity recommendations for children and youth in Australia. J Sci Med Sport 2004;7:405–406.

17 National Association for Sport and Physical Education: Physical Activity for Children: A Statement of Guidelines, ed 2. Reston, National Association for Sport & Physical Education, 2004.

18 US Department of Health and Human Services, US Department of Agriculture: Dietary Guidelines for Americans 2005 (accessed July 2005 at www.healthierus.gov/dietaryguidelines).

19 Department of Health: At Least Five a Week: Evidence on the Impact of Physical Activity and Its Relationship To Health. London, Department of Health, 2004.

20 Health Canada, The College of Family Physicians of Canada, Canadian Paediatric Society, Canadian Society for Exercise Physiology: Physical Activity Recommendations for Children. Ottawa, Minister of Public Works and Government Services Canada, 2002.

21 Commonwealth of Australia, Department of Health and Ageing: Australia's Physical Activity Recommendations for Children and Young People. Canberra, Department of Health and Ageing, 2004.

22 US Department of Transportation, Federal Highway Administration, Research and Technical Support Centre: Nationwide Personal Transportation Survey. Lantham, Federal Highway Administration, 1997.

23 Ham SA, Macera CA, Lindley C: Trends in walking for transportation in the United States, 1995 and 2001. Prev Chronic Dis [serialonline] 2005 Oct [accessed 13.3.06]. Available from URL: http://www.cdc.gov/pcd/issues/2005/oct/04_0138.htm.

24 Salmon J, Timperio A, Cleland V, Venn A: Trends in children's physical activity and weight status in high and low socio-economic status areas of Melbourne, Victoria, 1985–2001. Aust NZ J Publ Health 2005;29:337–342.

25 Harten N, Olds T: Patterns of active transport in 11–12 year old Australian children. Aust NZ J Publ Health 2004;28:167–172.

26 Carlin JB, Stevenson MR, Roberts I, Bennett CM, Gelman A, Nolan T: Walking to school and traffic exposure in Australian children. Aust NZ J Publ Health 1997;21:286–292.

27 Hands B, Parker H, Glasson C, Brinkman S, Read H: Physical Activity and Nutrition Levels in Western Australian Children and Adolescents: Report. Perth, Western Australian Government, 2004, pp 34–35, 42–44.

28 Lowry R, Wechsler H, Kann L, Collins JL: Recent trends in participation in physical education among US high school students. J Sch Health 2001;71:145–152.

29 Sport England: Young People and Sport in England: Trends in Participation 1994–2002. London, Sport England, 2003.

30 Australian Bureau of Statistics: Children's Participation in Cultural and Leisure Activities, Australia. Canberra, Australian Bureau of Statistics, 2001.
31 Australian Bureau of Statistics: Children's Participation in Cultural and Leisure Activities, Australia. Australia, Australian Bureau of Statistics, 2004.
32 Norton K, Dollman J, Klanarong S, Robertson I: Kid's sport. Who's playing what? Sport Health 2001;19:12.
33 Centers for Disease Control and Prevention: Physical activity levels among children aged 9–13 years – United States, 2002. MMWR Weekly 2003;52:785–788.
34 Sport and Recreation New Zealand: SPARC Trends. Trends in Participation in Sport and Active Leisure 1997–2001. Aukland, Sport and Recreation New Zealand, 2003.
35 Booth M: What proportion of Australian children are sufficiently active? Med J Aust 2000; 173:S6–S7.
36 Pratt M, Macera C, Blanton C: Levels of physical activity and inactivity in children and adults in the United States: current evidence and research issues. Med Sci Sports Exerc 1999;31:S526–S533.
37 Welk GJ, Corbin CB, Dale D: Measurement issues in the assessment of physical activity in children. Res Q Exerc Sport 2000;71:S59–S73.
38 Epstein LH, Paluch RA, Kalakanis LE, Goldfield GS, Cerny FJ, Roemmich JN: How much activity do youth get? A quantitative review of heart-rate measured activity. Pediatrics 2001;108:1–10.
39 Pate R, Freedson P, Sallis JF, Taylor W, Sirard J, Trost SG, Dowda M: Compliance with physical activity guidelines: prevalence in a population of children and youth. Ann Epidemiol 2002;12: 303–308.
40 Riddoch CJ, Andersen BL, Wedderkopp N, Harro M, Klasson-Heggebo L, Sardinha LB, Cooper AR, Ekelund U: Physical activity levels and patterns of 9- and 15-year-old European children. Med Sci Sports Exerc 2004;36:86–92.
41 Telford A, Salmon J, Timperio A, Crawford D: Examining Physical Activity Among 5- to 6- and 10- to 12-Year-Old Children: The Children's Leisure Activities Study. Pediatr Exerc Sci 2005;17: 266–280.
42 French SA, Story M, Jeffery RW: Environmental influences on eating and physical activity. Ann Rev Pub Health 2001;22:309–335.
43 Brownson RC, Boehmer TK, Luke DA: Declining rates of physical activity in the United States: What are the contributors? Ann Rev Pub Health 2005;26:421–443.
44 Sallis JF, Owen N: Ecological models of health behaviour; in Glanz K, Rimer BK, Lewis FM (eds): Ecological Models of Health Behaviour. San Francisco, Jossey-Bass, 2002.
45 O'Brien M, Jones D, Sloan D, Rustin M: Children's independent spatial mobility in the urban public realm. Childhood 2000;7:257–277.
46 Valentine G, McKendrick J: Children's outdoor play: exploring parental concerns about children's safety and the changing nature of childhood. Geoforum 1997;28:219–235.
47 Hinde S, Dixon J: Changing the obesogenic environment: insights from a cultural economy of car reliance. Transportation Res Part D 2005;10:31–35.
48 Prezza M, Pilloni S, Morabito C, Sersante C, Alparone FR, Guiliani MV: The influence of psychosocial and environmental factors on children's independent mobility and relationship to peer frequentation. J Commun Appl Soc Psychol 2001;11:435–450.
49 Timperio A, Crawford D, Telford A, Salmon J: Perceptions about the local neighbourhood and walking and cycling among children. Prev Med 2004;38:39–47.
50 Timperio A, Ball K, Salmon J, Roberts R, Giles-Corti B, Simmons D, Baur LA, Crawford D: Personal, family, social and environmental correlates of active commuting to school. Am J Prev Med 2006;30:45–51.
51 Carver A, Salmon J, Campbell K, Baur L, Garnett S, Crawford D: How do perceptions of local neighborhood relate to adolescents' walking and cycling? Am J Health Promot 2005;20:139–147.
52 Adkins S, Sherwood NE, Story M, Davis M: Physical activity among African-American Girls: the role of parents and the home environment. Obes Res 2004;12:38S–45S.
53 Romero AJ: Low-income neighborhood barriers and resources for adolescents' physical activity. J Adolesc Health 2005;36:253–259.
54 Gordon-Larsen P, McMurray RG, Popkin BM: Determinants of adolescent physical activity and inactivity patterns. Pediatrics 2000;105:e83.

55 Gomez JE, Johnson BA, Selva M, Sallis JF: Violent crime and outdoor physical activity among inner-city youth. Prev Med 2004;39:876–881.
56 Molnar BE, Gortmaker SL, Bull FC, Buka SL: Unsafe to play? Neighborhood disorder and lack of safety predict reduced physical activity among urban children and adolescents. Am J Health Promot 2004;18:378–356.
57 Romero AJ, Robinson TN, Kraemer HC, Erickson SJ, Haydel F, Mendoza F, Killen JD: Are perceived neighborhood hazards a barrier to physical activity in children? Arch Pediatr Adolesc Med 2001;155:1143–1148.
58 Saelens BE, Sallis JF, Frank LD: Environmental correlates of walking and cycling: findings from the transportation, urban design, and planning literatures. Ann Behav Med 2003;25:80–91.
59 Braza M, Shoemaker W, Seeley A: Neighborhood design and rates of walking and biking to elementary school in 34 California communities. Am J Health Promot 2004;19:128–136.
60 Veitch J, Ball K, Robinson S, Salmon J: Where do children play? A qualitative study of parents' perceptions of influences on children's active free-play. Health Place 2006;12:383–393.
61 Henning Brodersen N, Steptoe A, Williamson S, Wardle J: Sociodemographic, developmental, environmental, and psychological correlates of physical activity and sedentary behavior at age 11 to 12. Ann Behav Med 2005;29:2–11.

Jo Salmon, PhD
School of Exercise and Nutrition Sciences, Deakin University
221 Burwood Highway
Burwood VIC 3125 (Australia)
Tel. +61 3 9251 7254, Fax +61 3 9244 6017, E-Mail jo.salmon@deakin.edu.au

Tomkinson GR, Olds TS (eds): Pediatric Fitness. Secular Trends and Geographic Variability.
Med Sport Sci. Basel, Karger, 2007, vol 50, pp 200–209

Evolution of Maximal Oxygen Uptake in Children

Thomas W. Rowland

Baystate Medical Center, Springfield, Mass., USA

Abstract

Evidence exists that physiologic aerobic fitness, defined by maximal oxygen uptake related to body mass ($\dot{V}O_2 \cdot kg^{-1}$), bears health implications for children as well as adults. Identifying secular trends in $\dot{V}O_{2max} \cdot kg^{-1}$ is important, then, in assessing the impact of socio-cultural influences on aerobic fitness in youth. At present, no data exist to provide a population-based indication of secular trends in $\dot{V}O_{2max}$ in young persons. However, based on documented temporal changes in childhood obesity and physical activity levels, it can be anticipated that a decline of $\dot{V}O_{2max} \cdot kg^{-1}$ is occurring over time. This fall would be more likely due to increases in body fat in youth, inflating the size-normalizing factor ('per kg'), rather than a temporal deterioration in cardiovascular function per se.

Maximal oxygen uptake ($\dot{V}O_{2max}$) defines the limits of oxygen utilisation by the metabolic machinery of exercising muscle and serves as the fundamental marker of physiologic aerobic fitness. When expressed in absolute terms (i.e. litres per minute), $\dot{V}O_{2max}$ reflects *cardiovascular fitness* – a congregate value indicating the functional capacity of the myriad components of the oxygen delivery chain – anatomic and physiologic factors which begin as air intake into the lungs and ending in cellular oxidative phosphorylation.

Since $\dot{V}O_{2max}$ corresponds to body size, comparisons between individuals or in the same person over time – a major consideration in dealing with children – are typically adjusted for body mass. It is important to recognise that when $\dot{V}O_{2max}$ is expressed in this manner values become influenced by body fat content as well. In the denominator of $\dot{V}O_{2max} \cdot kg^{-1}$, body mass includes fat which is largely metabolically inert. Thus, a lean individual will have a greater $\dot{V}O_{2max} \cdot kg^{-1}$ than an obese subject who has an identical oxygen delivery capacity.

The means of determining $\dot{V}O_{2max}$ during a progressive treadmill or cycle test is the same in children as adults. However, certain aspects of maximal aerobic power are distinct to the pediatric age group (see [1] for discussion). Since a true $\dot{V}O_{2max}$ necessitates an exhaustive volitional effort, however, valid measures in young children are difficult to obtain. For this reason, most data in youth have been published in subjects over 8–10 years old.

It is not common for children to demonstrate a tapering or 'plateau' of $\dot{V}O_2$ during such testing, which has been utilised in adults as an indicator of a true maximal value. When children achieve certain heart rate or respiratory exchange ratio criteria, however, a maximal value can be assumed. Some have labeled this as peak $\dot{V}O_2$ rather than $\dot{V}O_{2max}$.

$\dot{V}O_{2max}$ in absolute terms rises progressively during childhood, with greater values in males than females. When expressed relative to body mass, values are essentially stable in boys across the childhood years at about $50\,\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$, while girls tend to show a progressive decline (a 20% decrease between years 8 and 13). A strong argument has been presented, however, that the ratio standard, or $\text{kg}^{1.0}$ is not an appropriate normalizing factor for $\dot{V}O_{2max}$, and that values should instead be expressed relative to allometrically-derived mass exponents (such as $\text{mass}^{0.67}$ or $\text{mass}^{0.75}$). Using such size adjustment, $\dot{V}O_{2max}$ relative to mass in males increases slowly during the growing years, while values in females are essentially stable. By whatever analysis, however, increase in body size – specifically the dimensions of the heart, lungs, and exercising muscle – is responsible for the rise in $\dot{V}O_{2max}$ during the course of childhood.

Compared to adults, $\dot{V}O_{2max}$ in children appears to be much less 'plastic' (i.e. relatively insensitive to changes in level of physical activity or endurance training). This may explain the relatively low tracking of $\dot{V}O_{2max}$ from childhood into the adult years (coefficients typically $r = 0.05–0.20$) [2].

$\dot{V}O_{2max}$ and Health

In adults, physiologic aerobic fitness as indicated by $\dot{V}O_{2max}$ has been linked to positive health outcomes. In the adult population surrogate markers of $\dot{V}O_{2max}$ such as treadmill endurance time and submaximal exercise testing have been associated with significantly diminished risk of coronary artery disease and myocardial infarction as well as a lower rate of all-cause mortality (see [3, 4] for review). Moreover, these reports indicated an inverse relationship between indirect markers of $\dot{V}O_{2max}$ and cardiovascular risk factors such as hypertension, unfavorable serum lipid profiles, and total and abdominal obesity [5, 6].

Studies examining the relationships between directly measured $\dot{V}O_{2max}$ and health outcomes in adults have produced similar results. Kavanagh et al. found

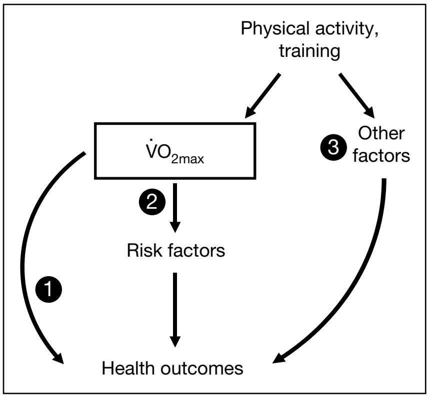


Fig. 1. Three potential mechanisms by which $\dot{V}O_{2max}$ could influence health outcomes (see text).

that for every $1\,mg \cdot kg^{-1} \cdot min^{-1}$ greater $\dot{V}O_{2max}$, mortality rate from ischemic heart disease in 60-year-old women fell by 10 percent [7]. Talbot et al. described a reduction in coronary heart disease risk related to $\dot{V}O_{2max}$ in both younger (<65 years old) and older men independent of other traditional risk factors [8]. A 16% increase in $\dot{V}O_{2max}$ with endurance training in 17–65-year-old subjects was associated with favourable changes in body composition and serum lipoprotein profile [9].

Why the body's capacity to transport oxygen to exercising muscle should have a salutary effect on such a wide diversity of pathogenetic mechanisms of disease is not altogether obvious. Evidence exists for a variety of effects [4]. The influence of $\dot{V}O_{2max}$ might be a direct one (i.e., enhanced peripheral vascular reactivity or myocardial vascularisation, inhibition of thrombosis, or reduced risk of arrhythmias with higher aerobic fitness might mitigate effects of atherosclerotic vascular disease). Alternatively, an expanded cardiovascular system and improved oxygen delivery with greater $\dot{V}O_{2max}$ could depress risk factors for cardiovascular disease (diminished resting and exercise sympathetic tone to reduce blood pressure levels, improved insulin sensitivity). Or, it might be that $\dot{V}O_{2max}$ and improved health outcomes are not causally related but both simply independent expressions of a third process (such as endurance training or regular physical activity, perhaps with genetic influences) (fig. 1).

In children and adolescents, of course, it is not possible to link $\dot{V}O_{2max}$ with disease outcomes such as coronary artery disease and the complications of obesity, hypertension, diabetes, and osteoporosis. Consequently, evidence for a salutary effect of $\dot{V}O_{2max}$ on health in this age group has focused instead on assessing relationships of maximal aerobic power with recognised risk factors for these diseases. And here the argument for a link between $\dot{V}O_{2max}$ and health is less compelling than that observed in adults.

In the healthy pediatric population, aerobic fitness appears to have little bearing on cardiovascular risk factors. With few exceptions [10], cross-sectional studies in non-trained pediatric subjects have indicated no significant relationship between directly-measured $\dot{V}O_2$ per kg and systolic or diastolic blood pressure, serum lipid concentrations, waist/hip circumference, serum insulin, or blood glucose levels once the influence of body fat content has been considered [11–15].

On the other hand, highly-trained child and adolescent endurance athletes tend to show a more favorable lipid profile (in particular, higher levels of HDL-cholesterol) compared to non-athletes [16]. When analyses are confined to this group, weak-to-moderate positive correlations between $\dot{V}O_{2max}$ and HDL-cholesterol have been reported [17–19]. Eisenmann et al., e.g. demonstrated a correlation coefficient of $r = 0.31$ ($p < 0.05$) between $\dot{V}O_{2max}$ and HDL-cholesterol levels once body fat had been accounted for in a group of 10- to 19-year-old distance runners [17].

Atomi et al. reported significantly higher levels of HDL-cholesterol in 21 trained soccer players ages 10–12 years compared to non-training control boys matched for height, weight, skeletal age, and percent body fat [18]. $\dot{V}O_{2max}$ values were 54.0 ± 1.0 (SE) $ml \cdot kg^{-1} \cdot min^{-1}$ and $48.9 \pm 1.0\, ml \cdot kg^{-1} \cdot min^{-1}$ in the athletes and non-athletes, respectively. When the two groups were combined, $\dot{V}O_{2max}$ related to lean body mass correlated significantly with HDL-cholesterol level ($r = 0.35$). Whether these findings in athletes reflect a training effect or rather a genetically-based constitutional characteristic of a preselected population of youth is unclear. As Tolfrey et al. pointed out [20] ‘a cause-effect relationship between exercise and the lipoprotein profile cannot be readily established from this design’.

In this regard, it is important to recognise that periods of aerobic training in non-athletic healthy children have failed to reveal any consistent alterations in serum lipoprotein levels [20]. In 12 such studies, HDL-cholesterol concentration rose in 4 (by 9–20%), decreased in one, and remained unchanged in 7. The inability of these programmes to improve HDL-cholesterol might be explained by the limited training duration. Only two exceeded 15 weeks in duration, and seven of the 12 lasted 12 weeks or less. It may be important, too, that such endurance training programs in prepubertal children, in distinction from those in adults, typically result in only small (~5%) improvements in $\dot{V}O_{2max}$. Highly-trained child endurance athletes, on the other hand, usually demonstrate a $\dot{V}O_{2max}$ which is approximately 30% grater than that of untrained children [21].

In respect to $\dot{V}O_2 \cdot kg^{-1}$ and lipid profiles in youth, it is possible from these data to suggest that there may, in fact, be a dose-response relationship, but one which is considerably weaker than that observed in adults. The long-term health implications of any such effect of this magnitude are, of course, problematic.

Endurance training programs in normotensive youth typically demonstrate no changes in resting blood pressure. However, improvements in $\dot{V}O_{2max}$ have accompanied endurance training programs in which blood pressure reductions have occurred in youth with mild pre-training hypertension [22]. For instance, Hagberg et al. demonstrated that a 6-month training program in 25 adolescents lowered average blood pressure from 137/80 to 129/75 with a rise in mean $\dot{V}O_{2max}$ from 43 to 48 $ml \cdot kg^{-1} \cdot min^{-1}$ [23].

The evidence supporting a link between $\dot{V}O_{2max}$ and cardiovascular risk factors in youth is not overly convincing either by cross-sectional or training studies. However, certain longitudinal data provide a more compelling case for the importance of aerobic fitness during the growing years. Using data from the Amsterdam Growth and health Longitudinal Study, Twisk et al. demonstrated that $\dot{V}O_{2max}$ measured serially between the ages of 13 and 27 years was inversely correlated with total cholesterol [24]. In the Danish Youth And Sports Study, Hasselstrom et al. found that relationships between $\dot{V}O_{2max}$ in adolescence and cardiovascular risk factors in young adulthood was weak, but when the *change* in aerobic fitness over the eight years of the study was considered, the relationships became significant [25].

Janz et al. assessed $\dot{V}O_{2max}$ and cardiovascular risk factors over five years in 125 healthy children beginning at the age of 10.5 years [26]. Changes in aerobic fitness explained 4% of the variability in systolic blood pressure, 11% of total cholesterol to HDL-cholesterol ratio, 5% of LDL-cholesterol levels, and 15% of adiposity at year five.

Secular Changes in $\dot{V}O_{2max}$ in Youth

It is of interest to health scientists and practitioners to analyze changes in aerobic fitness in the pediatric population over time. Such an assessment might provide (1) a marker of socio-cultural influences which may affect $\dot{V}O_{2max}$ and, in turn, (2) signal a need to for public health strategies to promote aerobic fitness for positive health outcomes.

Freedson and Goodman compiled data on 38 exercise studies which measured $\dot{V}O_{2max}$ relative to body mass in boys from 1938 to 1993 [27]. As indicated in figure 2, no obvious changes were evident over this 55-year period. Eisenmann and Malina performed the same type of analysis ten years later [28]. They compiled results of 43 studies in boys and 32 of girls which involved direct measurement of

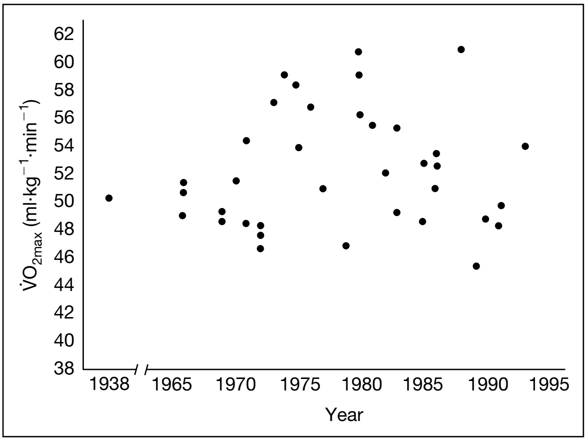


Fig. 2. $\dot{V}O_{2max}$ values in studies of boys between 1938 and 1993 (compiled in Freedson and Goodman [27]). Reprinted with permission.

$\dot{V}O_{2max}$ in non-athletic healthy subjects residing in the United States. $\dot{V}O_{2max}$ (both absolute and mass-relative) showed no change in boys over time.

Among studies in females, a greater degree of fluctuation of values between decades was observed. For instance, studies in the oldest group (age 15–19 years) had a mean value of $34.6\,ml \cdot kg^{-1} \cdot min^{-1}$ in the 1960's, a rise to $41.6\,ml \cdot kg^{-1} \cdot min^{-1}$ in the 1970's, and a decline back to $33.4\,ml \cdot kg^{-1} \cdot min^{-1}$ in the 1990s.

Values of $\dot{V}O_{2max}$ in children were stable in studies reported in the United Kingdom between 1975 and 1991 [29]. However, in the 45-year period between 1952 and 1997, measurements of $\dot{V}O_{2max}$ of Norwegian children and adolescents declined at an average rate of -0.12% annually [30].

These exercises in data-gathering are interesting but in truth provide little insight into the question of temporal changes in $\dot{V}O_{2max}$ in the pediatric population. They are not epidemiologic investigations but rather represent compilations of small studies designed to answer a certain physiologic question. The subjects involved are typically volunteer recruits and as such reflect children who are athletically-inclined, non-obese, and motivated to exercise. At best they can be considered to reflect trends in $\dot{V}O_{2max}$ in children over time in those who will volunteer for maximal exercise testing.

The problem is compounded by the fact that these studies have been performed in a large number of laboratories using different equipment, staffing, and testing conditions. Moreover, during the time span in consideration, equipment for measuring oxygen uptake has evolved dramatically. The importance of these factors is reflected in the wide range of $\dot{V}O_{2max}$ reported in these studies, the consequence of which is that there are no defined 'norms' for $\dot{V}O_{2max}$ in children and adolescents. At present there exist no population-based measurements of $\dot{V}O_{2max}$ in youth over time to assess temporal changes in aerobic physiologic fitness.

Determinants of $\dot{V}O_{2max}$: A Model for Secular Changes

Although there are no solid data to indicate if $\dot{V}O_{2max}$ is changing over time in youth, certain inferences can be drawn by considering the more documented temporal trends of factors which influence both the numerator and denominator of $\dot{V}O_{2max} \cdot kg^{-1}$. Based on these, a model of what should be *expected* to happen with $\dot{V}O_{2max}$ levels in the pediatric population over time can be constructed.

Barring genetic mutation, there is no reason that intrinsic changes within the oxygen delivery chain should be expected to vary over time. However, there are two external influences, habitual physical activity and body fat content, that have the potential for affecting temporal trends in $\dot{V}O_{2max}$ per kg.

Habitual Physical Activity

The dimensions (left ventricular size, plasma volume, muscle capillarisation) and function (muscle aerobic enzyme activity) of the oxygen delivery machine which define $\dot{V}O_{2max}$ are responsive to alterations in level of physical activity (i.e., endurance training). Would the perceived decline in habitual physical activity of children in response to an increasing technological society be expected to cause a temporal fall in $\dot{V}O_{2max} \cdot kg^{-1}$? If so, by how much?

The answers are not entirely clear. However, there are several lines of evidence to suggest that a population-wide decline in daily physical activity in youth might have little impact on $\dot{V}O_{2max}$. First, numerous studies have indicated that $\dot{V}O_{2max}$ bears little relationship to level of habitual activity in the pediatric population [31]. And, as noted above, if you not just increase daily activity but rather place a child in an intense program of regular aerobic training, little changes in $\dot{V}O_{2max}$ are observed (typically about 5%) [21]. Kemper et al. found a significant relationship in changes in $\dot{V}O_{2max}$ and physical activity in the same subjects between ages 13 and 27 years [32]. However, the influence of physical activity was very small, accounting for only a 2–5% rise in aerobic fitness.

The effect of a child's adopting a sedentary lifestyle on his or her $\dot{V}O_{2max}$ has not been well defined. In a study in which change in aerobic fitness was estimated after 9 weeks of *total* inactivity in children, $\dot{V}O_{2max}$ per kg declined only 13 per cent [33]. This information suggests that little decrease in the numerator of $\dot{V}O_{2max} \cdot kg^{-1}$ (i.e. absolute $\dot{V}O_{2max}$, or cardiovascular functional capacity should be expected over time from downward trends in habitual physical activity in children and adolescents.

Body Fat Content

As described above, an accumulation of metabolically-inert body fat inflates the denominator of $\dot{V}O_2 \cdot kg^{-1}$. Consequently, greater obesity is inversely related to $\dot{V}O_{2max} \cdot kg^{-1}$, even if true cardiovascular fitness (i.e. absolute $\dot{V}O_{2max}$ in the numerator) increases [34]. Given the dramatic rise in childhood obesity in recent decades, it should be expected *perforce* that a temporal decline in $\dot{V}O_{2max} \cdot kg^{-1}$ should be observed in both boys and girls.

It should be re-emphasised that such a trend would not reflect true cardiovascular functional capacity but rather a secular change in the factor (body mass) by which absolute $\dot{V}O_2$ max is being adjusted for body size. In this respect, secular declines in levels of physical activity which cause or exacerbate obesity would, in fact, be linked to a reduction in $\dot{V}O_{2max} \cdot kg^{-1}$. This would result by influencing the denominator rather than the numerator of $\dot{V}O_{2max} \cdot kg^{-1}$ (see above).

Conclusion

In summary, although not as persuasive as in adults, evidence does indicate a role for physiologic aerobic fitness in the future health of children and adolescents. At present there are no data by which trends in $\dot{V}O_{2max} \cdot kg^{-1}$ over time in the pediatric population can be judged. By examining established trends in factors that influence $\dot{V}O_{2max} \cdot kg^{-1}$, however, it should be expected that a downward trend over time is occurring. It is most likely, however, that such trends reflect temporal alterations in body composition (increasing obesity) rather than a true decrement of cardiovascular function over time.

References

1 Rowland TW: Children's Exercise Physiology. Champaign IL, Human Kinetics Books, 2005, pp 89–112.

2 Malina RM: Tracking of physical activity and physical fitness across the lifespan. Res Q Exerc Sport 1996;67(suppl 3):S48–S57.

3 Paffenbarger RS, Hyde RT, Wing AL: Physical activity and physical fitness as determinants of health and longevity; in Bouchard C, Shephard RJ, Stephens T, Sutton JR, McPherson BD (eds): Exercise, Fitness, and Health. Champaign IL, Human Kinetics Books, 1990, pp 33–48.

4 U.S. Department of Health and Human Services. Physical Activity and Health: A Report of the Surgeon General. Atlanta, GA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion, 1996.

5 Ross R, Katzmarzyk PT: Cardiorespiratory fitness is associated with diminished total and abdominal obesity independent of body mass index. Int J Obes Relat Metab Disord 2003;27:204–210.

6 McMurray RG, Ainsworth BE, Harrell JS, Griggs TR, Williams OD: Is physical activity or aerobic power more influential on reducing cardiovascular disease risk factors? Med Sci Sports Exerc 1998;30:1521–1529.

7 Kavanagh T, Mertens DJ, Hamm LF, Beyene J, Kennedy J, Corey P, Shephard RJ: Peak oxygen uptake and cardiac mortality in women referred for cardiac rehabilitation. J Am Coll Cardiol 2003;42:2139–2143.

8 Talbot LA, Morrell CH, Mettger EJ, Fleg JL: Comparison of cardiorespiratory fitness versus leisure time physical activity as predictors of coronary events in men aged $\leq$65 years and $>$65 years. Am J Cardiol 2002;89:1187–1192.

9 Wilmore JH, Green JS, Stanforth PR, Gagnon J, Rankinen T, Leon AS, Rao DC, Skinner JS, Bouchard C: Relationship of changes in maximal and submaximal aerobic fitness to changes in cardiovascular disease and non-insulin-dependent diabetes risk factors with endurance training: the HERITAGE Family Study. Metab Clin Exper 2001;50:1255–1263.

10 Tolfrey K, Campbell IG, Jones AM: Selected predictor variables and the lipid-lipoprotein profile of prepubertal girls and boys. Med Sci Sports Exerc 1999;31:1550–1557.

11 Kwee A, Wilmore JH: Cardiorespiratory fitness and risk factors for coronary artery disease in 8- to 15-year-old boys. Pediatr Exerc Science 1990;2:372–383.

12 Sady SP, Berg K, Beal D, Smith JL, Savage MP: Aerobic fitness and serum high density lipoprotein cholesterol in young children. Hum Biol 1984;56:771–781.

13 Al-Hazzaa HM, Sulaiman MA, al-Matar AJ, al-Mobaireek KF: Cardiorespiratory fitness, physical activity patterns and coronary risk factors in preadolescent boys. Int J Sports Med 1994;15:267–272.

14 Stensel DJ, Lin FP, Ho TF, Aw TC: Serum lipids, serum insulin, plasma fibrinogen, and aerobic capacity in obese and non-obese Singaporean boys. Int J Obes Relat Metab Disord 2001;25: 984–989.

15 Gutin B, Islam S, Manos T, Cucuzzo N, Smith C, Stachura ME: Relation of percentage of body fat and maximal aerobic capacity to risk factors for atherosclerosis and diabetes in black and white seven-to-eleven year old children. J Pediatr 1994;125:847–852.

16 Eisenmann JC: Blood lipids and lipoproteins in child and adolescent athletes. Sports Med 2002;32:297–305.

17 Eisenmann JC, Womack CJ, Reeves MJ, Pivarnik JM, Malina RM: Blood lipids of young distance runners: distribution and inter-relationships among training volume, peak oxygen consumption, and body fatness. Eur J Appl Physiol 2001;85:104–112.

18 Atomi Y, Kuroda Y, Asami T, Kawahara T: HDL-cholesterol of children (10 to 12 years of age) related to $\dot{V}O_{2max}$, body fat, and sex; in Rutenfranz J, Mocellin R, Klimt F (eds): Children and Exercise XII. Champaign IL, Human Kinetics Books, 1986, pp 167–172.

19 Smith BW, Metheny WP, Sparrow AW: Serum lipid and lipoprotein profiles in age-group runners; in Weiss MR, Gould D (eds): Sport for Children and Youths. Champaign IL, Human Kinetics Books, 1986, pp 269–273.

20 Tolfrey K, Jones AM, Campbell IG: The effect of aerobic exercise training on the lipid-lipoprotein profile of children and adolescents. Sports Med 2000;29:99–112.

21 Rowland TW: The aerobic trainability of athletic and non-athletic children; in Froberg K, Lammert O, St. Hansen H, Blimkie JRC (eds): Children & Exercise XVIII. Exercise and Fitness-Benefits and Risks. Odense, Odense University Press, 1997, pp 173–182.

22 Alpert BS, Wilmore JH: Physical activity and blood pressure in adolescents. Pediatr Exerc Sci 1994;6:361–380.

23 Hagberg JM, Goldring D, Ehsani AA, Heath GW, Hernandez A, Schechtman K, Holloszy JO: Effect of exercise training on the blood pressure and hemodynamic features of hypertensive adolescents. Am J Cardiol 1983;52:763–768.

24 Twisk JWR, Kemper HCG, van Michelen W: Tracking of activity and fitness and the relationship with cardiovascular disease risk factors. Med Sci Sports Exerc 2000;32:1455–1461.

25 Hasselstrom H, Hansen SE, Froberg K, Andersen LB: Physical fitness and physical activity during adolescence as predictors of cardiovascular disease risk in young adulthood. Danish Youth and Sports Study. An eight-year follow-up study. Int J Sports Med 2002;23(suppl 1):S27–S31.

26 Janz KF, Dawson JD, Mahoney LT: Increases in physical fitness during childhood improve cardiovascular health during adolescence: the Muscatine Study. Int J Sports Med 2002;23(suppl 1): S15–S21.
27 Freedson PS, Goodman TL: Measurement of oxygen consumption; in Rowland TW (ed): Pediatric Laboratory Exercise Testing. Champaign IL, Human Kinetics Books, 1993, pp 91–114.
28 Eisenmann JC, Malina RM: Secular trend in peak oxygen consumption among United States youth in the 20th century. Am J Hum Biol 2002;14:699–706.
29 Armstrong N, Williams J, Balding J, Gentile P, Kirby B: The peak oxygen uptake of British children with reference to age, sex, and sexual maturity. Eur J Appl Physiol 1991;62:369–375.
30 Fredrikson PM, Thaulow E, Nystad W, Ingjer F: Aerobic capacity among children and adolescents. Nordic results over the past 45 years. Tidsskr Nor Laegeforen 1998;118:3106–3110.
31 Morrow JR, Freedson PS: Relationship between habitual physical activity and aerobic fitness in adolescents. Pediatr Exerc Sci 1994;6:315–329.
32 Kemper HCG, Twisk JWR, Koppes LLJ, van Mechelen W, Post GB: A 15-year physical activity pattern is positively related to aerobic fitness in young males and females (13–27 years). Eur J Appl Physiol 2001;84:395–402.
33 Rowland TW: Effect of prolonged inactivity on aerobic fitness of children. J Sports Med Phys Fitness 1994;34:147–155.
34 Rowland TW: Effects of obesity on aerobic fitness in adolescent females. Am J Dis Child 1991;145:764–768.

Thomas W. Rowland, MD
Department of Pediatrics, Baystate Medical Center
Springfield, MA 01199 (USA)
Tel. +1 413 794 7350, Fax +1 413 794 7140, E-Mail Thomas.rowland@bhs.org

Tomkinson GR, Olds TS (eds): Pediatric Fitness. Secular Trends and Geographic Variability.
Med Sport Sci. Basel, Karger, 2007, vol 50, pp 210–225

Distributional Changes in the Performance of Australian Children on Tests of Cardiorespiratory Endurance

James Dollman, Timothy S. Olds

Nutritional Physiology Research Centre, School of Health Sciences, University of South Australia, Adelaide, Australia

Abstract

There is accumulating evidence of worldwide declines in cardiorespiratory endurance (CRE) among children. To date, few studies have focused on trends in distributional characteristics of CRE performance. This study analyzed 1985 and 1997 samples of Australian children on the 1.6 km run/walk test, using a variety of descriptive and inferential statistics to compare distributions of average running speed among 10- to 11-year-olds. The analysis was conducted on 965 boys and 935 girls from 1985, and 661 boys and 553 girls from 1997. Among boys there was a significant increase in the coefficient of variation of average completion times, with a marked decrease in negative skew. This was largely attributable to the largest declines occurring in the middle percentiles, with relatively smaller declines at low (<5th) and high (>90th) percentiles. The bulk of the scores have shifted towards the left side of the distribution, reducing the skew. Among girls the distributional trends were different; there was little change in 'scatter' and skew of test scores, with declines in performance being relatively uniform across the distribution. These findings contrast with previous reports of greater declines among the lowest ranked performers on CRE tests. The observed declines in all percentiles other than the lowest and highest ranked boys suggest that mechanisms for declining fitness are widespread throughout the population and may reflect changes in environmental barriers and enablers of regular physical activity among Australian youth.

Recent research into trends in children's performance on tests of cardiorespiratory endurance (CRE) has revealed deteriorating scores over the last 20 years [1]. While there is now clear evidence of a decline in average performance, changes in the distribution of children's fitness scores are less clear. The issue is potentially important in understanding both how the decline in performance came about, and how best to address it. If average test scores are being dragged down by an increasingly long tail of poor scores, it would suggest that some factor is differentially affecting certain subsets of children. If, on the other hand, there has been an across-the-board fall in scores, with little or no distributional change, a generalized influence – presumably environmental – may be at work. A reduction in the tail of superior performances, on the other hand, may have implications for talent identification, with a reduced pool of very fit youngsters.

There is evidence that the variability of CRE test scores is increasing. Tomkinson [2] reported consistent increases in the coefficient of variation (CV) of CRE test scores in Australasia. There were changes of −0.08 to +0.75% per annum in the CV(%) for performances of over 130,000 children on the 1.6 km walk/run, 600 yard run and 20 m shuttle run test (20 m SRT) between the 1960s and the 1990s. Assuming an average increase in CV of about 0.35%, this amounts to a performance deterioration of about 0.25 standard deviations (SD) for the 1.6 km run/walk per decade. Using large datasets from the Japanese Ministry of Education, Science and Culture, Noi and Masaki [3] also reported increases in the CVs of fitness test scores for 11-, 14- and 17-year-olds from 1980 onwards.

Unfortunately, trends in CVs do not provide information on what has been happening at the tails of the distribution, nor on changes in skewness. Using CVs alone, it is not possible to know whether the better performers improved, the poorer performers deteriorated, or both. A handful of studies have commented on secular trends in distributions. Wedderkopp [4] examined secular trends in CRE test performance using maximal work test data from three representative samples of Danish children and adolescents between 1983 and 1998. In general, unfit Danish children and adolescents were less fit in the 1990s than in the 1980s, with the fittest girls fitter, and the fittest boys less fit. Wilson [5] examined CRE test scores from a single boys' school over a 15-year period. There was an increasing negative skew (towards the poor-performing tail) in the 600 yard run. Shifts in distributional characteristics in 1.6 km run test performance were also reported by McNaughton et al. [6], who contrasted Australian schoolchildren tested in 1985 and 1995. The better performers in 1995 were superior to those of equivalent rank in 1985. In contrast, the average and below average performers in 1995 were worse than in 1985. Taken together, these few studies suggest that by and large it is change at the poorly performing tail of the distribution which is dragging the average scores down, while the better-performing tail has shown little change.

The aim of this study was to examine distributional changes in 1.6 km run/walk test performance between 1985 and 1997 among 10- to 11-year-old South Australians.

Methods

Performance scores on the 1.6 km run/walk from the Australian Schools Health and Fitness Survey (ASHFS; [7]) and the South Australian Schools Health and Fitness Survey (SASHFS; [8]), were assessed for evidence of a distributional shift. Protocols of administration for the test were carefully replicated between surveys, as the primary objective of the 1997 SASHFS was to describe trends since 1985 in a range of fitness and body composition variables.

Subjects and Sampling

In 1985, a nationally representative sample of 8,484 children aged 7–15 years participated in the ASHFS, providing extensive data on health and fitness through various field and technical tests, questionnaires and blood samples. The sampling design has been described in detail elsewhere [7]. Briefly, a self-weighted sample was drawn by selecting schools with a probability proportional to enrolment numbers, and then using simple random sampling to select 10 children per age/sex category within each school. Ninety percent of invited schools agreed to participate (n = 109), and 77.5% of students selected in the initial sample received parental consent to participate.

In the SASHFS, 33 schools were randomly chosen from a list of 580 South Australian primary schools. Within each school, all children who were either 10 or 11 years of age on September 30, 1997, were invited to be tested. Twenty-eight schools (85% of those invited) agreed to participate, and within participating schools 72% of children agreed to take part. The distribution of selected schools between metropolitan and non-metropolitan areas, and between government and non-government sectors, closely matched the overall distribution across the state.

All data, both from this and the 1985 study, were analyzed on the basis of the child's age in decimal years at the time of testing. Comparisons were confined to boys and girls who were aged 10–11 years at testing, on whom height, weight and 1.6 km run/walk data were available. This included 965 boys and 935 girls from 1985, and 661 boys and 553 girls from 1997.

1.6 km Run Test

Depending on the space available in schools, a circular 200 m or 400 m track was marked out. Children completed the test in several small groups, starting at different points on the track. Instructions were provided on 'pacing' to achieve the best time, and on the appropriate 'warm-down' procedure. Subjects were regularly informed of the number of laps to be completed and verbally encouraged throughout. Times were recorded to the nearest 0.1 s, with one timekeeper per runner. Performances were expressed as average running speeds ($m \cdot s^{-1}$).

Statistical Analysis

A range of statistical and graphical methods can be used to describe and compare distributions. In this study, we have quantified the scatter of a distribution about an average value using the CV (the standard deviation divided by the mean, expressed here as a percentage). The larger the CV, the greater is the scatter or spread of the distribution. CVs were compared for statistical significance, using the standard errors. In addition, the skewness or asymmetry of the distribution was quantified using the coefficient of (excess) skewness. A

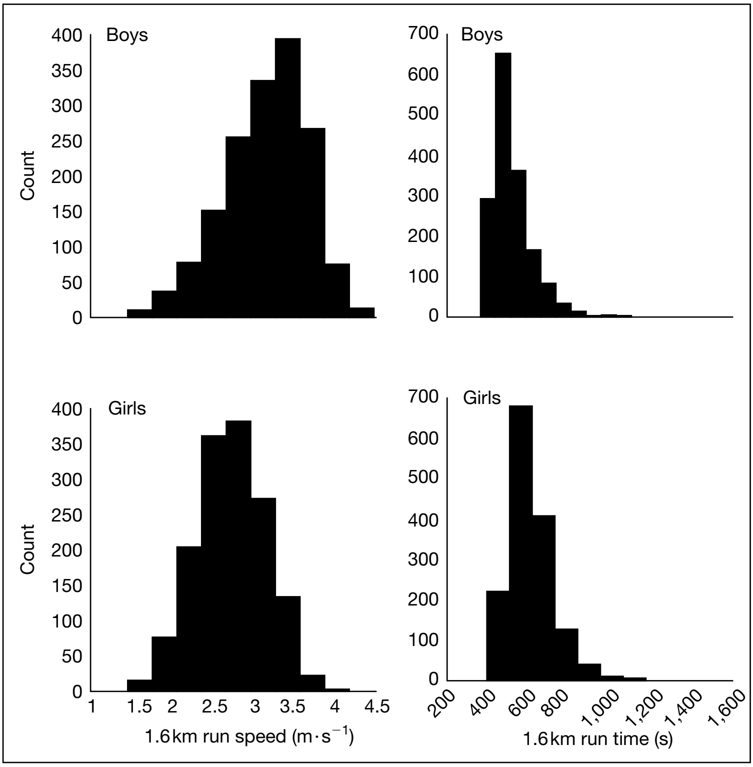


Fig. 1. Distributions of 1.6 km run speeds (m · s^{-1}; left panels) and times (s; right panels) for 10- to 11-year-old boys (upper panels) and girls (lower panels) from 1985 and 1997 combined.

positive skewness coefficient indicates a longer right tail of the distribution, with a large number of extremely high values. A negative coefficient indicates a correspondingly long left tail of low values. Skewness coefficients can be compared statistically using their standard errors.

The simplest graphical representation of a distribution is the frequency histogram. Figure 1 shows an example. Another method of representing a distribution is a quantile-quantile (QQ) plot which shows the scores corresponding to various percentiles on each distribution plotted against each other. An example is the upper left panel of figure 2. When the numbers in each distribution are the same, the QQ plot is just a scattergram of the sorted data of each distribution. The deviation of the QQ plot from the identity line indicates the differences between the distributions. In figure 2 for example, the differences between the two distributions are greatest in the middle part of the distribution. QQ plots usually do not show actual percentiles, but in the graphs shown here, key percentiles have been indicated by

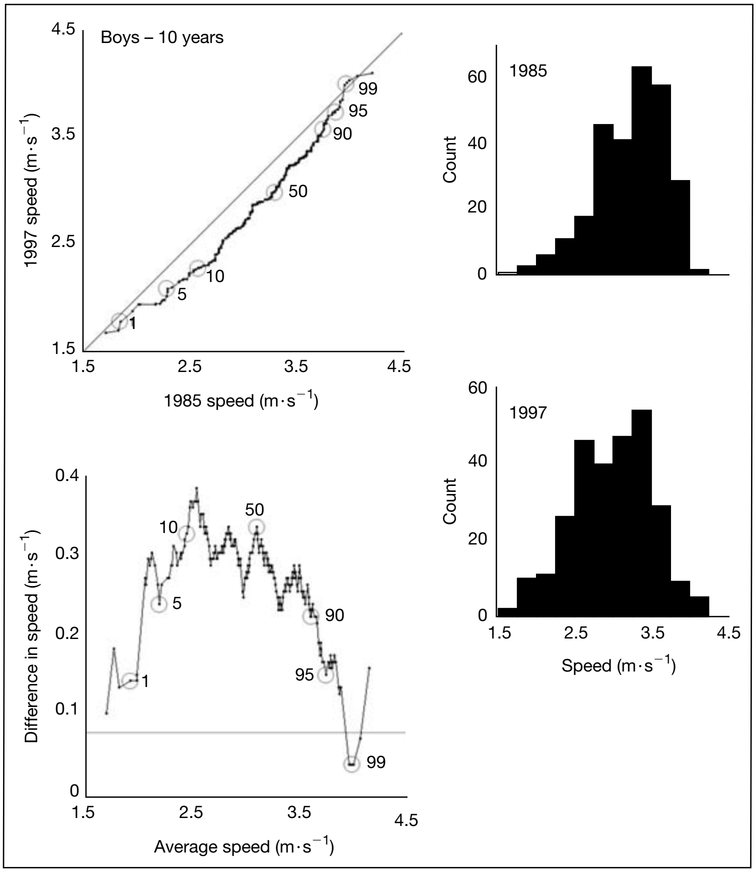


Fig. 2. Distributional changes in 1.6 km walk/run performance in 10-year-old boys. The upper left panel shows the QQ plot, and the lower left panel the MD plot. The circles represent the 1st, 5th, 50th, 90th, 95th and 99th percentiles. The right panel shows the frequency histograms.

numbered circles. Finally, a mean-difference (MD) plot graphs the differences between the two distributions at various percentiles against the average value at that percentile for each distribution, as shown in the lower left panel of figure 2. The MD plot is another view of the QQ plot, with the largest differences occurring in the middle of the range.

The distributions of 1.6 km run scores in 1985 and 1997 were compared for four groups: 10- and 11-year-old boys and girls. The QQ plots were generated by randomly choosing from the larger 1985 datasets a number of scores equivalent to the sample size from the smaller 1997 dataset. For example, there were data on 473 10-year-old boys from 1985, and on 279 10-year-old boys from 1997. Consequently, 279 scores were randomly chosen from the 1985 dataset, and plotted against the 1997 scores. MD plots were also based on the randomly chosen 1985 datasets. The statistics (CVs and skewness coefficients) were based on the entire datasets.

Results

Descriptive Statistics of the Survey Samples

Table 1 shows the sample sizes, ages and average 1.6 km running speeds for the participants. There were significant declines ($p < 0.0001$) in running speed between 1985 and 1997 in each age/sex group.

Distributions of 1.6 km Run Performances

Figure 1 shows the distribution of 1.6 km run times (s) and speeds ($m \cdot s^{-1}$) for boys and girls from the combined 1985 and 1997 datasets. The distribution of speeds shows a negative skew, while the distribution of times shows a more marked positive skew. The skews are less extreme for girls than for boys. These distributions are typical of running performance scores, and reflect a 'ceiling effect' in very fit children. The greater skews in boys probably reflect higher activity levels and a greater overall engagement in sport.

Distributional Shifts in 1.6 km Run Performances: Boys

Table 2 shows the distributional statistics for 10- and 11-year-old boys' performances from 1985 and 1997. The scatter of scores increased in both groups. The increases in the CVs were significant ($z = 6.21$, $p < 0.0001$ for 10-year-old boys; $z = 2.36$, $p = 0.018$ for 11-year-old boys). There were also significant decreases in negative skew: from -0.81 to -0.23 for 10-year-old boys ($z = 3.34$, $p = 0.0008$), and from -0.59 to -0.26 for 11-year-old boys ($z = 2.39$, $p = 0.017$).

Figures 2 and 3 show the QQ and MD plots and frequency histograms for 10- and 11-year-old boys. Visual inspection of the histograms shows that in both cases, the distributions have become less negatively skewed. The QQ and MD plots show that the reason for this is that the largest declines have occurred in the middle percentiles, with relatively smaller declines at low (<5th) and high (>90th) percentiles. The bulk of the scores have shifted towards the left side of the distribution, reducing the skew.

Distributional Shifts in 1.6 km Run Performance: Girls

Table 3 shows the distributional statistics for 10- and 11-year-old girls' performances from 1985 and 1997. The pattern here is quite different from that of boys. There has been very little change in the scatter of scores. The small increases in CVs were not significant. While the negative skew had decreased slightly, the changes were also not significant.

Table 1. Sample size, mean (SD) age (years) and mean (SD) 1.6 km running speed ($m \cdot s^{-1}$) for the participants

	1985				1997			
	boys		girls		boys		girls	
	10 years	11 years	10 years	11 years	10 years	11 years	10 years	11 years
n	473	492	467	468	279	386	260	293
Age (SD), years	10.4 (0.3)	11.4 (0.3)	10.4 (0.3)	11.4 (0.3)	10.6 (0.2)	11.4 (0.3)	10.6 (0.3)	11.4 (0.3)
Run speed (SD), $m \cdot s^{-1}$	3.22 (0.47)	3.28 (0.51)	2.74 (0.40)	2.80 (0.45)	2.98 (0.50)	3.04 (0.53)	2.56 (0.40)	2.61 (0.44)

Table 2. Distributional statistics for performances ($m \cdot s^{-1}$) on 1.6 km walk/run test for boys in 1985 and 1997

	10-year-old boys		11-year-old boys	
	1985	1997	1985	1997
CV, %	14.5	20.3[a]	15.4	17.3[a]
Skewness	−0.81	−0.23[a]	−0.59	−0.26[a]

CV = Coefficient of variation.
[a]1997 value significantly greater than 1985 value.

Figures 4 and 5 show the QQ and MD plots and frequency histograms for 10- and 11-year-old girls. The declines in performance have been relatively uniform across the distribution.

Discussion

The distributions of 1.6 km run scores in some groups have changed significantly between 1985 and 1997. Boys' scores have become more widely scattered, and less negatively skewed. The overall decline in boys' performances has been the result of a leftward shift in the middle of the distribution. In contrast, girls' scores have not shown distributional changes, and the overall decline in girls' performances has been the result of across-the-board declines.

In contradistinction to previous reports, this study did not find greater declines at the left (poorly performing) tail of the distributions. In boys, the declines at the tails were smaller, and in girls not different, than declines at other parts of the distribution. These patterns suggest causative factors which are quite general, and affect most children. The possible exceptions are very fit and very unfit boys.

The negatively skewed pattern of boys' scores in 1985 may reflect a ceiling effect. In a population where most boys are very active and engaged in sport, many will reach high levels of fitness. The distributions of girls' scores were not negatively skewed in 1985. This perhaps suggests that physical activity, sport and fitness do not have the same kind of salience in girls' lives as they do in boys', and fewer girls will seek to excel in these areas.

The unchanging performances between surveys among the fittest boys may reflect this upper limit of engagement in physical activity and physiological adaptation. On the other hand, the slowest boys in both surveys most likely

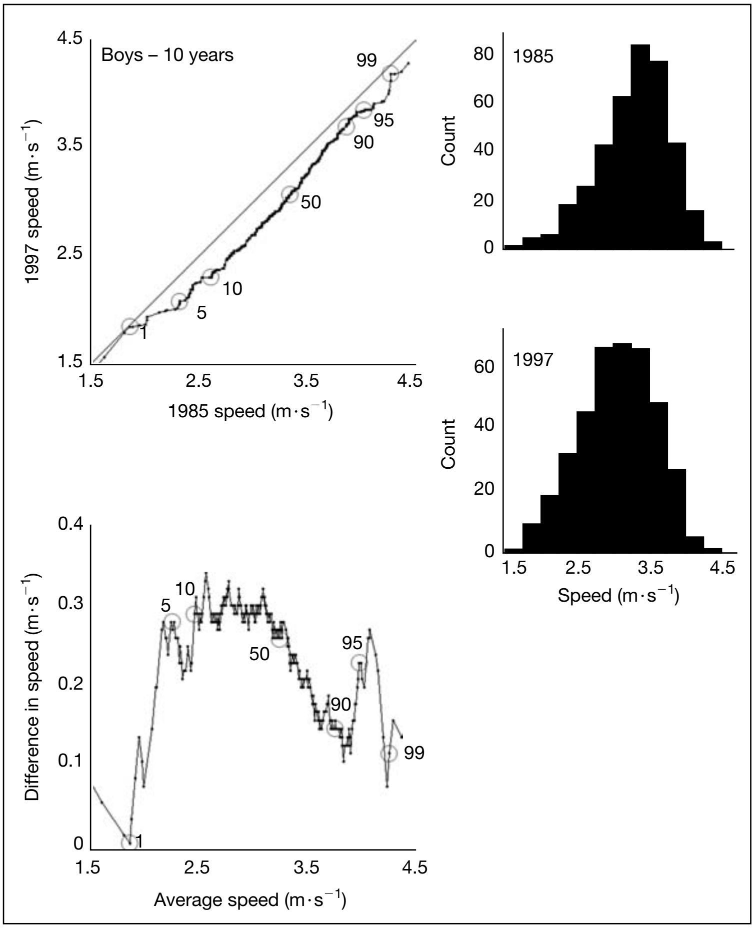


Fig. 3. Distributional changes in 1.6 km walk/run performance in 11-year-old boys. The upper left panel shows the QQ plot, and the lower left panel the MD plot. The circles represent the 1st, 5th, 50th, 90th, 95th and 99th percentiles. The right panel shows the frequency histograms.

completed the test at an effort level insufficient to induce physiological stress, and the similar completion times among boys in both surveys probably reflects a lower limit of motivation to engage in the task.

Contribution of Changes in Fatness

It can be strongly argued that increases in fatness will lead to declines in weight-bearing CRE performance. Cross-sectionally, running performance declines with increasing fatness. For example, in a national dataset of Australian

Table 3. Distributional statistics for performances ($m \cdot s^{-1}$) on 1.6 km walk/run test for girls in 1985 and 1997

	10-year-old girls		11-year-old girls	
	1985	1997	1985	1997
CV, %	14.8	15.6	15.4	16.7
skewness	−0.15	+0.03	−0.23	+0.13

CV = Coefficient of variation.

children [7], there were correlations of −0.37 to −0.46 ($p < 0.0001$) between measures of fatness (e.g. BMI and sum of skinfolds) and average 1.6 km running speed in boys and girls. However, the relationship between measures of fatness and running speed is curvilinear, with fatness having very little effect on running performance up to about the 50th percentile of BMI (fig. 6). Children of average fatness perform as well as children who are very lean, while children of above average BMI tend to perform worse on running tests.

Secular changes in fatness have coincided with changes in CRE performance, with increases in fatness and declines in CRE performance becoming marked since about 1970–1980 [9, 10]. In Australia [8, 11] and overseas [12, 13], studies have shown disproportionate increases in fatness in certain subsets of children and adolescents, with rates of increase more marked in fatter individuals. Distributions of fatness have shown increasing positive skews.

Olds and Dollman [14] compared the running performance of boys and girls from 1985 and 1997 matched for age, BMI and triceps skinfold thickness, in an attempt to tease out the contribution of changes in fatness to declines in performance. The matched children from 1997 still performed worse than their 1985 counterparts, with adjustment for fatness accounting for less than half of the overall decline in performance. Figure 7 shows QQ plots for the complete and matched datasets for boys and girls. Among boys, correcting for fatness explained about 50% of the overall performance difference up to about the 10th percentile. Beyond that point, the matched boys from 1997 actually outperformed their counterparts from 1985. With girls, a somewhat smaller proportion of the overall decline was explained by matching for fatness, and the proportion was similar across the percentile bands.

These considerations suggest that while changes in fatness account for a moderate proportion of changes in run performance, there must be other factors at work (perhaps lower levels of physical activity, or less experience with maximal sustained efforts), and that the effects are not consistent across the percentile

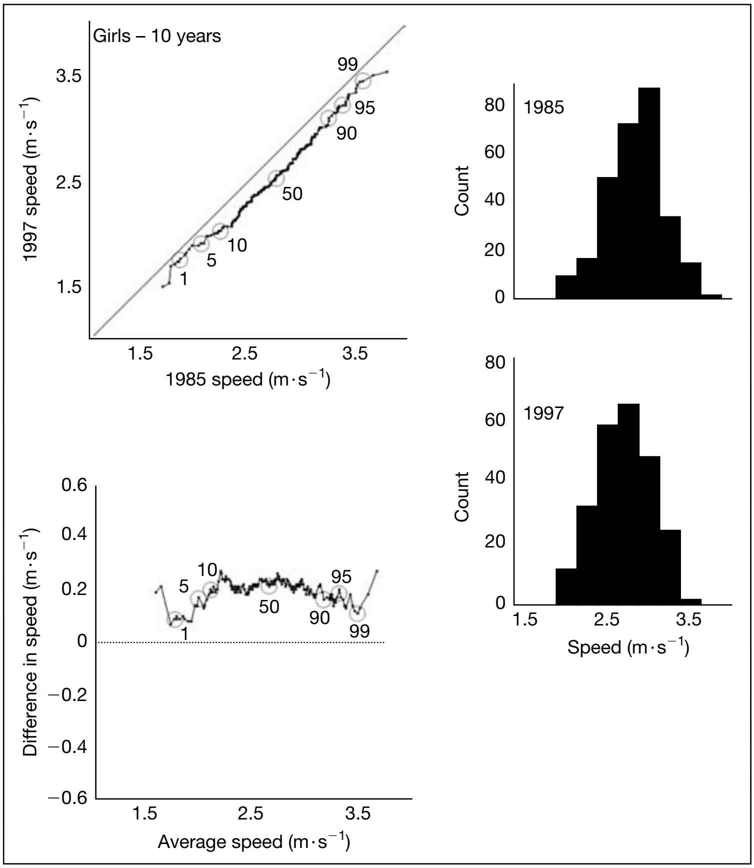


Fig. 4. Distributional changes in 1.6 km walk/run performance in 10-year-old girls. The upper left panel shows the QQ plot, and the lower left panel the MD plot. The circles represent the 1st, 5th, 50th, 90th, 95th and 99th percentiles. The right panel shows the frequency histograms.

bands, at least in boys. It is possible that a proportion of boys who excel at sport and games continue to engage in fitness-promoting activity, and are relatively resilient to environmental effects. Girls, and boys who do not excel (two groups who have less to gain from excellence at sport and games in terms of kudos and identity), may be more likely to disengage from fitness-promoting activities when environmental factors limit access to participation opportunities [15].

Unfortunately, there are few reliable data on secular trends in physical activity patterns in children and adolescents to test the hypothesis of differential declines in vigorous physical activity behaviors. There have been several reports of reduced

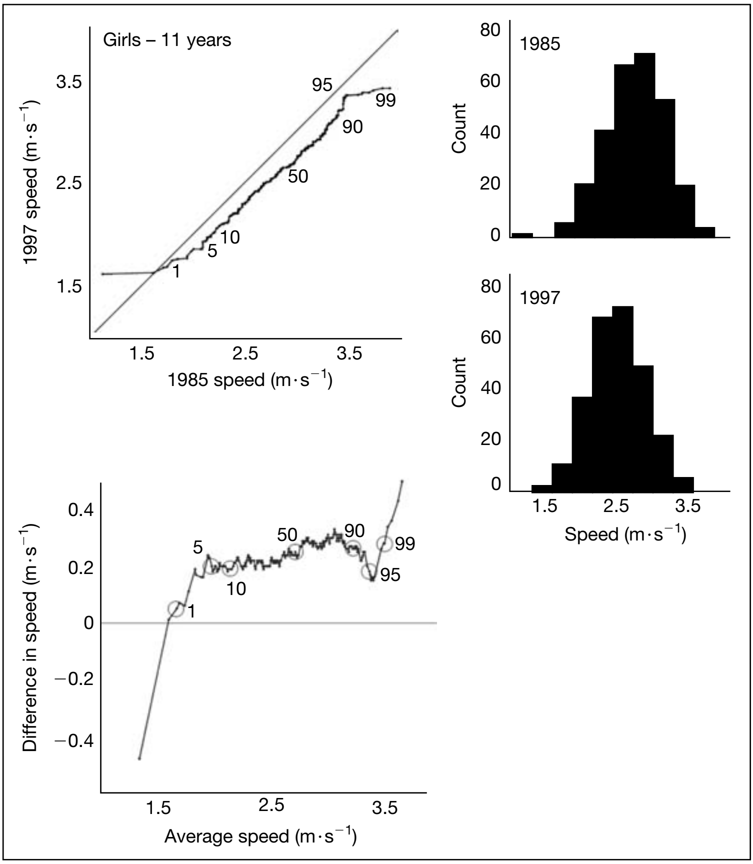


Fig. 5. Distributional changes in 1.6 km walk/run performance in 11-year-old girls. The upper left panel shows the QQ plot, and the lower left panel the MD plot. The circles represent the 1st, 5th, 50th, 90th, 95th and 99th percentiles. The right panel shows the frequency histograms.

engagement in particular contexts of physical activity, such as physical education, organized sport and active transport [16]. However, no previous studies have analyzed distributional changes to determine whether relatively high, medium and low 'consumers' of physical activity are more or less engaged now compared with previous generations. The results of this analysis recommend investigations of the distribution of physical activity patterns across the socio-demographic landscape, with a view to identifying targets for intense intervention.

Studies of temporal changes in children's CRE are limited by a number of biological and methodological factors. In this study CRE is represented by the

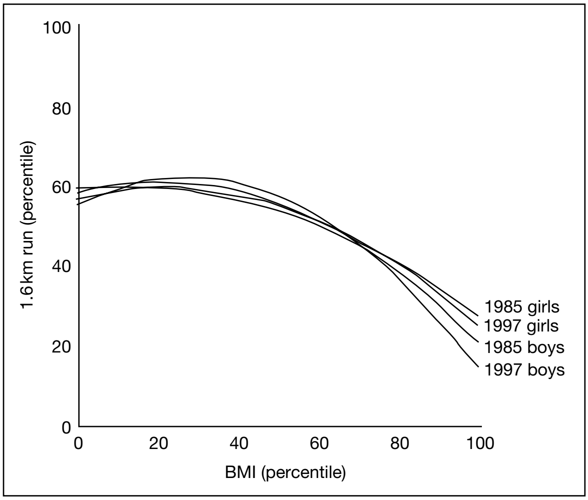


Fig. 6. Plot of percentiles of running speeds (higher percentiles represent better performances) against BMI in 10- to 11-year-old boys and girls from the 1985 and 1997 datasets. The curves represent the best-fit second-order polynomials. Correlation coefficients range from −0.32 to −0.47.

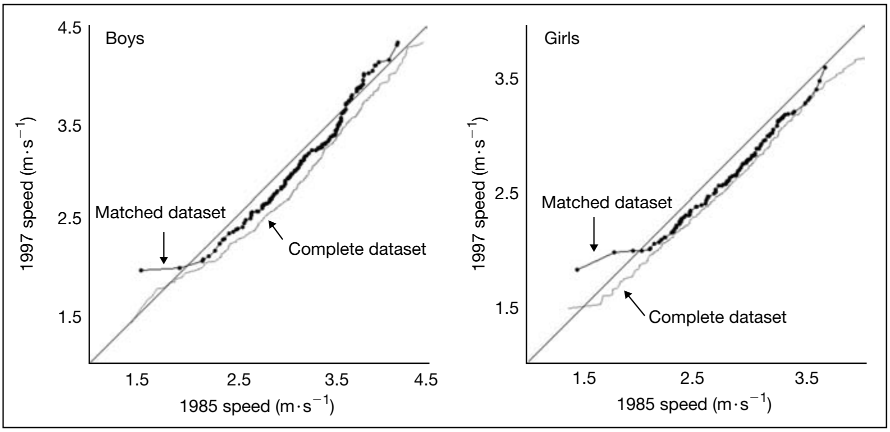


Fig. 7. QQ plots of 1.6 km running speeds from 1985 and 1997 on boys and girls matched for age, BMI and triceps skinfold thickness. The continuous grey line represents a comparison of the entire (unmatched) 1985 and 1997 datasets, and the filled dots the matched datasets.

1.6 km run/walk test. Performances in field tests are affected by factors other than CRE, such as motivation and mechanical efficiency. A detailed analysis of the relationship between 1.6 km run/walk performance and the physiological determinants of $\dot{V}O_{2max}$ (36 boys; 12.2 ± 0.5 year) revealed that stroke volume was related, but not maximal arteriovenous oxygen difference and maximum heart rate [17]. Overall, $\dot{V}O_{2max}$ explained only 28% of the variance in 1.6 km run/walk time, with percent body fat explaining 31%, and approximately 40% remaining unexplained. Nevertheless, a review by Krahenbuhl et al. [18] established that validity of field tests of children's CRE increases with distance, and that 1,600 m is the best field predictor of $\dot{V}O_{2max}$ among both boys and girls. From the health perspective, it could be argued that CRE performance scores, by integrating factors such as motivation and tolerance of discomfort during exercise, are more likely to reflect a child's willingness to participate in health-promoting physical activity.

Distance run performance will be affected by environmental factors such as temperature, humidity and ground conditions, in ways that could be attributed to physiological stress and motivation. Test conditions were unlikely to have varied systematically between 1985 and 1997. In both surveys, trials were conducted on grassed surfaces in over 90% of schools, with the remainder on bitumen or gravel [7]. Trials were conducted in winter and spring, and were postponed if the ambient temperature exceeded 30°C.

Practice can have a significant impact on CRE performance tests. Watkins and Moore [19] reported that Scottish schoolgirls (12–15 years) improved their 1 mile run times by 37–48 s over three trials in the space of two weeks, presumably due to improved tactical awareness rather than a training effect. There were anecdotal reports of rehearsals for both the 1985 and 1997 surveys in a few schools, but there is no reason to believe that one survey's results are contaminated to a greater extent than the other.

The slower moving 'pack' of participants in the 1997 survey may have led to a cohort pace reduction effect, in that those capable of running faster were tactically confused or less motivated by those around them. This may in part explain the relatively small change in the running speed of the best performed boys between surveys.

Secular trends in fitness and adiposity are confounded by changes in the timing of biological maturation from one generation to the next. In girls, the age of menarche has been advancing at the rate of 3–4 months each decade, while in boys, the voice is breaking earlier by about 2 months per decade [20]. Consequently, when 10-year-old girls from 1985 and 1997 are compared, from a maturational perspective the 1997 cohort is closer to the 10.6-year-old from 1985. Since performance on fitness tests generally improves with age [10], we would expect improved performance between 1985 and 1997 based on maturational advances alone. The deterioration in CRE performances in boys, other than among the fastest and slowest, and in girls 'across the board', may therefore be underestimating declines in physiological fitness among the majority of children.

Trends in cardiorespiratory fitness, fat mass, fat-free mass, maturational tempo, physical activity and willingness to fully engage will interact in many possible causal networks to determine CRE test performance. However, the declining CRE performance among a high proportion of the youth population, even after accounting for changes in fatness, underscores the need to fully identify where, and among whom, regular vigorous physical activity is occurring.

References

1 Tomkinson GR, Léger LA, Olds TS, Cazorla G: Secular trends in the performance of children and adolescents (1980–2000): an analysis of 55 studies of the 20 m shuttle run in 11 countries. Sports Med 2003;33:285–300.
2 Tomkinson G: Secular trends in fitness performance of Australasian children and adolescents; unpubl PhD thesis, Adelaide, University of South Australia, 2004.
3 Noi S, Masaki T: The educational experiments of school health promotion for the youth in Japan: analysis of the 'sport test' over the past 34 years. Health Promot Int 2002;17:147–160.
4 Wedderkopp N: Atherosclerotic cardiovascular risk factors in Danish children and adolescents: a community based approach with a special reference to physical fitness and obesity; unpublished PhD thesis, Denmark, University of Southern Denmark, 2001.
5 Wilson T: The evolution of fitness and fatness in boys of high socio-economic status; unpubl Honours thesis, Adelaide, University of South Australia, 2002.
6 McNaughton L, Morgan R, Smith P, Hannan G: An investigation into the fitness levels of Tasmanian primary schoolchildren. ACHPER Healthy Lifestyles J 1996;43:4–10.
7 Pyke JE: Australian Health and Fitness Survey 1985. Adelaide, Australian Council for Health, Physical Education & Recreation, 1987.
8 Dollman J, Olds T, Norton K, Stuart D: The evolution of fitness and fatness in 10–11-year-old Australian schoolchildren: changes in distributional characteristics between 1985 and 1997. Pediatr Exerc Sci 1999;11:108–121.
9 Booth ML, Chey T, Wake M, Norton K, Hesketh K, Dollman J, Robertson I: Change in the prevalence of overweight and obesity among young Australians, 1969–1997. Am J Clin Nutr 2003;77:29–36.
10 Tomkinson GR, Olds TS, Gulbin J: Secular trends in physical performance of Australian children: evidence from the Talent Search program. J Sports Med Phys Fitness 2003;43:90–98.
11 Magarey AM, Daniels LA, Boulton TJC: Prevalence of overweight and obesity in Australian children and adolescents: reassessment of 1985 and 1995 data against new standard international definitions. Med J Aust 2001;174:561–564.
12 Flegal KM, Troiano RP: Changes in the distribution of body mass index of adults and children in the US population. Int J Obes Relat Metab Disord 2000;24:807–818.
13 Rasmussen F, Johansson M, Hansen HO: Trends in overweight and obesity among 18 year-old males in Sweden between 1971 and 1995. Acta Paediatr 1999;88:431–437.
14 Olds TS, Dollman J: Are secular declines in children's aerobic fitness explained by changes in fatness? Pediatr Exerc Sci 2004;16:201–209.
15 Epstein LH, Roemmich JN: Reducing sedentary behavior: role in modifying physical activity. Exerc Sport Sci Rev 2001;29:103–108.
16 Dollman J, Norton K, Norton L: Evidence for secular trends in children's physical activity behaviours. Br J Sports Med. In press.
17 Rowland T, Kline G, Goff D, Martel L, Ferrone L: Physiological determinants of maximal aerobic power in healthy 12-year-old boys. Pediatr Exerc Sci 1999;11:317–326.

18 Krahenbuhl GS, Pangrazi RP, Petersen GW, Burkett LN, Schneider MJ: Field testing of cardiorespiratory fitness in primary school children. Med Sci Sports 1978;10:208–213.
19 Watkins J, Moore B: The effects of practice on performance in the one mile run test of cardiorespiratory fitness in 12–15 year old girls. ACHPER Healthy Lifestyles J 1996;43:11–14.
20 Himes JH: Secular changes in body proportions and composition; in Roche AF (ed): Secular Trends in Human Growth, Maturation and Development. Chicago, Society for Research in Child Development, 1979, pp 28–58.

Dr. James Dollman
Nutritional Physiology Research Center, School of Health Sciences
University of South Australia
City East Campus, GPO Box 2471
Adelaide SA 5001 (Australia)
Tel. +61 8 8302 1413, Fax +61 8 8302 2766, E-Mail james.dollman@unisa.edu.au

Tomkinson GR, Olds TS (eds): Pediatric Fitness. Secular Trends and Geographic Variability.
Med Sport Sci. Basel, Karger, 2007, vol 50, pp 226–240

Declines in Aerobic Fitness: Are They Only Due to Increasing Fatness?

Timothy S. Olds[a], *Kate Ridley*[c], *Grant R. Tomkinson*[b]

[a]Nutritional Physiology Research Centre and [b]Centre for Applied Anthropometry, School of Health Sciences, University of South Australia, and [c]School of Education, Flinders University, Adelaide, Australia

Abstract

Aims: This study quantifies the cross-sectional and longitudinal relationships between young people's fatness (BMI, skinfold thickness) and fitness (performance on tests of aerobic fitness). **Background:** Over the last 20–30 years, young people have become fatter and less fit. It is likely that the decline in fitness is largely due to increases in fatness. There are strong mechanistic connections; within cohorts, variability in fatness accounts for about 20% of variability in running performance; there is a strong correlation between overweight prevalence and relative fitness across specific cohorts from different countries; and secular declines in fitness coincide temporally with increases in BMI. **Methods:** Australians aged 10–12 years tested in 1985 were matched for age, sex, BMI and triceps skinfold thickness with their counterparts tested in 1997 (n = 279 matched pairs), and 12–15 year-old tested in 1995–1996 were matched with their counterparts tested in 1999–2000 (n = 2,834 matched pairs). Performance differences on running tests in the matched datasets were compared with performance differences in the complete (unmatched) datasets. **Results:** Performance differences persisted even when young people were matched for fatness. Matching for fatness reduced overall performance differentials by 29–61%. Other factors such as reduced physical activity and subsequent training effect are likely to have contributed to the decline.

The aim of this paper is to quantify the effect of increases in young people's fatness on declines in young people's fitness. We use the terms 'fitness' and 'fatness' for brevity. 'Fitness' should be understood as performance on tests of aerobic fitness (typically involving tests lasting at least 3–5 min), and 'fatness' as adiposity operationalized by age- and sex-specific BMI and skinfold thicknesses.

There is now overwhelming evidence that in most parts of the world young people have been getting fatter [1] and less fit [2] for at least the last 20 years.

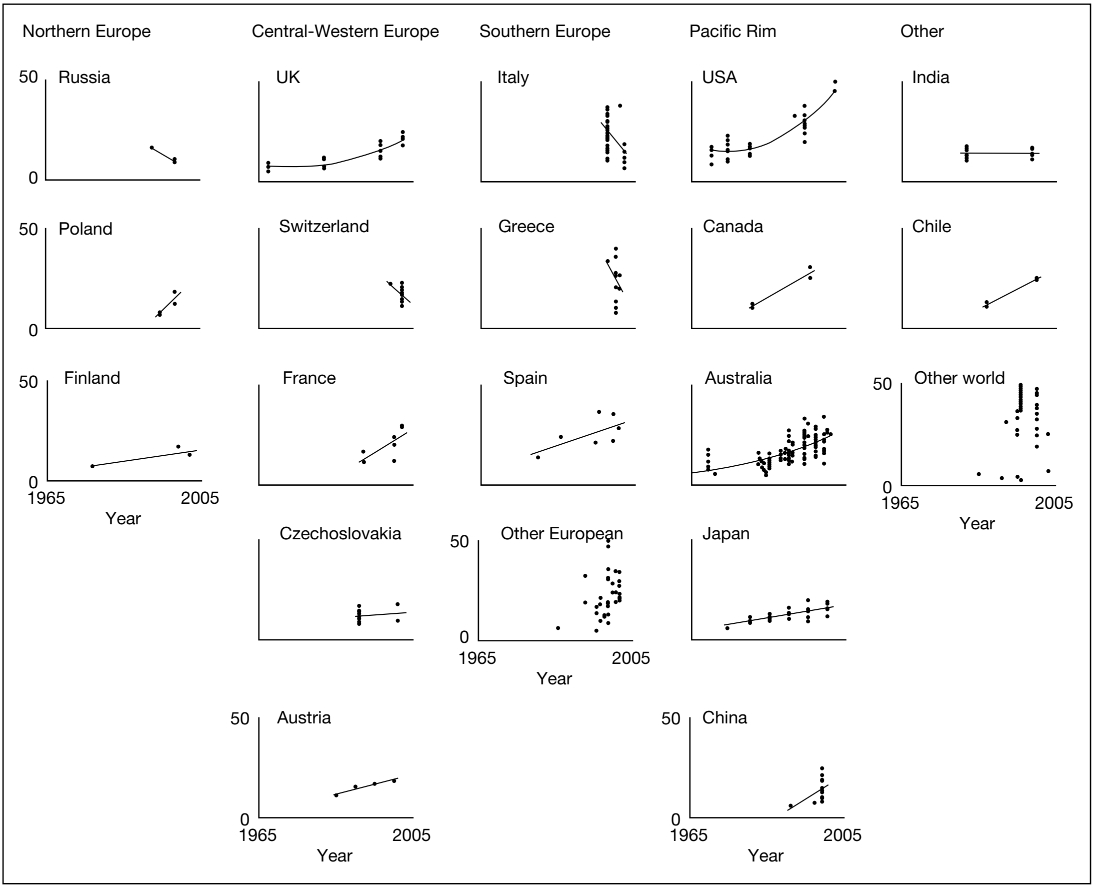


Fig. 1. Secular changes in the prevalence of overweight and obesity in young people (using the Cole cut-offs) in countries around the world. Data sources are available in Tomkinson [32].

Figure 1 shows collated data on secular trends in the prevalence of overweight and obesity in young people around the world using internationally agreed criteria [3]. There have been increases in all but a few countries, more marked in the US than elsewhere.

It is tempting to causally link increased fatness with decreased fitness. It seems natural that fatter young people will perform worse on fitness tests, particularly those involving running. This association has been suggested by a number of researchers [4–6]. There are good reasons for making this association: plausible mechanistic links, significant cross-sectional correlations, and parallel secular trends in fitness and fatness.

However, fitness, fatness and physical activity can interact in many possible causal networks [7]. One view is that fitness performance has declined because young people are less active than they were in the past. In a recent review of the literature on changes in aerobic fitness [7], the author concluded that 'if changes in aerobic fitness in young people are declining, and if this fall is not just due to increases in body fat, it might be assumed that sedentary living plays a direct etiological role'. The decrease in moderate-to-vigorous physical activity has resulted in a reduced training effect, and hence reduced fitness. While there are few reliable data on secular trends in physical activity patterns in young people, a number of local snapshots strongly suggest that young people are less active, and more inactive, than in previous decades [8]. There are documented declines in vigorous physical activity in US high school students [9], young people's use of active transport in both the UK and the US [10–12], and participation rates in US high school physical education classes [9, 13]. There has been one recent report of declines in the number of organized sports young people are participating in [14]. There is stronger evidence in relation to increasing screen-based inactivity both in young people and in adults [15, 16]. Nor can we rule out the possibility of changes in young people's motivation, cognitive familiarity with pacing, or motor skills.

The etiological issue is of more than just theoretical interest. If we want to reverse the decline in fitness, it is important to know whether it is solely due to increases in fatness, in which case anti-overweight strategies (e.g. dietary control) may be appropriate, or whether declines in vigorous activity are important, in which case strategies might also focus on increasing physical activity. If reduced levels of physical activity sufficient to elicit a training effect are an important factor in falls in aerobic fitness performance, and if aerobic fitness is considered to be a desirable goal of physical education, then physical educators should be considering ways of re-introducing vigorous activity into young people's lives, perhaps through school and club sport. However, in many countries, public policy is more directed towards health-related fitness.

Mechanistic Links

A number of studies have addressed the effect of added mass on running economy. Among the consistent findings has been that added mass placed centrally, and especially peripherally, increases the aerobic demand of steady-state running when expressed as ml $O_2 \cdot kg^{-1}$ body weight (BW) $\cdot$ min^{-1} [17, 18]. However, when expressed relative to total body weight (i.e. body weight plus added weight), passive or artificial central loads will, at least in young people, often reduce the O_2 cost of running at a given speed [19], perhaps due to better re-use of elastic energy.

Fat constitutes an extra load to carry and reduces mass-specific aerobic power approximately on a pro rata basis, a major determinant of running performance. Unlike a passive load, fat mass will also incur some extra metabolic 'maintenance' costs, such as breathing and thermoregulation. There are also potential psychosocial pathways linking increased levels of body fat and poorer performance: fatter young people tend to have lower self-esteem and self-efficacy, which may make them less motivated in fitness tests [20].

Cross-Sectional Correlations between Fitness and Fatness

A second argument for the association between fatness and performance comes from cross-sectional data. Studies have generally found significant correlations between various measures of fatness and running performance in trained adults [21, 22], with 0–38% of the variance in running performance being explained by variability in fatness. Krahenbuhl et al. [23] found that the sum of skinfolds explained 0–25% of the variance in running performance over 549–1,609 m in 8-year-old American young people.

Two large Australian datasets allow us to further explore this relationship. Pyke [24] and Dollman et al. [25] tested a total of 3,878 10- to 12-year-old young people using the 1.6 km walk/run test. They also measured BMI. The Australian Sports Commission's Talent Search project collected BMI and 20 m shuttle-run test (20 m SRT) data on 17,684 Australian 12- to 15-year-old between 1995 and 2000 [26]. In the following analyses, BMI was normalized [27] using Box-Cox transformation [28], and the response variables were expressed as average running speed (1.6 km walk/run) and running speed at the final completed stage (20 m SRT). Running speed was then regressed against BMI and sum of skinfolds. The results are shown in table 1. These results are quite consistent across sexes, age bands and tests. The percentage of variance in running performance explained by BMI is 5–25%. The effect of fatness appears to diminish with age.

BMI is an imperfect measure of fatness, particularly in young people, where higher BMIs may signal greater maturation or greater muscle mass, which might be expected to improve rather than hinder running performance. A better measure is the sum of skinfolds. For the Pyke and Dollman datasets, comparable skinfold measurements were available for the subscapsular, triceps, biceps, supraspinal and abdominal skinfolds. The sum of skinfolds was calculated and normalized using the Box-Cox method. Table 2 shows the relationship between the sum of skinfolds and running speed over 1.6 km for the 2,267 10- to 12-year-old Australians for whom data were available. Here the correlations are somewhat larger, explaining 14–32% of the variance in running performance. While there are clearly associations between fatness and performance, fatness appears to explain only about 20% of the variance in performance. There must also be

Table 1. Relationship between BMI and running speed in 10- to 12-year-old Australian young people tested using the 1.6 km run and 12- to 15-year-old young people tested using the 20 m shuttle run test (20 m SRT)

	1.6 km walk/run			1.6 km 20 m SRT			
	10 years	11 years	12 years	12 years	13 years	14 years	15 years
Boys							
r	0.39	0.48	0.38	0.42	0.34	0.25	0.21
n	749	870	555	972	4,225	3,064	1,524
Girls							
r	0.33	0.38	0.38	0.33	0.33	0.25	0.10
n	724	756	524	1,064	3,670	2,113	952

The Pearson product-moment correlation coefficient (r) and sample size (n) are shown.

Table 2. Relationship between sum of skinfolds and running speed in 10- to 12-year-old Australian young people tested using the 1.6 km run

	Age		
	10 years	11 years	12 years
Boys			
r	0.50	0.57	0.49
n	339	379	490
Girls			
r	0.38	0.51	0.45
n	304	287	468

The Pearson product-moment correlation coefficient (r) and sample size (n) are shown.

other factors such as maturation, test familiarity, motivation and genetic aptitude, which are important. The interactions between genetics, fatness, maturation, motor skill and physiological characteristics are extremely complex, but fall outside the scope of this discussion.

While we see consistent correlations between fatness and fitness in these samples, do we find similar correlations when international comparisons are made? Since the publication of internationally agreed cut-offs for classifying young people as overweight or obese [3], a great deal of data has become available on the comparative prevalence of overweight around the world (e.g. [29]). We correlated these data with fitness performance data on young people who had been tested using the 20 m SRT since 1980. The results for young people from each country were expressed as the average age- and sex-specific z-score relative to data on 418,026 young people from 37 countries [30]. These scores were then matched with overweight prevalence estimates for young people of the same sex, from the same country, of approximately the same age (to within 2 years), and measured in approximately the same time period (to within 3 years). A total of 186 age × country × sex × year of test comparisons were possible, including data from 15 countries. When several studies could be used as comparisons for the same study of overweight prevalence, sample-weighted z-scores were calculated.

The results are shown in figure 2. A semilog (fitness z-score vs. ln of prevalence) provided a good fit, indicating a floor effect on fitness as overweight increased. There was a significant negative correlation between performance and prevalence ($r = -0.66$, $p < 0.0001$; fig. 2), with variability in overweight prevalence accounting for 43% of the variability in performance. The countries with the fittest young people, notably those of northern Europe, had the lowest prevalence of overweight and obesity, while the countries with the least fit young people (USA, Brazil) had the highest prevalence's. Each 1% increase in the prevalence of overweight was associated with a fall of about 0.03 SDs in performance. One limitation to this analysis is the blanket use of standard BMI cut-offs across populations. Some researchers have suggested that ethnically specific cut-offs should be used to account for inter-ethnic body size, shape and composition differences [31].

Parallels in the geographical distributions of aerobic performance and prevalence of overweight in young people confirm the relationships found in intra-cohort and secular trend analyses. Variability in the prevalence of overweight is clearly associated with, but does not completely explain, variability in aerobic performance. The factors other than fatness contributing to variability in fitness between groups may be different from those contributing to variability within groups. A wide range of cultural factors, including the role of sport in public life, the involvement of children in physical work, socio-economic factors affecting access to passive or active recreation facilities, and social expectations regarding performance in physical and intellectual domains may be important at the level of the nation.

Secular Trends in Fitness and Fatness

Mechanistic and correlational arguments provide strong support for the notion that fitness performance is affected by fatness. They do not necessarily

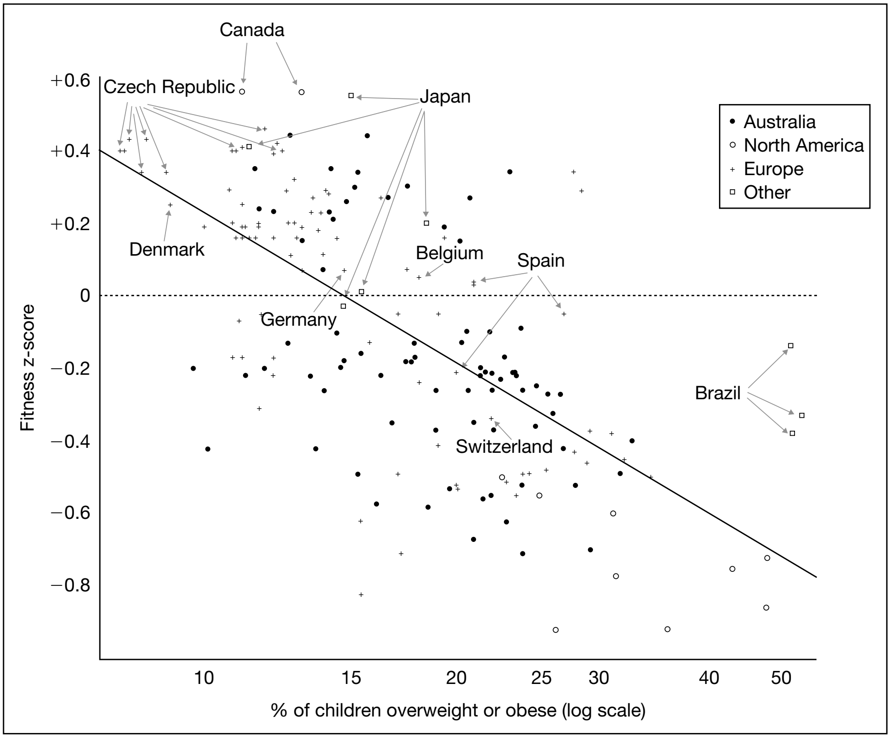


Fig. 2. Relationship between aerobic performance (mean z-score for 20 m SRT relative to all young people) and the prevalence of overweight in 15 countries. Data are shown for Australia, North America (USA and Canada), Europe (Belgium, Czech Republic, Denmark, France, Germany, Italy, Poland, Spain, Switzerland, UK) and other countries (Japan and Brazil). Note that the abscissa uses a log scale. Data sources are available in Tomkinson [32].

entail, however, that changes in fatness are associated with changes in fitness. While many factors contribute to inter-individual variability in fitness performance, only some may show systematic secular changes, and hence be associated with changes in performance. Conversely, factors which may not impact cross-sectionally on fitness performance because of uniform levels of exposure in the cohort, may change over time and hence result in secular changes in performance. While there are no studies which have longitudinally tracked fitness and fatness changes in the same individuals, we have considerable data on secular trends in fitness and fatness at the population level. The coincident decline in fitness performance and rise in BMI suggests a causal connection between the two.

Tomkinson [32] has collated data on the fitness performance of 24,874,247 young people from several dozen countries, including data on 78,863 Australian young people. Using these data, it is possible to summarize numerically and graphically the time-related patterns of change in performance on fitness tests. The method and source data are described in detail in Tomkinson [32; see also chapter by Tomkinson and Olds, this vol., pp. 46–66], and are summarized here. Time-related patterns of change were calculated using both world and Australian fitness data. The method was also applied to data on changes in BMI in Australian young people and to collated data from around the world, to establish patterns of evolution of BMI. All data were indexed for graphical purposes to a value of 100 in 1978.

The results are shown in the top two panels of figure 3. In the global perspective, performance on tests of aerobic fitness improved sharply until 1970. There was a relative performance plateau between 1970 and 1980, followed by a 20-year decline at the rate of about 0.5% per year. Australian fitness data are only available from 1978 onwards, but show a similar decline. BMI trends are strikingly similar for Australia and the world, with a steady climb until about 1980, followed by a sharp rise. These patterns show that the rapid decline in fitness has coincided with the steep increase in BMI, although fitness was also improving at a time when BMI was increasing from the mid-1950s to 1970. It is possible that this occurred at a time when increases in BMI reflected increases in fat-free mass associated with post-war recovery of world food supplies. One of the problems with using BMI as an index of body composition change is that small changes in median BMI may conceal very large changes at the higher percentiles, as distributions become markedly more skewed [33, p 659].

One country where comprehensive records of young people’s BMI and fitness performance have been maintained is the Korean Republic, where fitness assessment using running tests has been compulsory for all young people since 1970. The lower panel of figure 3 shows secular trends in the aerobic performance and BMI of Korean young people. Curves were fitted to the data using best-fit quadratics. The fitness curve is based on 22,167,125 young people, and the BMI curve on 43,313,201 young people. There is a clear inverse relationship between the two curves.

Quantifying the Contribution of Changes in Fatness to Changes in Fitness

One way of determining how much changes in fatness contribute to changes in fitness is to use a matching analysis. In matching analyses, young people tested at one time-period are matched for sex, age and fatness with

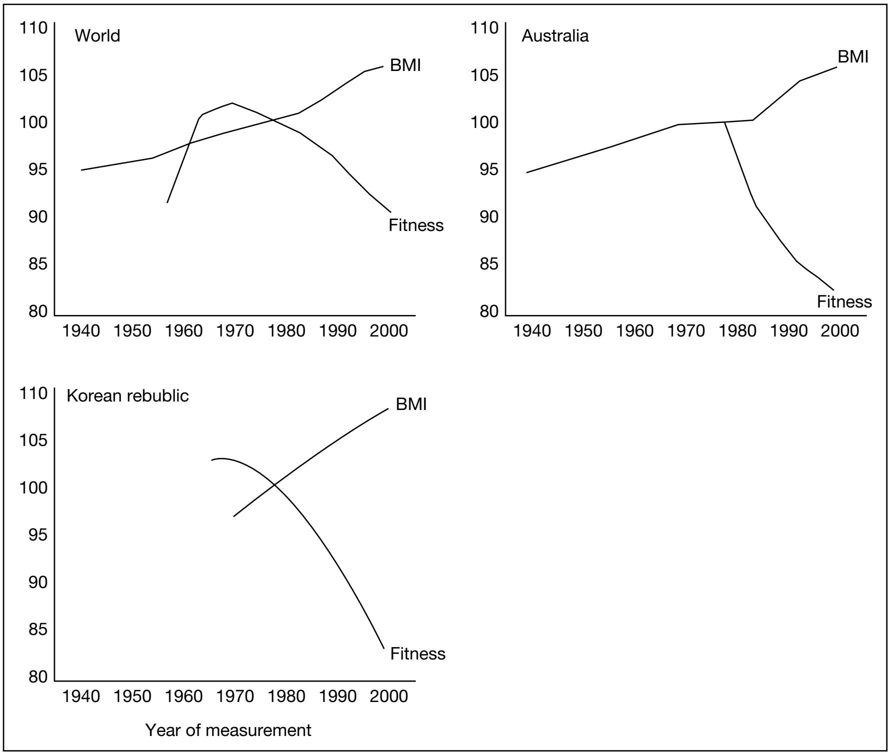


Fig. 3. Evolution of BMI and performance on tests of aerobic fitness in young people from around the world (left top panel), Australia (right top panel), and the Korean Republic (bottom panel). Values are standardized to 100 in 1978. Note that no Australian fitness data were available before 1978. The ordinate axes are relative values, and hence the absolute BMIs and fitness performance of young people from Australia, the world and Korea are not commensurable. Data sources and treatment may be found in Tomkinson [32].

young people tested years later. If there is no performance difference between the matched samples, then declines in fitness could be attributed entirely to increases in fatness. Conversely, if residual fitness differences remained in spite of the matching procedure, it is likely that factors other than changes in fatness are associated with fitness declines. The contribution of changes in fatness to changes in fitness can be quantified as the ratio of the fitness difference in the matched sample to the fitness difference in the complete sample.

The Australian datasets described at the beginning of this chapter were used in matching analyses. Of the 2,748 10- to 12-year-old young people tested

Table 3. Mean (SD) values for age and 1.6 km run speed, and median values for BMI and triceps skinfold thickness for boys, girls and all young people from the 1985 and 1997 matched samples

	Boys		Girls		All young people	
	1985	1997	1985	1997	1985	1997
n	159	159	120	120	279	279
Age	11.5 (1.1)	11.5 (0.8)	11.6 (1.2)	11.6 (0.8)	11.6 (1.1)	11.5 (0.8)
BMI	17.5	17.4	17.8	17.7	17.6	17.5
Triceps, mm	10.4	10.8	13.4	13.5	12.0	11.7
Speed, $m \cdot s^{-1}$	3.23 (0.49)	3.13 (0.52)[a]	2.78 (0.39)	2.66 (0.40)[b]	3.04 (0.50)	2.93 (0.52)[c]

[a] Not significantly different from boys in 1985 ($p = 0.09$).

[b] Significantly different from girls in 1985 ($p = 0.02$).

[c] Significantly different from all young people in 1985 ($p = 0.01$).

in 1985, 159 boys and 120 girls could be matched for age at last birthday, sex, BMI (to within ±1%) and triceps skinfold thickness (to within ±5%) with an equal number of boys and girls from the 1997 survey [34]. When average speeds on the 1.6 km walk/run test were compared using unpaired t tests, young people from the 1997 survey performed significantly worse than fatness-matched young people from the 1985 survey. The decline in performance was evident for boys (3.13 vs. 3.23 $m \cdot s^{-1}$; $p = 0.09$), girls (2.66 vs. 2.78 $m \cdot s^{-1}$; $p = 0.02$) and all young people (2.93 vs. 3.04 $m \cdot s^{-1}$; $p = 0.01$; table 3).

These fitness performance declines were compared to declines in the complete dataset [i.e. considering all young people in 1985 ($n = 2,748$) and all young people in 1997 ($n = 1,430$)], in order to estimate what percentage of the performance decline could be attributed to changes in fatness. When the complete 1985 and 1997 datasets were compared, the differences in 1.6 km running speed were considerably greater than the declines in the matched dataset, and all were significant at the $p < 0.0001$ level. For boys, mean running speed decreased from 3.28 to 3.02 $m \cdot s^{-1}$, a reduction of 7.9%. For girls, speed decreased from 2.79 to 2.60 $m \cdot s^{-1}$ (6.8%). The differences in speed for boys in the matched sample (3.1%) represented 39% of the differences in the unmatched samples (7.9%). In girls, the differences in speed in the matched sample (4.3%) represented 63% of the differences in the unmatched sample (6.8%). In other words, the differences in fitness performance were reduced by 61 and 37% for boys and girls respectively by matching for BMI and skinfold thickness.

Table 4. Mean (SD) values for age and 1.6 km run speed, and median values for BMI for boys, girls and all young people from the 1985 and 1997 matched samples

	Boys		Girls		All young people	
	1995–1996	1999–2000	1995–1996	1999–2000	1995–1996	1999–2000
n	1,607	1,607	1,227	1,227	2,834	2,834
Age	13.7 (0.9)	13.9 (0.8)	13.7 (0.9)	13.8 (0.9)	13.7 (0.9)	13.9 (0.8)
BMI	19.6	19.5	19.8	19.8	19.7	19.6
Speed, $m \cdot s^{-1}$	11.42 (1.23)	11.22 (1.24)[a]	10.18 (1.05)	10.02 (1.08)[b]	10.70 (1.31)	10.18 (1.34)[c]
$\dot{V}O_{2max}$ $ml \cdot kg^{-1} \cdot min^{-1}$	47.7 (6.3)	46.6 (6.5)[a]	41.2 (5.7)	40.4 (5.9)[b]	44.9 (6.8)	43.9 (7.0)[c]

[a] Significantly different from boys in 1995–1996 ($p < 0.0001$).
[b] ignificantly different from girls in 1995–1996 ($p < 0.0001$).
[c] Significantly different from all young people in 1995–1996 ($p < 0.0001$).
[d] Estimated using the equation of Léger et al. [35].

A similar analysis was undertaken with a subset of the second of the large Australian datasets, where 12- to 15-year-old were tested using the 20 m SRT. Young people tested in 1995–1996 were matched with young people tested in 1999–2000 for school, sex, age at last birthday and BMI (to within ±1%). This resulted in a matched sample of 1,607 boys and 1,227 girls in each cohort. A decline in running speed at the last completed stage of the 20 m SRT was evident for boys (11.22 $m \cdot s^{-1}$ in 1999–2000 vs. 11.42 $m \cdot s^{-1}$ in 1995–1996; $p < 0.0001$), girls (10.03 vs. 10.18 $m \cdot s^{-1}$; $p < 0.0001$) and all young people (10.70 vs. 10.18 $m \cdot s^{-1}$; $p < 0.0001$; table 4). Estimated $\dot{V}O_{2max}$ [35] showed similar patterns.

Again, these performance declines were compared to declines in the complete dataset of all young people in 1995–1996 and 1999–2000 (n = 4,570 boys and 3,368 girls), to estimate what percentage of the performance decline could be attributed to changes in fatness. When the complete 1995–1996 and 1999–2000 datasets were compared, the differences in final stage running speed were again greater than the declines in the matched dataset. For boys, mean running speed decreased from 11.46 to 11.09 $m \cdot s^{-1}$, a reduction of 3.2%. This compared to a decline of only 1.8% in the matched boys' dataset. In other words, the difference in fitness performance was reduced by 46% for boys by matching for BMI. For girls, speed decreased from 10.16 to 9.95 $m \cdot s^{-1}$ (2.1%), compared to 1.5% in the matched girls' dataset. In the case of girls, the difference in fitness performance was reduced by 29% by matching for BMI.

Again, the results from the two datasets are strikingly consistent: matching for fatness (operationalized by BMI and triceps skinfold thickness) reduces but does not eliminate the performance differential, accounting for about 30–60% of the decline.

Conclusions

A consideration of mechanisms, correlational data and temporal trends strongly supported an association between increased fatness and decreased fitness in young people. However, when young people from different time periods were matched for fatness, fitness differentials persisted, and were reduced by only about 50%.

Factors other than increased fatness are therefore contributing to declines in fitness performance. What might these factors be? Exposure to high-intensity exercise may be important. High-intensity exercise will elicit a training effect, and there is some evidence that high-intensity exercise may be especially efficacious in maintaining energy balance, at least in adults. While running tests such as the 20 m SRT and the 1.6 km walk/run have low measurement error, they are only moderately good predictors of the underlying 'construct' of aerobic fitness (i.e. $\dot{V}O_{2max}$). Performance on running tests is affected by a constellation of psychosocial factors, both cognitive (e.g. judgment of pace and effort) and affective (e.g. self-efficacy). It is conceivable that there have been secular changes in these factors, but no data are available. Furthermore, there are probably complex interactions among biological maturation, secular change in body size and shape and psychosocial factors. If young people are less accustomed to running, for example, their performance may be impaired. However, there is no direct evidence of this having occurred. There have also been changes in the socio-demographic characteristics of Australian children. After the end of the Vietnam War, Australia saw a wave of Asian immigration which resulted in an increase in the percentage of Asian-born Australians from 0.75% in 1981 to about 2.5% in 1991. At the same time the school population has been changing. There has been some shift of physically and mentally disabled children from special schools into mainstream schools, with the result that they are more likely to be captured in mass surveys. However, these changes are likely to have only relatively small quantitative effects.

It should also be borne in mind that, although matched for age, sex and fatness, the young people from the earlier and later samples occupy rather different positions relative to their cohorts. The matched young people from the later samples had BMIs and skinfold thicknesses which were, on average, less than the rest of their cohort, while those from the earlier samples had BMIs and skinfold thicknesses which were greater than the rest of their cohort. It is possible that young people who are lean relative to their cohort might be more motivated to be physically active, and hence fitter in virtue of a greater training effect. If this is the case, they may not be representative of the wider population of young people from their cohort. However, these potential differences would only serve to reduce the proportion of the difference in fitness performance which would be explained by fatness.

BMI is also an imperfect index of the underlying construct of adiposity. Secular trends in BMI may reflect increases in lean body mass or earlier maturation. More mature young people with a higher fat-free mass would be expected to perform better on running tests. In the Australian datasets, BMI increases by about 0.4–0.6 $\mathrm{kg} \cdot \mathrm{m}^{-2}$ with each year of age in the 10- to 15-year age range. The age of sexual maturity (indicated by menarche and voices breaking in boys) has been advancing by about 0.2–0.4 years every decade [36], although in some countries the trend appears to have slowed or stopped in the last two or three decades [33, pp 660–664]. There are no recent data for Australia. Assuming the trend towards earlier maturation is continuing, we would expect increases of about 0.1–0.2 $\mathrm{kg} \cdot \mathrm{m}^{-2}$ each decade even without increases in fatness. These represent about 20% of the actual secular increases found in the two Australian datasets analyzed in this study. The effect of correcting for this ‘non-fatness’ component of secular increases in BMI would be to further reduce the proportion of changes in fitness which could be ascribed to increases in fatness.

While there have been shifts in the mean fitness and fatness scores, there are few data available on distributional shifts. What evidence there is [25] suggests that rather than across-the-board upward or downward shifts, we are seeing increasingly long tails of fat and unfit young people, while the leanest and fittest young people are comparable to their counterparts from earlier time periods. Tomkinson [32] has shown significant increases in the coefficients of variation of fitness scores over the last 30 years in Australia, probably due to an increasing negative skew. Future research should be directed at shifts in the distribution of fitness performance.

What of the future? Globally, overweight prevalence is now increasing at the rate of about 9% per decade (fig. 1). Since a 1% increase in prevalence predicts a 0.03 SD decline in aerobic performance, equivalent to about 3% of mean 20 m SRT performances, we would expect a decline in performance of about 2.5–3% per decade in aerobic performance. This is reasonably close to the figure (4% per decade) estimated by Tomkinson et al. [2] based on data from 11 countries. Given that we have little reason to believe that overweight prevalence will stabilize or fall in the near future, we must also expect continuing falls in aerobic performance.

In conclusion, this study suggests that fatness accounts for about 15–45% of the observed cross-sectional (within and between country) variability of performance on tests of aerobic fitness, and about 30–60% of the changes in performance over time. The residual variability and differences remain unexplained.

References

1 World Health Organisation: Obesity: Preventing and Managing the Global Epidemic. Geneva, World Health Organisation, 1998.

2 Tomkinson GR, Léger L, Olds T, Cazorla G: Secular trends in the fitness of young people and adolescents 1980–2000: an analysis of 20 m shuttle run studies. Sports Med 2003;33:385–400.

3 Cole TJ, Bellizzi M, Flegal K, Dietz WH: Establishing a standard definition for child overweight and obesity worldwide: international survey. BMJ 2000;320:1–6.

4 Rode A, Shephard RJ: Growth, development and acculturation: a ten year comparison of Canadian Inuit young people. Hum Biol 1984;56:217–230.

5 Watanabe T, Yamamoto Y, Miyashita M, Mutoh Y: Secular change in running performance of Japanese adolescents: a longitudinal developmental study. Am J Hum Biol 1998;10:765–779.

6 Westerstahl M, Barnekow-Bergkvist M, Hedberg G, Jansson E: Secular trends in body dimensions and physical fitness among adolescents in Sweden from 1974 to 1995. Scand J Med Sci Sports 2003;13:128–133.

7 Rowland TW: Declining cardiorespiratory fitness in youth: fact or supposition? Pediatr Exerc Sci 2002;14:1–8.

8 Dollman J, Norton K, Norton L: Evidence for secular trends in children's physical activity behaviour. Br J Sports Med 2005;39:892–897.

9 Heath GW, Pratt M, Warren CW, Kann L: Physical activity patterns in American high school students. Arch Pediatr Adol Med 1994;148:1131–1136.

10 Black C, Collins A, Snell M: Encouraging walking: the case of journey-to-school trips in compact urban areas. Urban Stud 2001;38:1121–1141.

11 Roberts I: Safely to school? Lancet 1996;347:1642.

12 Tudor-Locke C, Ainsworth B, Popkin BM: Active commuting to school: An overlooked source of young people's physical activity? Sports Med 2001;31:305–309.

13 Pratt M, Macera CA, Blanton C: Levels of physical activity and inactivity in young people and adults in the United States: current evidence and research issues. Med Sci Sports Exerc 1999;31:S526–S533.

14 Norton K, Dollman J, Klanarong S, Robertson I: Kids' sport: who's playing what? Sport Health 2001;19:12–14.

15 French SA, Story M, Jeffery RW: Environmental influences on eating and physical activity. Ann Rev Publ Health 2001;22:309–335.

16 Gortmaker SL, Must A, Sobol AM, Peterson K, Colditz GA, Dietz WH: Television viewing as a cause of increasing obesity among young people in the United States, 1986–1990. Arch Pediatr Adol Med 1996;150:356–362.

17 Cavanagh PR, Kram R: Stride length in distance running: velocity, body dimensions, and added mass effects. Med Sci Sports Exerc 1989;21:467–479.

18 Cureton KJ, Sparling PB, Evans BW, Johnson SM, Kong UD, Purvis JW: Effect of experimental alterations in excess weight on aerobic capacity and distance running performance. Med Sci Sports 1978;10:194–199.

19 Thorstensson A: Effects of moderate external loading on the aerobic demand of submaximal running in men and 10 year-old boys. Eur J Appl Physiol 1986;55:569–574.

20 Welk GJ: The youth physical activity promotion model: a conceptual bridge between theory and practice. Quest 1999;51:5–23.

21 Conley DL, Krahenbuhl GS: Running economy and distance running performance of highly trained athletes. Med Sci Sports Exerc 1980;12:357–360.
22 Costill DL: The relationship between selected physiological variables and distance running performance. J Sports Med 1967;7:61–66.
23 Krahenbuhl GS, Pangrazi RP, Petersen GW, Burkett LN, Schneider MJ: Field testing of cardiorespiratory fitness in primary school children. Med Sci Sports 1978;10:208–213.
24 Pyke J: Australian Health and Fitness Survey 1985. Adelaide, Australian Council for Health Physical Education & Recreation, 1987.
25 Dollman J, Olds T, Norton K, Stuart D: The evolution of fitness and fatness in 10–11-year-old Australian school young people: changes in distributional characteristics between 1985 and 1997. Pediatr Exerc Sci1999;11:108–121.
26 Tomkinson GR, Olds TS, Gulbin J: Evolution of the fitness of Australian young people: evidence from the Talent Search Program. J Sports Med Phys Fitness 2003;43:90–98.
27 d'Agostino RB: Test for normal distribution; in d'Agostino RB, Stephens MA (eds): Goodness-of-Fit Techniques. New York, Marcel Dekker, 1986, pp 367–419.
28 Box GEP, Cox DR: An analysis of transformations. J Royal Stat Soc [B] 1964;26:211–252.
29 Lobstein T, Frelut M-L: Prevalence of overweight among young people in Europe. Obes Rev 2003;4:195–200.
30 Olds TS, Tomkinson G: Worldwide variation in the performance of children and adolescents: an analysis of 109 studies of the 20-m shuttle run test in 37 countries. J Sports Sci 2006;24: 1025–1038.
31 Deurenberg P, Deurenberg-Yap M: Differences in body composition assumptions across ethnic groups: practical consequences. Curr Opin Clin Nutr Metab Care 2001;4:377–383.
32 Tomkinson G: Secular trends in fitness performance of Australasian young people and adolescents; unpubl PhD thesis, Adelaide, University of South Australia, 2004.
33 Malina RM, Bouchard C, Bar-Or O: Growth, Maturation and Physical Activity. Champaign, Human Kinetics, 2004.
34 Olds TS, Dollman J: Are secular declines in young people's aerobic fitness explained by changes in fatness? Pediatr Exerc Sci 2004;16:201–209.
35 Léger LA, Mercier D, Gadoury C, Lambert J: The multistage 20 metre shuttle run test for aerobic fitness. J Sports Sci 1988;6:93–101.
36 Norton KI, Olds TS (eds): Anthropometrica. Sydney, UNSW Press, 1996.

Prof. Timothy S. Olds
Nutritional Physiology Research Centre, School of Health Sciences
University of South Australia
City East Campus, GPO Box 2471
Adelaide SA 5001 (Australia)
Tel. +61 8 8302 1411, Fax +61 8 8302 6658, E-Mail tim.olds@unisa.edu.au

Subject Index