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Worldwide variation in the performance of children and adolescents: An analysis of 109 studies of the 20-m shuttle run test in 37 countries

TIM OLDS[1], GRANT TOMKINSON[1], LUC LÉGER[2], & GEORGES CAZORLA[3]

[1]*Centre for Applied Anthropometry, University of South Australia, Adelaide, SA, Australia,* [2]*Département de kinésiologie, Université de Montréal, Montréal, Québec, Canada and* [3]*Association pour la recherche et l'évaluation en activité physique et sportive, Faculté des sciences du sport, Université de Bordeaux II, Talence, France*

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Abstract

This study is a meta-analysis of 109 reports of the performance of children and adolescents on the 20-m shuttle run test (20-mSRT). The studies were performed in 37 countries and included data on 418,026 children, tested between 1981 and 2003. Results were expressed as running speed ($km \cdot h^{-1}$) at the final completed stage of the 20-mSRT. Raw data were combined with pseudodata using Monte Carlo simulation. The 20-mSRT performances were expressed as z-scores relative to all children of the same age and sex from all countries. An overall "performance index" was derived for each country as the average of the age- and sex-specific *z*-scores for all children from that country. Factorial analysis of variance was used to compare scores among countries and regions, and between boys and girls of the same age. There was wide and significant ($P < 0.0001$) global variability in the performance of children. The best performing children were from the Northern European countries Estonia, Iceland, Lithuania, and Finland (0.6–0.9 standard deviations above the global average). The worst performing children were from Singapore, Brazil, USA, Italy, Portugal, and Greece (0.4–0.9 standard deviations below the global average). There is evidence that performance was negatively related to being overweight, as well as to a country's average temperature.

Keywords: *Children, fitness, variation, shuttle run*

Introduction

A number of previous studies have drawn attention to geographical variability in children's aerobic test performance (Fredriksen, Thaulow, Nystad, & Ingjer, 1998, Koenig-McIntyre, 1992, Rutenfranz *et al.*, 1973, Shephard, 1976). Unfavourable comparisons between the fitness of American children relative to Europeans in the 1950s and 1960s inspired efforts to introduce standardized testing and physical education in US schools (Knuttgen, 1960). However, there have been few systematic attempts to compare the fitness of children from different parts of the world. A number of circumstances make such a comparison difficult. The wide variety of fitness tests makes data incommensurable. There is now strong evidence, too, of widespread and quite rapid secular changes in children's aerobic test performance (Tomkinson, Léger, Olds, & Cazorla, 2003a), making it difficult to compare results across countries where tests have been administered recently (when children were generally less fit) and countries where tests were administered some time ago (when children were generally fitter). In many cases, the results of studies are difficult to locate, having been consigned to the "grey literature" because they were commissioned by government or private agencies, or conducted as part of unpublished postgraduate research theses. Until recently, with the development of the internet and email, as well as powerful database and statistical software, mechanisms for data sharing were cumbersome and inefficient, especially when dealing with large data sets.

This is unfortunate, because transnational comparisons based on standard instruments yield interesting insights. Recent studies have compared the fatness and energy intake (Livingstone, 2001) and physical activity levels (Riddoch *et al.*, 2004) of children from different countries. These studies potentially yield information on lifestyle factors associated with paediatric overweight, and could

Correspondence: T. Olds, Centre for Applied Anthropometry, School of Health Sciences, University of South Australia, C7-41 City East Campus, GPO Box 2471, Adelaide, SA 5001, Australia. E-mail: tim.olds@unisa.edu.au

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suggest effective interventions. A comprehensive fitness survey could also result in the construction of a set of world fitness norms, which might be used in much the same way as the world standard body mass index (BMI) values for children that have been widely adopted, based on large international data sets (Cole, Bellizzi, Flegal, & Dietz, 2000). There are also several hypotheses that can be tested using cumulated international fitness test data. It is often felt, for example, that the aerobic fitness of children and adolescents from very affluent countries is poor, due to the effortless lifestyle afforded by sedentary technologies, declines in community-based physical activity, and the unlimited availability of energy-rich food (Hill & Melanson, 1999). There is also some debate about whether Olympic success "trickles down" to the grass roots level, encouraging children's participation in sports, and hence enhancing fitness. There has, however, been little objective evidence for this hypothesis.

The 20-m shuttle run (20-mSRT) with 1-min stages is a reliable and valid field test to estimate peak oxygen consumption ($\dot{V}O_{2peak}$) (Léger, Mercier, Gadoury, & Lambert, 1988). It has been widely used to assess the aerobic fitness of children. Despite a plethora of data, no attempt has been made to cumulate the results of studies that have used the 20-mSRT. The test has a number of variants, and small differences in the conduct of the test and the analysis of results make it difficult to compare data from different sources. Tomkinson *et al.* (2003a) analysed secular trends in 20-mSRT performance. Their meta-analysis highlighted the difficulties arising from the different metrics used for expressing 20-mSRT results, the existence of variant forms of the test, artefacts created by averaging over a range of age groups, and the exact time at which stage numbers were called on the tapes used.

In this paper, we have cumulated studies using the 20-mSRT with children and adolescents, expressing their results using the common metric of running speed at the last completed stage. Our aims were: to describe worldwide variation in the fitness of children and adolescents across a number of countries; to compare performance between boys and girls, and between different age groups; to provide descriptive norms for different age-sex groups; and to explore associations between children's fitness and broad socio-economic characteristics at the level of the country.

Methods

Sources

Any study that used the 20-mSRT to assess the fitness of healthy young people aged 6 – 19 years was considered as a candidate study for this meta-analysis. Data on elite young sportspeople or groups with specific disabilities or disease conditions (e.g. obesity) were not considered. Studies were located by searching on-line databases (Sports Discus, Medline, AustROM, CINAHL, Digital Dissertations, Current Contents) using the following keywords: shuttle, shuttle run, MSFT, 20MST, 20mSRT, beep test, multi-stage, in combination with the modifiers child, children, pre-adolescent, adolescent, adolescence, pubescent, pubescence boy, girl, young, youth, and infant. No language or date restrictions were applied. When published reports were obtained, all relevant references contained in the studies were followed up. Finally, attempts were made to personally contact the authors of each report to ask if they knew of further studies, and to clarify details of their own study. Some of the authors were able to supply the raw data upon which their studies were based.

A total of 131 candidate studies were located. Of these, 22 were excluded for one or more of the following reasons:

- the authors reported their results in ways that could not be transformed to the common metric we adopted, namely running speed at the final completed stage (see below);
- results were reported for large, undifferentiated age ranges (e.g. 12 – 17 years) or combined boys and girls into a single group;
- the test protocol used was unknown; or
- the study reported data, or subsets of the data, which had been reported in other located studies.

The remaining 109 studies included data on 418,026 children from 37 countries in 1373 age × sex × country slices. Table I lists the 109 studies analysed, together with the year of measurement, age range, and typical sample sizes for each age × sex group. The breakdown of sample numbers by country is shown in Table III. Of the 109 studies, 56 (51%) were published in scientific journals and books, 30 (28%) were commissioned technical reports, 16 (15%) were unpublished data obtained through personal communication, and 7 (6%) were unpublished postgraduate theses. Twenty studies provided raw data on a total of 71,835 tests (17% of all data points), while the remainder gave summary statistics in the form of means and standard deviations.

Data treatment and statistical analysis

The general methodological approach used in this meta-analysis is outlined in Figure 1. Because there are three distinct 20-mSRT protocols in use

Table I. Summary of the studies used in this analysis.

Reference	Country	Year[a]	Sex	Age range	Sample sizes
ACHPER (1996)	Australia	1994	M, F	9–18	39–104
Australian Sports Commission (1994)	Australia	1993	M, F	12–17	301–542
Booth *et al.* (1997)	Australia	1997	M, F	9, 11, 13, 15	399–634
Brewer *et al.* (1988)	Australia	1991	M, F	11–14	57–256
Cooley and McNaughton (1999)	Australia	1998	M, F	11–16	339–636
Western Australian Institute of Sport (pers. comm., 2002)	Australia	1999–2001	M, F	12–15	951–3461
Tasmanian Institute of Sport (pers. comm., 2002)	Australia	1996–2001	M, F	12–15	1520–3304
Gibbs *et al.* (1995)	Australia	1995	F	9.5±0.7	36–38
Jill Hage (pers. comm., Dec. 1999)	Australia	1999	F	13, 14, 16, 17	3–107
Hands (2000)	Australia	1999	M, F	6–12	14–37
Jenner *et al.* (1992)	Australia	1988	M, F	12±0.4	527–565
A. Lindquist (pers. comm., Dec. 1999)	Australia	1998–1999	F	7–14	2–40
Lloyd & Antonas (2000)	Australia	1999?	M, F	11–12	35–53
Shane Masson (pers. comm., Dec. 1999)	Australia	1999	M, F	14, 16	6–11
Sara Mulkearns (pers. comm., Aug. 2001)	Australia	1996–1998	F	8–10	45–79
Okely *et al.* (1997)	Australia	1996	M	14	51
Annette Raynor (pers. comm., Sept. 2001)	Australia	1999	M, F	6–12	5–20
South Australian Sports Institute (pers. comm., 2002)	Australia	2001	M, F	11–15	8–1116
Tomkinson *et al.* (2003b)	Australia	1995–2000	M, F	12–15	1018–4451
Vandongen *et al.* (1995)	Australia	1990	M, F	10–12	485–486
Mr. Colin Walker (pers. comm., 2002)	Australia	1998	M	13	13
Sue Woolard (pers. comm., 1999)	Australia	1999	F	8–13	20
Baquet *et al.* (2000)	Belgium	1997	M, F	11–18	6–88
Beunen *et al.* (1991)	Belgium	1990	M, F	6–18	84–423
Lefèvre *et al.* (1998)	Belgium	1993, 1997	M, F	12–18	40–288
Nupponen & Telama (1998)	Belgium	1994–1995	M, F	12, 15	423–700
Pirnay (1995)	Belgium	1991–1992	M, F	10–18	90–247
Poortmans *et al.* (1986)	Belgium	1984–1985	M, F	6–19	9–82
Cazorla *et al.* (1987)	Benin	1987	M, F	8–18	139–425
Gouthon (1987)	Benin	1987	M, F	13–18	16–35
Falgairette *et al.* (1994)	Bolivia	1992	M	10, 13	12–16
Hobold (2003)	Brazil	2002?	M, F	7–17	90–153
Pieta (2000)	Brazil	1999?	M, F	7–14	83–148
Léger *et al.* (1984)	Canada	1981	M, F	6–17	112–404
Massicotte (1990)	Canada	1989–1990	M, F	6–17	75–402
Cazorla *et al.* (1985)	Côte d'Ivoire	1985	M, F	7–18	57–314
Gajda (1994)	Czech Republic	1992–1993	M, F	7–14	83–188
Lars Bo Andersen (pers. comm., Sept. 2001)	Denmark	1996–1997	M, F	15–19	183–3198
Cazorla *et al.* (1986b)	Djibouti	1986	M, F	11–18	20–182
Jürimäe & Volbekiene (1998)	Estonia	1993–1994	M, F	11–17	133–294
Kull & Jürimäe (1994)	Estonia	1992–1993	M, F	17±0.3	132–207
Oja & Jürimäe (1998)	Estonia	1996–1997	M, F	6	133–161
Raudsepp & Jürimäe (1996)	Estonia	1994–1995	M	7–10	45–55
Raudsepp & Jürimäe (1997)	Estonia	1994–1995	F	7–10	48–57
Viljanen *et al.* (2000)	Finland	1993	M, F	7, 10, 14, 16	63–249
Nupponen & Telama (1998)	Finland	1995	M, F	12, 15	254–307
Baquet *et al.* (1999)	France	1992	M, F	6–11	14–49
Baquet *et al.* (2001)	France	1997	M, F	10–15	8–88
Baquet *et al.* (2000)	France	2000	M, F	8–10	3–12
Blonc *et al.* (1992)	France	1991?	M, F	11–16	20–124
Cazorla (1987)	France	1987	M, F	7–12	119–693
Cazorla *et al.* (1997)	France	1996–1997	M, F	7–11	47–110
Carzorla *et al.* (1999)	France	1999	M, F	11–18	85–234
Colin Walker (pers. comm., March 2002)	France	1992	M	10, 13	28–41
Levarlet-Joye & Fievetz (1990)	France	1989?	M	11–14	7–33
Van Praagh *et al.* (1987)	France	1985–1986	M, F	10–11	64–75
Van Praagh *et al.* (1988)	France	1986	M	7, 12	15–18
Nupponen & Telama (1998)	Germany	1994–1995	M, F	12, 15	216–264
Georgiadis (1993)	Greece	1990–1991	M, F	6–18	103–297
Manios *et al.* (1999)	Greece	1992–1993	M, F	6	264–305
Eston *et al.* (1998)	Hong Kong	1995–1996	M, F	7–15	5–32
Macfarlane *et al.* (1998)	Hong Kong	1995–1996	M, F	8–11	28–31
Barabás & Sebestyén (1995)	Hungary	1992–1994	M	18–19	330–475

(*continued*)

Table I. (*Continued*)

Reference	Country	Year[a]	Sex	Age range	Sample sizes
Nupponen & Telama (1998)	Hungary	1994–1995	M, F	12, 15	100–114
Gunnarsson & Sigríksson (1999)	Iceland	1998	M, F	6–15	255–528
MacDonncha *et al.* (1999)	Ireland	1998?	M	15	22
Bellucci (1997)	Italy	1994	M, F	12–14	10–23
Cilia & Bellucci (1993)	Italy	1992	M, F	12–14	189–259
Cilia *et al.* (1996)	Italy	1995	M, F	12–15	23–120
Cilia *et al.* (1997)	Italy	1997	M, F	12–19	73–404
Cilia *et al.* (1998)	Italy	1997	M, F	14–19	16–68
Council of Europe (1986)	Italy	1985–1986	F	14–18	44–79
MECSST (1999–2002)	Japan	1998–2001	M, F	6–19	52–1123
Jürimäe & Volbekiene (1998)	Lithuania	1993	M, F	11–17	66–150
Cazorla *et al.* (1986a)	Mauritius	1986	M, F	7–17	137–160
van Mechelen *et al.* (1986)	Netherlands	1983	M, F	12	41
van Mechelen *et al.* (1987)	Netherlands	1987	M, F	12–16	101–285
Maciaszek & Osinski (2001)	Poland	2000?	M, F	10–14	245–371
Mleczko & Ozimek (2000)	Poland	1991–1992	M, F	15–19	150–303
Przeweda & Dobosz (2003)	Poland	1999	M, F	7–19	623–3470
Mota *et al.* (2002)	Portugal	1998–2000	M, F	9–15	17–115
Miguel Oliveira (pers. comm., 2002)	Portugal	2001–2002	M, F	10–19	28–250
Cazorla *et al.* (1988)	Sénégal	1988	M, F	7–18	72–163
Cazorla *et al.* (1990)	Seychelles	1990	M, F	7–18	142–259
Ms. Annette Raynor (pers. comm., July 2002)	Singapore	1999	M, F	6–11	4–17
Kasa & Majherová (1997)	Slovakia	1996	M, F	11–14	24–45
Kyselovicová (2000)	Slovakia	1993–1995	F	15–16	15–38
Moravec (1996)	Slovakia	1993	M, F	7–19	54–554
du Randt (1996)	South Africa	1995–1996	M, F	11–16	45–210
García Baena (1999)	Spain	1999	M, F	13–18	10–70
Brito Ojeda *et al.* (1995)	Spain	1993?	M, F	10–19	35–50
Prat *et al.* (1998)	Spain	1984–1985	M, F	10–18	140–267
Javier Rivas (pers. comm., June 2002)	Spain	1987	M, F	9–18	6–303
Sainz (1992)	Spain	1986–1989	M, F	10–15	37–180
Sainz (1996)	Spain	1990–1994	M, F	9–17	54–671
Lieveld *et al.* (1993)	Suriname	1992	M	14	70–115
Cauderay *et al.* (2000)	Switzerland	1996–1997	M, F	9–19	36–214
Çalis *et al.* (1992)	Turkey	1991	M	15	19–30
Armstrong *et al.* (1988)	UK (England)	1987?	M	12	77
McVeigh *et al.* (1995)	UK (Scotland)	1994?	M, F	13	15–18
Eston *et al.* (1998)	UK (Wales)	1995–1996	M, F	7–15	7–15
Boreham *et al.* (1987)	UK (Northern Ireland)	1986	M, F	13, 15	13–32
Boreham *et al.* (1990)	UK (Northern Ireland)	1988	M, F	15	18–23
Boreham *et al.* (2001)	UK (Northern Ireland)	1989–1990	M, F	12, 15	251–258
Mahoney & Boreham (1992)	UK (Northern Ireland)	1991	M, F	7, 9, 11	91–109
Mahoney (1992)	UK (Northern Ireland)	1990–1991	M, F	12	50–53
Nichols & Riddoch (1986)	UK (Northern Ireland)	1986	M, F	12–15	32–163
Riddoch (1990)	UK (Northern Ireland)	1988–1989	M, F	11–18	87–237
Twisk *et al.* (1999)	UK (Northern Ireland)	1992–1993	M, F	15	229–230
Michael Beets (pers. comm., 2003)	USA	1999–2001	M, F	8–19	5–63
Michael Beets (pers. comm., 2003)	USA	2003	M, F	14–19	5–32
Chun *et al.* (2000)	USA	1997	M, F	12	116–120
Dinschel (1994)	USA	1993?	M, F	9–12	3–39
Liu *et al.* (1992)	USA	1990	M, F	13–14	22–26
Mahar *et al.* (1997)	USA	1995	M, F	10	113–144
Pitetti *et al.* (2002)	USA	2001?	M, F	10, 11	13–28
Wolford (1998)	USA	1997	M, F	10	97–102

Note: The table shows the country and year(s) in which measurements were taken, the sex of the children tested, the age range of the children tested, and the range of sample sizes for each age × sex slice in the study.
[a]Where the year in which measurements were made was unclear (indicated by a question mark), we assumed that children were tested one year before the year of publication.
Abbreviations: F = female; M = male.

(Tomkinson *et al.*, 2003a), primary data treatment involved correction for the protocol used in each study, using methods that have been described in detail elsewhere (Tomkinson *et al.*, 2003a). When not reported, the year of testing was taken to be the year before the year of publication. We attempted to

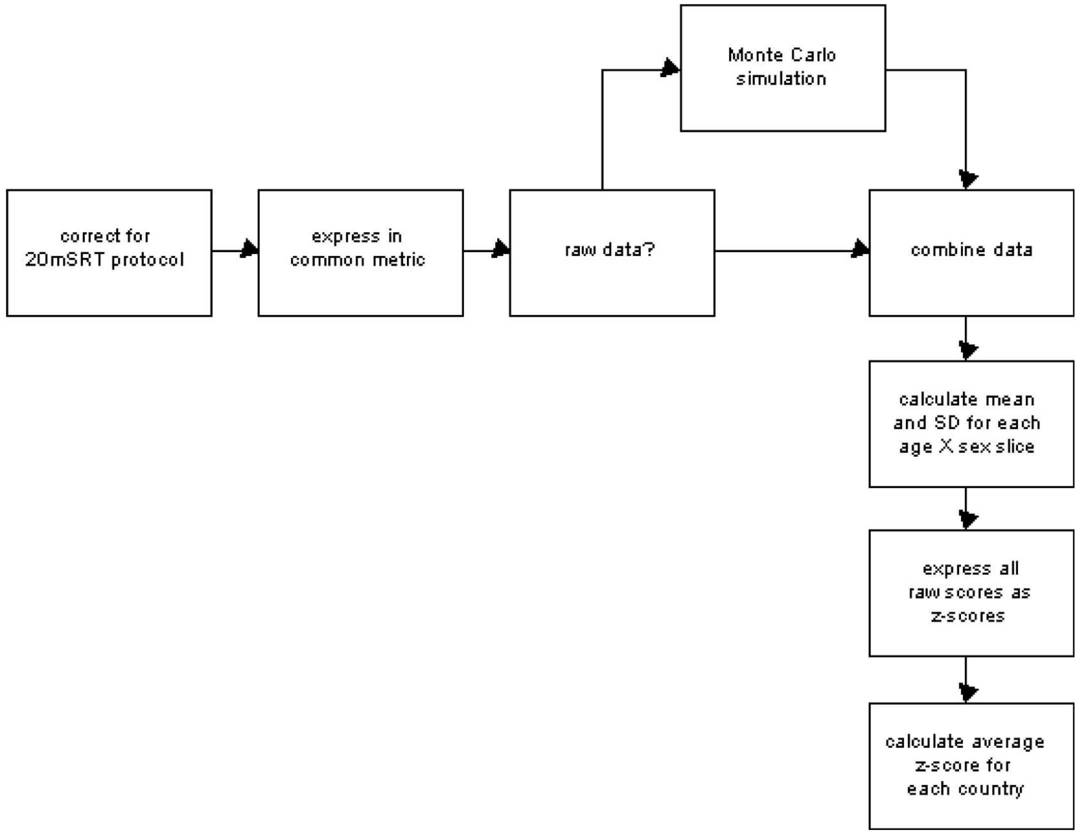

Figure 1. Flow chart showing the methodology applied in this study. Results from studies were first corrected according to which protocol they used (Léger, Eurofit, or Queens University of Belfast), and then expressed in the common metric of running speed ($km \cdot h^{-1}$) at the final completed stage. If raw data were not available, pseudo data were generated using Monte Carlo simulation. These were then combined with the raw data. The mean and standard deviation running speeds for each age × sex slice were calculated, and each individual child's performance was expressed as a *z*-score. The average *z*-score for all children from each country constituted that country's performance index.

contact the study authors when any clarification about protocols or results was required, and also to check that we were not "double counting" data that had already been reported as part of other studies. Running speed at the last completed stage was used as the common metric across studies. To obtain overall means for each country, or for each age × sex group, we used Monte Carlo simulation to combine data from different sources. This technique attempts to "recreate" the unavailable raw data by using a random normal generator to produce "pseudo" data points based on reported means and standard deviations. It assumes that distributions are approximately normal, which was true of the raw data sets that were available. Pseudo data sets were repeatedly generated until the calculated mean differed from the reported mean by $<0.5\%$, and the calculated standard deviation differed from the reported standard deviation by $<2.5\%$. These pseudo data sets were then merged with raw data from other studies. This methodology has been described in detail previously (Tomkinson *et al.*, 2003a).

The main aim of this study was to compare mean running speeds across countries, and between children of different ages and sexes. Running speeds were expressed as *z*-scores relative to the grand mean for all children of that age and sex from all countries. The mean of these *z*-scores for all children from a particular country constituted that country's overall "performance index". This index represented the overall standardized deviation of the performance of a country's children from the global age- and sex-specific mean, and was used as a method of comparing the fitness of children and adolescents from different countries. Mean scores were used to compare children across ages and sexes.

Factorial analysis of variance (ANOVA) was used to compare performance indices among countries and regions, and to compare mean running speeds among children of different ages, and between boys and girls of the same age. Spearman's rho was used to quantify the strength of the relationship between a country's performance index and various broad-brush socio-economic factors, such as per capita gross domestic product (GDP), indices of the equality of the distribution of wealth, the percentage of young people in the population, and Olympic success.

Results

Age- and sex-related variation

Performance on the 20-mSRT improved linearly until the early post-pubertal years (about age 12 years in girls and 16 years in boys) and then plateaued. Boys' performance improved at the rate of 0.3 km · h^{-1} per year of age until age 16, and girls' performance improved at the rate of 0.25 km · h^{-1} per year of age until age 12. From age 16 to 19 in boys and from age 12 to 19 in girls, running speeds increased at only 0.03 km · h^{-1} with each year of age. In spite of the evident plateauing, running speeds at each age were significantly different from those at every other age ($P < 0.0001$) because of the very large sample sizes.

Boys performed significantly better than girls ($P \leq 0.0001$) at every age, with the performance gap increasing with age (Table II and Figure 2).

Variation among countries

The performance indices (i.e. the average *z*-scores) for each of the 37 countries surveyed are shown in Table III. They ranged from +0.863 for Estonia to −0.867 for Singapore. There were significant differences between the performance indices of different countries ($F = 970$, $P < 0.0001$). The best performing nations were Northern European countries, notably Iceland and the Baltic states. The top seven nations were all from Northern and Central Europe. The worst performing nations were Southern European countries (Greece, Italy, Portugal, and Spain), Brazil, and some of the developed Pacific Rim nations (USA, Singapore, Hong Kong, and Australia). Of the bottom ten countries, seven came from Southern Europe and the Pacific Rim. When grouped into geographical regions (Northern, Central, Western, and Southern Europe; Africa; Pacific Rim; and Other Countries), there were significant differences in the unweighted mean performance index ($P < 0.0001$). Northern Europe (mean performance index = +0.60) outperformed all other regions, and all regions except the Pacific Rim (−0.26) and Other Countries (−0.19) outperformed Southern Europe (−0.40).

In Europe, there was a clear north – south fitness gradient (Figure 3). The top five ranked countries were all from Northern Europe (Estonia, Iceland, Finland, Lithuania, and Ireland), while three Southern European countries (Greece, Portugal, and Italy) were among the six lowest ranked countries.

Discussion

Variation among countries

The variation in mean fitness between countries spanned over 1.7 standard deviations: 95% of Estonian children would perform better than the average Singaporean child. This span of performances equates, using a validated equation (Léger *et al.*, 1988), to a difference of about 10–12 ml · kg^{-1} · min^{-1} (or about 25% of average $\dot{V}O_{2peak}$) between the most fit and least fit groups of children. To make these differences more concrete, it would mean that the average Estonian male adolescent would finish about 600 m ahead of the average young Singaporean in a 12-min run.

The superiority of Northern and Central European children, and the relatively poor performance of North American children, has been a recurrent

Table II. Sample size and the mean and standard deviation of running speed at the final completed stage (km · h^{-1}) for each age × sex slice.

	Boys			Girls		
Age (years)	*n*	mean	*s*	*n*	mean	*s*
6	5 685	8.917	0.545	5 606	8.804	0.513
7	10 138	9.454	0.871	10 168	9.188	0.700
8	9 526	9.882	1.000	10 868	9.461	0.812
9	12 935	10.120	1.085	12 700	9.671	0.882
10	13 859	10.459	1.142	13 751	9.965	0.930
11	15 480	10.716	1.202	15 446	10.135	1.011
12	24 544	10.951	1.237	24 255	10.241	1.041
13	27 535	11.166	1.303	27 110	10.220	1.061
14	27 106	11.517	1.323	24 924	10.311	1.086
15	22 465	11.812	1.283	20 197	10.366	1.031
16	13 311	12.122	1.462	13 547	10.396	1.055
17	15 108	12.192	1.450	14 884	10.408	1.159
18	8 580	12.263	1.395	8 913	10.393	1.053
19	4 917	12.182	1.315	4 468	10.442	1.068
Total	211 189			206 837		

Note: In this analysis, all reported results were first converted to the protocol of Léger *et al.* (1984). In this protocol, the running speed at the completion of Stage 1 is 8.5 km · h^{-1}, and increases by 0.5 km · h^{-1} each stage thereafter. n = sample size; s = standard deviation.

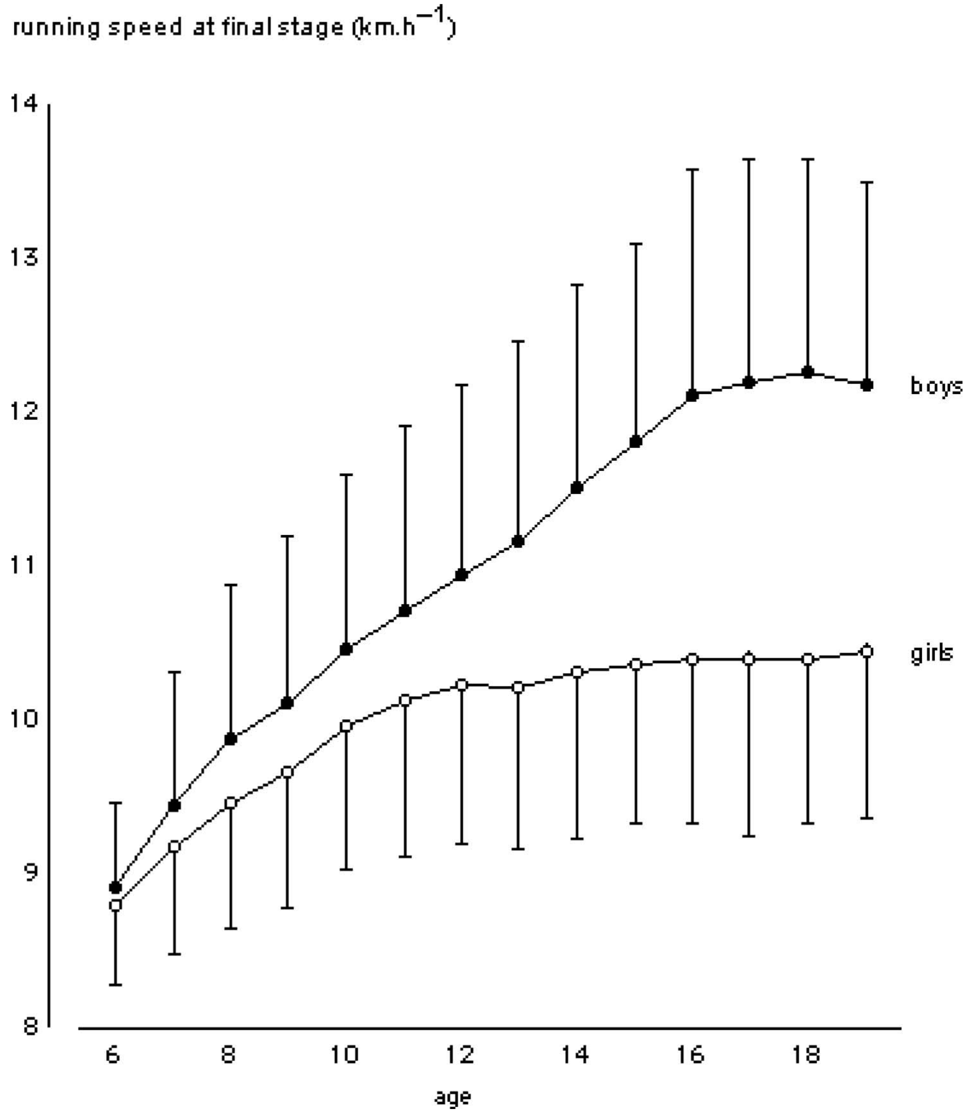

Figure 2. Age-related evolution of 20-mSRT performance (running speed in km · h^{-1} at the final completed stage) in boys (solid circles) and girls (open circles). The error bars show the standard deviations.

theme in studies since the 1960s. In 1960, Knuttgen reported that 99% of Danish seventh- to twelfth-grade girls and 96% of Danish boys performed better than American averages on the AAHPER 600-yard walk/run test. Shephard (1976) noted that Scandinavian children were much better on $\dot{V}O_{2peak}$ tests than children from North America. In 1973, it was reported that 10-, 15-, and 17-year-old German boys and girls performed decidedly better on a PWC_{170} test (W · kg^{-1}) than comparable Canadian children, and were of similar fitness to Czech children measured in other studies (Rutenfranz *et al.*, 1973). Fredriksen *et al.* (1998) compared directly measured $\dot{V}O_{2peak}$ values of European children, finding that children from Northern Europe were better than their peers from other parts of Europe. More recently, Koenig-McIntyre (1992) compared the one-mile run performances of 10-year-old Finnish, Norwegian, and Swedish children to those of US children. The passing percentages on criterion-referenced tests of the Northern European children (54–85%) easily exceeded those of US children (42–44%).

Methodological issues

The issue of the representativeness of samples in cumulation studies of this sort has been discussed previously (Tomkinson *et al.*, 2003a). In the studies used in this analysis, sampling procedures ranged from random national samples to local convenience samples, but no samples consisted entirely of disabled, diseased, or athletic groups. In meta-analyses drawing upon a large number of studies with a very large total sample size, the sheer mass of data points will tend to dampen irregularities arising

Table III. Performance indices (mean age- and sex-specific *z*-scores) for the 37 countries for which data were available (also shown are the lower and upper 95% confidence limits and the sample size).

Country	*n*	Performance index	LCL	UCL
Estonia	5 529	0.863	0.835	0.891
Iceland	8 160	0.773	0.751	0.795
Finland	2 420	0.621	0.581	0.661
Lithuania	1 601	0.547	0.514	0.580
Ireland	22	0.544	0.117	0.971
Hungary	1 244	0.508	0.451	0.565
Czech Republic	3 881	0.323	0.295	0.351
Côte d'Ivoire	3 881	0.292	0.262	0.322
France	11 301	0.266	0.248	0.284
Canada	13 474	0.245	0.229	0.261
Denmark	14 764	0.233	0.212	0.250
Japan	95 763	0.216	0.209	0.223
Germany	977	0.179	0.132	0.226
Benin	5 280	0.117	0.095	0.139
Mauritius	3 294	0.102	0.074	0.130
Bolivia	28	0.061	−0.300	0.422
Slovakia	4 684	0.051	0.029	0.073
South Africa	1 230	0.040	−0.022	0.102
Sénégal	3 023	0.033	−0.002	0.068
Djibouti	1 784	0.016	−0.021	0.053
Seychelles	5 118	−0.011	−0.037	0.015
Belgium	19 942	−0.017	−0.029	−0.005
UK	6 333	−0.046	−0.070	−0.022
Suriname	270	−0.118	−0.204	−0.032
Netherlands	1 956	−0.131	−0.164	−0.098
Spain	17 460	−0.152	−0.164	−0.140
Poland	75 874	−0.190	−0.197	−0.183
Australia	82 129	−0.201	−0.208	−0.194
Turkey	72	−0.207	−0.400	−0.014
Hong Kong	562	−0.324	−0.390	−0.258
Switzerland	3 270	−0.399	−0.427	−0.371
Greece	6 999	−0.453	−0.471	−0.435
Portugal	2 994	−0.489	−0.521	−0.457
Italy	6 588	−0.493	−0.896	−0.090
USA	1 878	−0.620	−0.664	−0.576
Brazil	4 137	−0.683	−0.698	−0.668
Singapore	104	−0.867	−1.041	−0.693

Note: LCL = lower 95% confidence limit; *n* = sample size; UCL = upper 95% confidence limit.

from sampling inconsistencies. This is particularly true in cases where there have been a number of different studies from the same country. Results based on one or two small-sample studies are less reliable. In the present study, this was the case for Bolivia, Germany, Hong Kong, Ireland, Singapore, Suriname, and Turkey. By contrast, the results for Australia, Belgium, Estonia, France, Italy, Spain, and the UK were based on at least 5000 children and at least six separate studies each. They typically represented a wide geographical dispersion. For example, the Spanish studies covered children from Catalonia, the Canary Islands, the Basque Country, and Madrid; the Australian studies represented children from every state; and the British studies

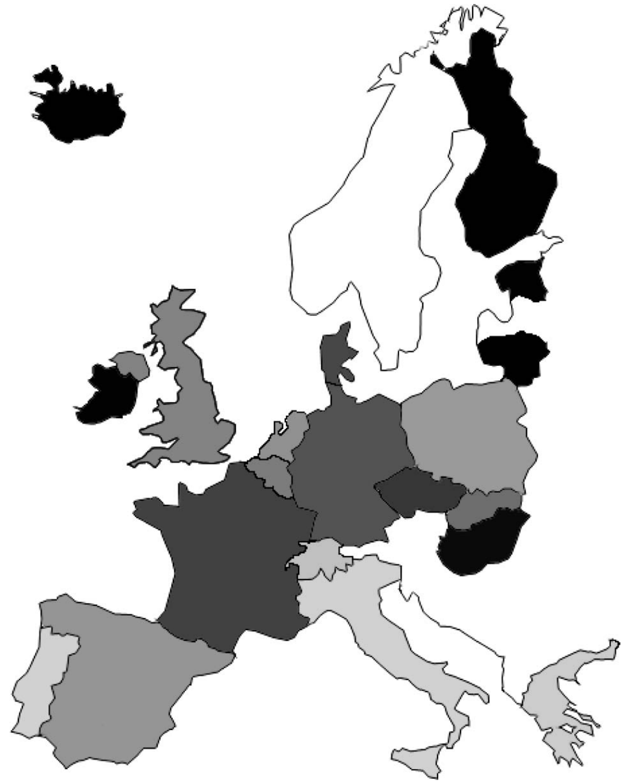

Figure 3. The performance index of 20 European countries is indicated here by shading, where darker shading indicates a higher performance index and lighter shading indicates a lower index. There are no data on the white areas.

included children from each of the constituent nations. There were also very large samples (>75,000) for Japan and Poland. We can therefore have considerable confidence in these results.

All children were tested between 1981 and 2003. However, there is now convincing evidence that in this period performance on tests of cardiovascular fitness has declined globally (Tomkinson *et al.*, 2003a), at a rate of about 0.4% per year. This would mean that a direct comparison of scores would tend to reflect relatively poorly on those countries where the bulk of the measurements had been taken very recently (for example, Brazil, where the mean year of testing was 2001), and artefactually enhance the performance indices of those countries where the bulk of the testing had taken place earlier (for example, Canada, with a mean year of testing of 1985). When the mean performance index for each country was regressed against the mean year of testing, the index declined by an average of 0.032 units with every year of testing. Correcting for this effect by increasing or decreasing the performance index appropriately yielded a time-corrected performance index. The ranking of countries was not greatly changed, and there was a strong correlation between the uncorrected and corrected rankings ($\rho = 0.92$, $P < 0.0001$). The main beneficiaries were Australia (28th to 19th place), Djibouti (20th to 12th), Japan (12th to 6th), and Poland (27th to 17th), whereas Benin (14th to 21st), Canada (10th to 18th), Mauritius (15th to 23rd), and the Netherlands (25th to 33rd) all fell in the rankings.

Motivation is likely to be an important factor in test performance, both at the individual level and at a social or cultural level. The degree of "humiliation tolerance", for example, will affect a child's drive to do their best. However, none of the studies in this review quantified motivation.

Possible socio-economic correlates

There are a number of broad socio-economic factors that could, in principle, impact on children's fitness. These include the affluence of the country, its distribution of wealth, the "critical mass" of young people (i.e. the percentage of children and adolescents in a society), and the importance of sport in the national psyche. In addition, one would anticipate associations between aerobic test performance and both the children's physical activity and the incidence of paediatric overweight.

Physical activity and overweight

Several recent studies have compared physical activity among children from different countries using objective measurements. Vincent, Pangrazi, Raustorp, Tomson and Cuddihy (2003) found that Swedish children took more daily steps than Australian children, who in turn were more active than American children. Riddoch *et al.* (2004) found the following order in the activeness of children from different countries using accelerometry: Norway, Estonia, Portugal, Denmark. Livingstone (2001) 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 (2003) confirmed this trend, with high levels of child overweight in Spain, Italy, and Greece compared with Denmark, Germany, the Czech Republic, and Slovakia. If we consider that overweight and lack of physical activity are contributing factors to low aerobic fitness, then all of these findings are broadly consistent with the fitness differentials reported here.

Affluence

There are plausible mechanistic arguments that a society's affluence might affect the fitness of its children. Wealthy countries can provide children with the time and equipment necessary for recreation, including school-based sport lessons. These children also have the social capital and education to understand the importance and value of vigorous physical activity, and health care systems to protect them from debilitating childhood diseases. On the other hand, children from affluent societies may also have the time and resources for greater sedentary activity (watching television, playing video games). They are less likely to use active transport and less likely to perform vigorous household or commercial work.

In this study, there was no clear relationship between the performance index and national wealth. Per capita GDP, expressed in $PPP or parity purchasing power, was available for 36 of the 37 countries in this meta-analysis (http://www.cia.gov/cia/publications/factbook/geos). There was no relationship between GDP and the performance index ($\rho = 0.02$, $P = 0.89$). High fitness levels were found in children from the relatively poor transitional economies of Eastern Europe (e.g. Estonia, with a per capita GDP of $PPP 11,000). Conversely, very wealthy countries could show either very high fitness (Iceland, $PPP 30,200) or very low fitness (USA, $PPP 36,300). Relative affluence, at least in so far as it is quantified by GDP, was unrelated to children's fitness.

Distribution of wealth

A case can also be made *a priori* that countries where the distribution of wealth is less equal will show lower fitness. Relatively disadvantaged families in these countries (typically, the under-employed) may not have adequate resources or the social capital to encourage active recreation in their children, while the relatively advantaged (the over-employed) may lack time or succumb to the effortless lifestyle of abundance. Furthermore, there is a great deal of evidence that income inequality is correlated with lower life expectancy, increased risk of cardiovascular and other diseases, impairment of children's growth, and social disintegration (Wilkinson, 2000). In strongly hierarchical societies, subordinate members experience high anxiety, as an evolutionary legacy of the need to be prepared for fight or flight when threatened by superordinates. This is manifested in higher cortisol concentrations and subsequent impairment of growth and immune function (Wilkinson, 2000). The most common economic measure of the distribution of income within a country is the Gini coefficient. It ranges from 0 ("perfect equality") to 1 ("maximum inequality"). Gini coefficients for the distribution of household income were available for 30 of the 37 countries in this meta-analysis (http://www.cia.gov/cia/publications/factbook/geos).

There was again no significant relationship ($\rho = -0.26$, $P = 0.16$) between the Gini coefficient and the performance index. Children in countries with low Gini coefficients tended to have high levels of fitness, while those in countries with relatively high Gini coefficients could have either high or low fitness. The country with the fittest children (Estonia) had a relatively high Gini coefficient of 0.37. As with absolute differences in wealth among countries, variability in wealth within countries may work either to enhance or reduce fitness.

Cultural commitment to sport: Olympic success

Children's fitness is likely to be affected not only by economic but also by cultural factors, such as the importance of sport and physical activity in the nation's psyche. The national cultural commitment to sport is difficult to quantify, but a reasonable proxy might be a country's performance in the Olympic Games. We used an ''Olympic index'' based on the number of medals won in post-war summer and winter Olympics, corrected for participation rates and for the number of medals available at each Olympics. This number was then divided by the country's population (for details, see http://users.skynet.be/hermandw/olymp/reloly.html). There was a moderate but significant relationship between the performance index and the Olympic index ($\rho = 0.32$, $P = 0.028$ one-tailed). In particular, Finland, Denmark, Estonia, and Iceland had both a high performance index and a high Olympic index, whereas Singapore, Hong Kong, and Brazil scored poorly on both indices.

This correlation may be interpreted in several ways. In could mean that there is a ''trickle-down'' effect, whereby countries that invest a large amount of money in elite athletic performance reap benefits at the grass roots level. Equally, it may be interpreted as evidence for a ''trickle-up'' effect, whereby countries with high grass roots fitness produce athletes who can participate in elite competition. It is also possible that a third factor – for example, the extent to which a government will invest in sports infrastructure – affects each index independently. It should be noted, however, that 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.

Critical mass of children

There is also a rationale for suggesting that aerobic test performance could be affected by the number of children in a society. A large percentage of children may constitute a ''critical mass'', which makes it politically and logistically easier to encourage youth sport. In our data set, however, there was no relationship between the percentage of the population aged 0–14 years (http://www.cia.gov/cia/publications/factbook/geos) and the performance index ($\rho = 0.10$, $P = 0.56$).

There are thus few obvious socio-economic correlates of fitness at the national level. It is possible that cultural factors, which are harder to quantify, may be important. The Northern European (Baltic and Scandinavian) and, to a lesser extent, the Central European states stood out as having excellent levels of children's fitness. This may partly be due to their long tradition of institutionalized and organized participation in physical activity, 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 led to massive youth movements throughout the twentieth century.

Climate

There was a significant negative relationship ($r = -0.44$, $P = 0.007$) between the performance index and the average annual temperature of the capital city of the country, so that children from colder countries performed better. This could be related to the effect of temperature on test performance: children would be expected to perform worse under very hot and perhaps humid conditions. However, it might also be expected that children would perform poorly under very cold conditions. Alternatively, the differences in performance could reflect different cultural attitudes towards physical activity in hot and cold countries, with children from very hot countries tending to avoid exertion in the heat. The most likely explanation, however, is that this relationship is an artefact created by the outstanding performance of children from Northern Europe. When these countries are excluded from the analysis, there is no longer a significant relationship between temperature and performance ($r = 0.18$, $P = 0.34$).

Differences between the sexes

Boys easily outperformed girls, the differences being significant ($P \leq 0.0001$) in every age group. Because differences between the sexes are consistent across a wide range of countries with different social, political, and economic systems, they are probably biological rather than social in origin. Previous studies that failed to find differences between pre-pubertal boys and girls probably suffered from small sample sizes.

Conclusion

The data provided in Table II represent world standard performance on the 20-mSRT for the mean year of testing (1996). They may therefore serve as a yardstick to compare performances among countries and across ages and sexes.

This comprehensive review of worldwide variation in children's aerobic test performance showed wide variation in fitness levels. Baltic and Scandinavian countries fared best; Mediterranean and developed Pacific Rim countries had the least fit children. The Northern European countries provide a model of how affluent nations can sustain high apparent fitness in their children, and further research should explore the reasons for this. Neither affluence nor the distribution of wealth appears to be important in determining children's performance. Recent studies (Olds & Dollman, 2004; Tomkinson, Olds, & Gulbin, 2003b) have suggested that about half the decline in aerobic test performance in Australia over the last decade is associated with increases in fatness, although the causal arrow may point in either direction. The agreement in between-country variability in the incidence of overweight and test performance supports these findings. Cultural and even climatic factors may also play a role.

The data on which these conclusions are based are lacunary. There are at present very few data on developing countries, especially in South America and Asia, and data on certain age-groups in developed countries are lacking. For some countries, the sample sizes were very small, while the other studies did not use random samples. A coordinated global approach is needed to systematically monitor changes in children's fitness. Mechanisms should be put in place to facilitate data-pooling, such as an Internet-based data repository. There is also a critical need for standardization in the way the 20-mSRT is administered and the results analysed and reported.

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