Normative health-related fitness values for children: Analysis of 85347 test results on 9-17-year-old Australians since 1985

Article *in* British Journal of Sports Medicine · October 2011

DOI: 10.1136/bjsports-2011-090218 · Source: PubMed

2 authors:

Mark Jon Catley
University of South Australia

Grant Tomkinson
University of South Australia

Normative health-related fitness values for children: analysis of 85347 test results on 9–17-year-old Australians since 1985

Mark J Catley, Grant R Tomkinson

▸ The appendix to this paper is published online only. To view this file please visit the journal online (http://dx.doi.org/10.1136/bjsports-2011-090218).

Health and Use of Time (HUT) Group, Sansom Institute for Health Research, University of South Australia, Adelaide, Australia

Correspondence to
Dr Grant R Tomkinson, Health and Use of Time (HUT) Group, Sansom Institute for Health Research, University of South Australia, GPO Box 2471, Adelaide, SA 5001, Australia; grant.tomkinson@unisa.edu.au

Received 13 May 2011
Accepted 22 September 2011
Published Online First
21 October 2011

To cite: Catley MJ, Tomkinson GR. *Br J Sports Med* 2013, **47**, 98–109.

ABSTRACT

Objectives To provide sex- and age-specific normative values for health-related fitness of 9–17-year-old Australians.

Methods A systematic literature search was undertaken to identify peer-reviewed studies reporting health-related fitness data on Australian children since 1985—the year of the last national fitness survey. Only data on reasonably representative s amples of apparently healthy (free from known disease or injury) 9–17-year-old Australians, who were tested using field tests of health-related fitness, were included. Both raw and pseudo data (generated using Monte Carlo simulation) were combined with sex- and age-specific normative centile values generated using the Lambda Mu and Sigma (LMS) method. Sex- and age-related differences were expressed as standardised effect sizes.

Results Normative values were displayed as tabulated percentiles and as smoothed centile curves for nine health-related fitness tests based on a dataset comprising 85347 test performances. Boys typically scored higher than girls on cardiovascular endurance, muscular strength, muscular endurance, speed and power tests, but lower on the flexibility test. The magnitude of the age-related changes was generally larger for boys than for girls, especially during the teenage years.

Conclusion This study provides the most up-to-date sex- and age-specific normative centile values for the health-related fitness of Australian children that can be used as benchmark values for health and fitness screening and surveillance systems.

BACKGROUND

Physical fitness is considered to be an important marker of current and future health in children and adults.[1] In children, cardiovascular fitness is a weak-to-strong predictor of total and abdominal adiposity, cardiovascular disease risk factors, cancer and mental health.[1 2] Certain muscular fitness components (eg, strength and endurance) are moderate predictors of cardiovascular disease risk factors, skeletal health and mental health.[1] Meaningful relationships have also been reported between running speed (another muscular fitness component) and skeletal health.[3] In adults, cardiovascular fitness is a strong and independent predictor of all-cause mortality and cardiovascular disease mortality and morbidity,[4] stroke,[5] cancer, mental health,[6] health-related quality of life[7] and many other cardiometabolic risk factors and comorbidities.[8 9] Moreover, physical fitness tracks moderately well from childhood through to adulthood.[10–13] This evidence highlights the need to include health-related fitness testing (ie, the testing of fitness components such as cardiovascular and muscular fitness that have the strongest links with health outcomes) as part of existing health and fitness screening and surveillance systems.

Although the most valid assessments of fitness require sophisticated laboratory equipment and a high level of tester expertise, they unfortunately are not suitable for mass testing. On the other hand, properly conducted field tests offer simple, feasible, and practical alternatives, which typically demonstrate good reliability and validity.[2 14–17] In Australia, unlike in Europe and North America where standardised test batteries such as the Eurofit[18] or FITNESSGRAM[19] are widely administered, a number of different field-based fitness tests and testing protocols have been used over time. For example, the most popular field test of cardiovascular fitness in Australia in the 1960s and 1970s was the 549-m (600 yd) run; in the 1980s and 1990s, it was the 1600-m run; and over the past decade or so, it has been the 20-m shuttle run.[20] Many physical educators and sports coaches in Australia continue to administer tests that are no longer in favour, largely because normative data (which are now several decades old) are available. This makes it difficult to assess the current status of health-related fitness in Australian children. Further compounding the problem is that the last national fitness survey of Australian children was conducted in 1985,[21] and with convincing evidence of recent temporal changes in several components of fitness,[22–24] the usefulness of such data seems to be limited.

Because there has never been a follow-up to the 1985 national survey, this study aimed to locate large and reasonably representative datasets of Australian children to generate normative centile values for health-related fitness. This study also aimed to quantify sex- and age-related differences in health-related fitness. These normative data will facilitate the identification of children with (a) low fitness in order to set appropriate goals and to promote positive health behaviours, and (b) specific fitness characteristics that may be considered important for sporting success.

METHODS

Data sources

A systematic review of the peer-reviewed scientific literature was undertaken to locate studies reporting descriptive summary data on Australian children tested for health-related fitness using field tests. Candidate studies were searched for in

Table 1 Summary of the included studies that have been used to assess the health-related fitness of 9–17-year-old Australians since 1985

								Tests reported in included studies								
Study	Year	Age (years)	*N*	Raw data	Sampling method	Sample base	Protocol	Push-ups	Sit-ups	Standing broad jump	Basketball throw	50 m sprint	Sit-and-reach	Hand-grip	1.6 km run	20 m shuttle run
ACHPER[50]	1994	9–18	39–104	yes	School-based; stratified, proportional	State (VIC)	ACHPER[50]		•		•		•		•	•
Barnett *et al*[51]	2007	15–17	21–69	no	School-based; stratified, random	State (NSW)	ACHPER[50]									•
Birchall[52]	1990	5–12	6–184	yes	School-based; convenience	State (VIC)	Pyke[21]	•	•	•		•	•		•	
Booth *et al*[53]	1997	9, 11, 13,15	399–634	no	School-based; stratified, proportional	State (NSW)	ACHPER[50]		•		•					•
Booth *et al*[54]	2004	9–15	357–466	no	School-based; stratified, proportional	State (NSW)	ACHPER[50]									•
Burke *et al*[55]	2004	10–13	38–117	yes	School-based; stratified, proportional	Capital city (WA)	ACHPER[50]									•
Cooley and McNaughton[56]	1998	11–16	339–636	no	School-based; stratified, proportional	State (TAS)	ACHPER[50]									•
Dollman *et al*[57]	1997	10–12	118–450	yes	School-based; stratified, proportional	State (SA)	Pyke[21]			•		•			•	
Dollman pers. comm.	2002	11–12	19–154	yes	School-based; stratified, random	State (SA)	Pyke[21]						•	•		
Dollman, pers. comm.	2002	8–12	8–389	yes	School-based; stratified, proportional	State (SA)	ACHPER[50] Pyke[21]			•						•
Hands[58]	2000	6–12	14–37	yes	School-based; stratified, random	Capital city (WA)	ACHPER[50] Pyke[21]		•	•	•	•	•	•		•
McIntyre, pers. comm.	2009	10–11	23–44	yes	School-based; stratified, random	Capital city (WA)	ACHPER[50]									•
McNaughton *et al*[59]	1995	7–10	30–83	no	School-based; stratified, random	State (TAS)	Pyke[21]					•			•	
Pyke[21]	1985	7–15	405–497	yes	School-based; stratified, proportional	National	Pyke[21]	•	•	•		•	•	•	•	
Vandongen *et al*[60]	1990	11	485–486	no	School-based; stratified, random	Capital city (WA)	ACHPER[50]								•	•

identifies test data that are available.
ACHPER, Australian Council for Health, Physical Education and Recreation; year, year of testing; *n*, sample size range per sex by age by test group; VIC, TAS, SA, WA, NSW

November 2009 using a computer search of online bibliographic databases (Ausport, CINAHL, Medline, PubMed, Scopus and SPORTDiscus). The search string used for the computer search was: ((((((((((((((fitness) OR aerobic) OR anaerobic) OR cardio*) OR endurance) OR agility) OR flexibility) OR speed) OR power) OR strength) OR sprint*) OR jump*) OR push-up*) OR sit-up*) OR grip strength) OR sit and reach) AND (((((((child*) OR paediatric*) OR adolesc*) OR boy*) OR girl*) OR youth*) OR teen*) AND (Australia*). All titles and abstracts (when available) were assessed to identify eligible articles, with full-text articles retrieved if there was doubt in an article's eligibility. A number of Australian researchers were contacted through email to ask whether they knew of any appropriate studies or unpublished datasets.

Inclusion/exclusion criteria

Studies were included if they explicitly reported descriptive health-related fitness test data for apparently healthy (free from known disease or injury) 9–17-year-old Australians who were tested from 1985 onwards and if they reported data at the sex by age by test level, on children directly measured using field-based fitness tests for which explicit testing protocols were available. Studies were excluded if they reported descriptive data that were published in another identified study. The reference

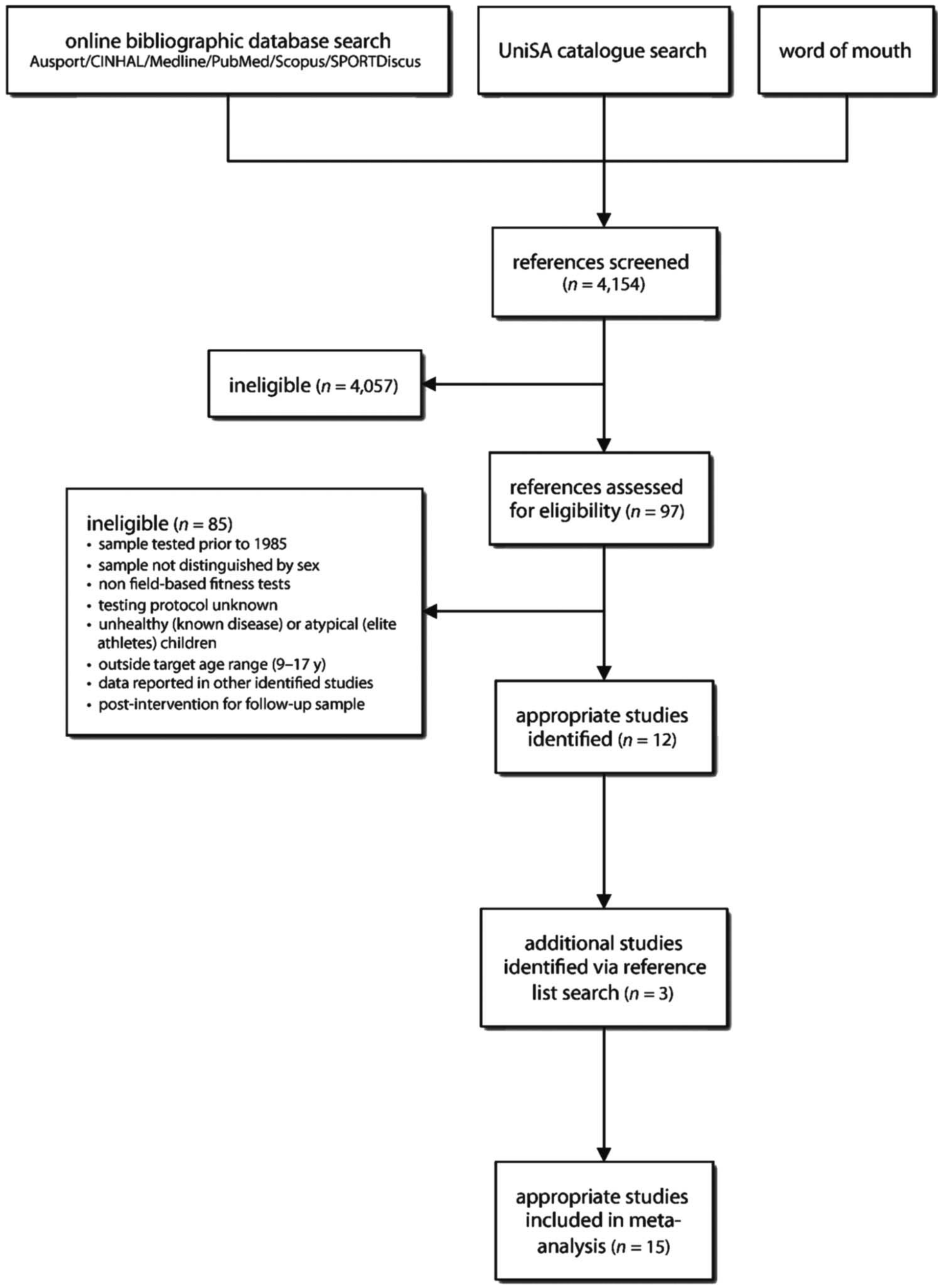

Figure 1 Flowchart outlining the identification of the included studies.

lists of all included studies were examined and cross-referenced to identify additional studies. Attempts were made to contact the corresponding author of each study to request raw data and/or to clarify study details.

Initial data analysis

The following descriptive data were extracted from each included study: sex, age, year of testing, sample size, mean, SD, fitness test type and test protocol. Only data for commonly used fitness tests that were collected using protocols that were originally described in national or state-based fitness surveys of Australian children were retained for further analysis. Tests were considered to be 'common' if they were used to measure fitness in children across a broad range of ages and in at least two separate studies. Data for each fitness test were expressed in a common metric, and protocol differences were corrected where possible (eg, 20 m shuttle run data were expressed as the number of completed stages using the correction procedures described by Tomkinson *et al*).[25] However, if protocol correction was not possible, then only fitness data collected using the most common test protocol were retained. All available raw data were checked for anomalies by running range checks with data ±3 SDs away from the respective study by sex by age by test mean excluded. Age was expressed in whole years as the age at last birthday.

Statistical analysis

Sex- and age-specific normative centile values were calculated using a dataset comprising raw data and pseudo data that were generated using the method described by Tomkinson.[24] Normative centile values were generated using LMSChartmaker Light (v2.3, The Institute of Child Health, London) software,

Table 2 1.6 km run (s) centile values and LMS summary statistics by sex and age in 9- to 17-year-old Australians

Age (year)	P_5	P_{10}	P_{20}	P_{30}	P_{40}	P_{50}	P_{60}	P_{70}	P_{80}	P_{90}	P_{95}	L	M	S
Boys														
9	750	684	618	578	547	522	499	476	452	423	401	−1.042	521.963	0.183
10	732	666	602	564	535	511	489	469	447	420	400	−1.284	511.053	0.175
11	710	646	585	549	523	500	480	461	441	416	397	−1.466	500.394	0.166
12	682	621	563	530	505	485	467	449	430	408	392	−1.721	484.819	0.157
13	643	587	535	505	483	465	448	432	415	395	380	−1.895	464.529	0.148
14	605	556	509	482	462	446	431	416	401	382	369	−1.987	445.569	0.140
15	575	531	490	465	447	432	418	404	390	373	360	−1.979	431.504	0.133
16	552	514	477	454	437	423	410	397	383	366	354	−1.865	422.693	0.128
17	534	500	467	446	430	417	404	392	379	362	350	−1.707	416.545	0.123
Girls														
9	829	769	706	666	635	609	584	559	533	499	475	−0.779	608.674	0.167
10	820	759	697	657	626	600	576	552	526	494	470	−0.878	600.149	0.166
11	801	741	680	641	611	586	562	539	514	483	460	−0.929	585.820	0.165
12	784	726	666	629	600	575	552	529	505	474	452	−0.921	574.682	0.164
13	771	716	658	621	593	569	546	524	500	469	447	−0.852	568.706	0.163
14	763	711	655	620	592	567	545	523	498	468	445	−0.737	567.486	0.162
15	760	710	656	621	594	570	547	525	500	469	446	−0.591	569.809	0.161
16	757	710	658	624	597	573	550	527	502	471	446	−0.428	572.723	0.160
17	753	708	658	625	598	575	552	529	504	471	446	−0.263	574.536	0.159

Note, percentile data were calculated from 11 423 1.6 km run performances collected between 1985 and 1997.
L, skew; M, median; P, percentile; S, coefficient of variation.

which analyses data using the LMS method.[26] The LMS method fits smooth centile curves to reference data by summarising the changing distribution of three sex- and age-specific curves representing the skewness (L: expressed as a Box-Cox power), the median (M) and the coefficient of variation (S). Using penalised likelihood, the curves can be fitted as cubic splines using non-linear regression, and the extent of smoothing required can be expressed in terms of smoothing parameters or equivalent degrees of freedom.[27]

For each fitness test, differences in means between: (a) age-matched Australian boys and girls (eg, 10-year-old boys vs 10-year-old girls); (b) sex-matched Australian children of different ages (eg, 10-year-old boys vs 11-year-old boys); and (c) sex- and age-matched Australian and international children[18 28–30]

Table 3 20 m shuttle run (completed stages) centile values and LMS summary statistics by sex and age in 9- to 17-year-old Australians

Age (year)	P_5	P_{10}	P_{20}	P_{30}	P_{40}	P_{50}	P_{60}	P_{70}	P_{80}	P_{90}	P_{95}	L	M	S
Boys														
9	1	1	2	2	2	3	3	3	4	5	6	0.213	2.573	0.568
10	1	2	2	3	3	4	4	5	5	7	8	0.373	3.537	0.543
11	1	2	3	3	4	4	5	5	6	7	8	0.520	4.131	0.517
12	1	2	3	3	4	4	5	6	6	8	9	0.643	4.460	0.486
13	2	2	3	4	4	5	5	6	7	8	9	0.744	4.888	0.453
14	2	3	4	4	5	6	6	7	8	9	10	0.835	5.664	0.418
15	3	3	4	5	6	7	7	8	9	10	11	0.926	6.527	0.380
16	3	4	5	6	7	7	8	8	9	10	11	1.031	7.159	0.343
17	4	5	6	6	7	8	8	9	10	11	11	1.143	7.690	0.306
Girls														
9	1	1	1	1	2	2	2	2	3	4	5	−0.065	1.842	0.535
10	1	1	2	2	2	2	3	3	4	5	6	0.086	2.468	0.557
11	1	1	2	2	2	3	3	4	4	6	7	0.220	2.844	0.573
12	1	1	2	2	3	3	3	4	5	6	7	0.324	3.016	0.577
13	1	1	2	2	3	3	4	4	5	6	7	0.400	3.138	0.569
14	1	1	2	2	3	3	4	4	5	6	7	0.457	3.225	0.554
15	1	1	2	3	3	3	4	4	5	6	7	0.505	3.412	0.536
16	1	2	2	3	3	4	4	5	5	6	7	0.554	3.672	0.518
17	1	2	2	3	4	4	5	5	6	7	8	0.603	4.032	0.499

Percentile data were calculated from 18 075 20 m shuttle run performances collected between 1990 and 2009.
The 20 m shuttle run can be scored in different metrics other than as the number of completed stages, such as the number of completed laps, the speed at the last completed stage and as mass-specific peak oxygen uptake estimates (see Tomkinson *et al*[25] for details on how to correct 20 m shuttle run performances to different metrics).
L, skew; M, median; P, percentile; S, coefficient of variation.

Table 4 50 m sprint (s) centile values and LMS summary statistics by sex and age in 9- to 15-year-old Australians

Age (year)	P_5	P_{10}	P_{20}	P_{30}	P_{40}	P_{50}	P_{60}	P_{70}	P_{80}	P_{90}	P_{95}	L	M	S
Boys														
9	10.6	10.2	9.8	9.5	9.3	9.1	9.0	8.8	8.6	8.3	8.1	−1.837	9.136	0.078
10	10.5	10.1	9.7	9.4	9.2	9.0	8.8	8.7	8.5	8.2	8.0	−2.185	9.009	0.080
11	10.4	10.0	9.6	9.3	9.1	8.9	8.7	8.5	8.3	8.1	7.9	−2.405	8.877	0.081
12	10.2	9.8	9.3	9.1	8.9	8.7	8.5	8.3	8.1	7.9	7.7	−2.446	8.673	0.081
13	9.8	9.4	9.0	8.8	8.6	8.4	8.2	8.1	7.9	7.7	7.5	−2.489	8.377	0.079
14	9.4	9.0	8.7	8.4	8.2	8.1	7.9	7.8	7.6	7.4	7.2	−2.701	8.063	0.076
15	9.0	8.6	8.3	8.1	7.9	7.7	7.6	7.5	7.3	7.1	7.0	−3.021	7.738	0.073
Girls														
9	11.7	11.3	10.8	10.5	10.3	10.0	9.8	9.6	9.3	9.0	8.8	−0.981	10.033	0.088
10	11.1	10.7	10.3	10.0	9.8	9.5	9.3	9.1	8.9	8.6	8.4	−1.453	9.542	0.084
11	10.7	10.3	9.9	9.6	9.4	9.2	9.0	8.8	8.6	8.3	8.1	−1.803	9.161	0.082
12	10.4	10.0	9.6	9.3	9.1	8.9	8.7	8.6	8.4	8.1	7.9	−1.977	8.919	0.080
13	10.2	9.8	9.4	9.2	9.0	8.8	8.6	8.4	8.3	8.0	7.8	−1.991	8.787	0.078
14	10.0	9.7	9.3	9.1	8.9	8.7	8.5	8.4	8.2	7.9	7.8	−1.884	8.686	0.076
15	9.9	9.6	9.2	9.0	8.8	8.6	8.5	8.3	8.1	7.9	7.7	−1.724	8.638	0.075

Note, percentile data were calculated from 10 104 50 m sprint performances collected between 1985 and 1999.
L, skew; M, median; P, percentile; S, coefficient of variation.

were expressed as standardised effect sizes.[31] Positive effect sizes indicated that mean fitness test performances for boys (age-matched analysis), older children (sex-matched analysis) or Australian children (sex- and age-matched analysis) were higher than those for girls, younger children or international children, respectively. Effect sizes of 0.2, 0.5 and 0.8 were used as thresholds for small, moderate and large.[31]

RESULTS

Table 1 summarises the 15 included studies. Of these, 12 were identified through bibliographic database searching and word of mouth, and three were identified through reference list searching. Corresponding authors of all the studies were contacted through email to clarify study details and/or to request raw data. All authors satisfactorily clarified study details, and seven of them supplied raw data (figure 1).

The final dataset comprised 85347 individual test results and 142 sex by age by test groups with a median sample size of 537 (range: 54–2612). Data were available for six fitness components and nine fitness tests: cardiovascular endurance (20 m shuttle run, 1.6 km run), muscular strength (hand-grip), muscular endurance (push-ups and sit-ups), muscular power (standing broad jump and basketball throw), muscular speed (50 m sprint) and flexibility (sit-and-reach). Raw data were available for 74% of all data points.

Normative fitness data for 9–17-year-old Australians are presented as tabulated percentiles from 5 to 95 (P_5, P_{10}, P_{20}, P_{30}, P_{40}, P_{50}, P_{60}, P_{70}, P_{80}, P_{90}, P_{95}) in tables 2–10. The sex- and age-

Table 5 Basketball throw (m) centile values and LMS summary statistics by sex and age in 9- to 17-year-old Australians

Age (year)	P_5	P_{10}	P_{20}	P_{30}	P_{40}	P_{50}	P_{60}	P_{70}	P_{80}	P_{90}	P_{95}	L	M	S
Boys														
9	2.3	2.5	2.7	2.9	3.1	3.3	3.4	3.6	3.8	4.1	4.4	0.623	3.260	0.198
10	2.5	2.8	3.0	3.3	3.4	3.6	3.8	4.0	4.2	4.5	4.8	0.675	3.608	0.192
11	2.8	3.1	3.4	3.6	3.8	4.0	4.2	4.4	4.7	5.0	5.3	0.733	4.026	0.188
12	3.1	3.4	3.8	4.0	4.3	4.5	4.7	4.9	5.2	5.6	5.9	0.792	4.471	0.188
13	3.5	3.8	4.2	4.5	4.8	5.0	5.3	5.5	5.8	6.2	6.6	0.843	5.012	0.187
14	3.9	4.2	4.7	5.0	5.3	5.5	5.8	6.1	6.4	6.9	7.2	0.898	5.522	0.186
15	4.2	4.6	5.0	5.4	5.7	6.0	6.3	6.6	6.9	7.4	7.8	0.943	5.975	0.185
16	4.4	4.8	5.3	5.6	6.0	6.3	6.5	6.9	7.2	7.7	8.2	0.964	6.254	0.185
17	4.5	4.9	5.5	5.8	6.2	6.5	6.8	7.1	7.5	8.0	8.5	0.966	6.467	0.187
Girls														
9	2.1	2.3	2.5	2.7	2.9	3.0	3.2	3.3	3.5	3.7	3.9	1.116	3.015	0.182
10	2.3	2.6	2.8	3.0	3.2	3.3	3.5	3.7	3.8	4.1	4.3	1.024	3.336	0.181
11	2.6	2.8	3.1	3.3	3.5	3.6	3.8	4.0	4.2	4.5	4.7	0.942	3.646	0.180
12	2.8	3.1	3.4	3.6	3.8	4.0	4.2	4.3	4.6	4.9	5.2	0.873	3.970	0.180
13	3.0	3.3	3.6	3.9	4.1	4.3	4.5	4.7	4.9	5.3	5.6	0.816	4.265	0.179
14	3.2	3.4	3.8	4.0	4.2	4.4	4.6	4.8	5.1	5.4	5.7	0.739	4.410	0.175
15	3.3	3.6	3.9	4.1	4.3	4.5	4.7	4.9	5.1	5.5	5.8	0.606	4.486	0.169
16	3.4	3.7	4.0	4.2	4.4	4.6	4.7	5.0	5.2	5.6	5.9	0.394	4.557	0.162
17	3.6	3.8	4.1	4.3	4.5	4.6	4.8	5.0	5.3	5.6	5.9	0.140	4.634	0.154

Note, percentile data were calculated from 5,541 basketball throw performances collected between 1994 and 1999; L, skew; M, median; P, percentile; S, coefficient of variation.

Table 6 Standing broad jump (cm) centile values and LMS summary statistics by sex and age in 9- to 15-year-old Australians

Age (year)	P_5	P_{10}	P_{20}	P_{30}	P_{40}	P_{50}	P_{60}	P_{70}	P_{80}	P_{90}	P_{95}	L	M	S
Boys														
9	105	113	121	127	133	138	142	147	153	161	168	1.244	137.506	0.138
10	109	117	126	133	138	143	148	154	160	168	174	1.490	143.430	0.138
11	112	121	131	138	144	149	154	160	166	174	181	1.654	149.322	0.138
12	117	126	137	144	150	156	161	167	173	182	189	1.704	155.838	0.137
13	126	136	147	154	161	166	172	178	185	194	201	1.629	166.340	0.135
14	137	146	157	165	172	178	184	190	197	206	214	1.526	177.688	0.131
15	148	157	169	177	183	189	196	202	209	219	228	1.446	189.485	0.127
Girls														
9	95	102	110	116	122	126	131	136	142	150	157	1.098	126.379	0.149
10	100	108	117	123	128	133	138	143	149	158	165	1.152	133.177	0.147
11	106	114	123	129	135	140	145	151	157	166	173	1.197	140.142	0.145
12	111	118	128	135	140	145	151	156	163	171	179	1.211	145.432	0.142
13	115	123	132	139	145	150	155	161	167	176	183	1.183	150.080	0.138
14	119	127	136	143	148	154	159	164	171	180	187	1.158	153.551	0.134
15	122	129	139	145	151	156	161	166	173	181	188	1.148	155.661	0.130

Percentile data were calculated from 11 194 standing broad jump performances collected between 1985 and 2002.
L, skew; M, median; P, percentile; S, coefficient of variation.

specific LMS values for all fitness tests are also shown. The LMS values depict the nature of the age-related distributions for boys and girls and can be used to calculate z-scores and hence percentile values by looking up a z-table, using the following formula:

$$z = \frac{\left(\frac{x}{M}\right)^L - 1}{L \times S}$$

where z is z score, x is performance, L is sex- and age-specific L-value, M is the sex- and age-specific M-value and S is the sex- and age-specific S-value.

Figures 2 and 3 show the smoothed centile curves (P_{10}, P_{50}, P_{90}).

Figure 4 shows the sex-related differences in mean fitness. Boys consistently scored higher than girls on health-related fitness tests, except on the sit-and-reach test, with the magnitude of the differences typically increasing with age and often accelerating from about 12 years of age. Overall, the magnitude of differences between boys and girls was large for the 1.6 km run, 20 m shuttle run, basketball throw and push-ups; moderate for the 50-m sprint, standing broad jump and sit-and-reach; and small for sit-ups and hand-grip strength. Figure 5 shows the age-related changes in mean fitness. The age-related changes were typically larger for boys than for girls, especially during the teenage years, and for muscular fitness tests than for cardiovascular fitness tests. Fitness also tended to peak from about the age of 15 years. Figure 6 shows that the differences in health-related fitness between Australian and international children were generally small, with Australian children scoring slightly higher on hand-grip strength (mean ±95% CI: 0.20±0.03 SDs) and 50 m sprint tests (0.24±0.02 SDs), and slightly lower on sit-and-reach (−0.36±0.02 SDs), standing broad jump (−0.25±0.02 SDs) and 20 m shuttle run tests (−0.49±0.01 SDs).

Table 7 Push-ups (no. in 30 s) centile values and LMS summary statistics by sex and age in 9- to 15-year-old Australians

Age (year)	P_5	P_{10}	P_{20}	P_{30}	P_{40}	P_{50}	P_{60}	P_{70}	P_{80}	P_{90}	P_{95}	L	M	S
Boys														
9	4	6	8	9	11	12	14	15	17	20	22	0.846	12.310	0.452
10	4	6	8	10	11	13	14	16	18	21	23	0.894	12.943	0.447
11	4	6	8	10	12	13	14	16	18	20	22	0.940	12.942	0.438
12	4	6	9	10	12	13	15	16	18	20	22	0.980	13.200	0.422
13	5	7	9	11	13	14	16	17	19	22	24	1.020	14.255	0.399
14	6	8	11	13	14	16	17	19	21	23	25	1.070	15.954	0.370
15	7	10	13	15	16	18	19	21	23	25	27	1.126	17.697	0.337
Girls														
9	2	3	5	7	8	9	10	12	13	16	18	0.719	8.989	0.550
10	2	3	5	6	7	9	10	11	13	16	18	0.652	8.655	0.583
11	2	3	4	6	7	8	9	11	13	16	18	0.584	8.142	0.624
12	1	2	4	5	6	7	9	10	12	15	18	0.518	7.395	0.672
13	1	2	3	4	6	7	8	10	12	15	18	0.453	6.792	0.720
14	1	2	3	4	5	6	8	9	11	15	18	0.390	6.384	0.765
15	1	2	3	4	5	6	7	9	11	14	18	0.329	5.818	0.812

Percentile data were calculated from 7,342 push-up test performances collected between 1985 and 1991.
L, skew; M, median; P, percentile; S, coefficient of variation.

Table 8 Sit-ups (no. in 180 s) centile values and LMS summary statistics by sex and age in 9- to 17-year-old Australians

Age (year)	P_5	P_{10}	P_{20}	P_{30}	P_{40}	P_{50}	P_{60}	P_{70}	P_{80}	P_{90}	P_{95}	L	M	S
Boys														
9	3	5	8	11	14	17	21	25	30	40	48	0.321	17.046	0.755
10	5	8	13	17	20	24	29	34	40	50	59	0.466	24.459	0.669
11	6	10	16	21	25	29	34	39	45	55	60	0.629	29.422	0.594
12	8	14	21	26	31	36	40	45	51	60	60	0.841	35.561	0.514
13	10	17	25	31	36	40	45	50	55	60	60	1.056	40.288	0.443
14	12	20	29	34	39	43	48	52	57	60	60	1.232	43.454	0.389
15	14	22	31	36	41	45	49	53	58	60	60	1.335	44.942	0.359
16	16	24	32	38	42	46	50	54	58	60	60	1.426	46.209	0.332
17	18	26	34	40	44	47	51	55	59	60	60	1.517	47.466	0.306
Girls														
9	5	8	12	15	18	21	25	29	35	43	51	0.394	21.258	0.642
10	7	10	14	18	22	26	30	34	40	50	58	0.485	25.666	0.605
11	8	11	17	21	25	29	34	39	45	54	60	0.571	29.444	0.569
12	9	13	19	24	28	32	37	42	48	57	60	0.646	32.123	0.534
13	10	15	21	26	30	34	39	44	50	59	60	0.705	34.408	0.504
14	11	15	22	27	31	35	40	45	50	59	60	0.741	35.334	0.482
15	11	16	22	27	31	35	40	44	50	58	60	0.757	35.327	0.464
16	12	17	23	28	32	36	40	44	50	57	60	0.761	35.690	0.447
17	13	18	24	28	32	36	40	45	50	58	60	0.761	36.333	0.431

Percentile data were calculated from 8 837 sit-up test performances collected between 1985 and 1999.
L, skew; M, median; P, percentile; S, coefficient of variation.

DISCUSSION

This study provides the most up-to-date sex- and age-specific normative centile values for 9–17-year-old Australians across a range of health-related fitness tests, which can be used as benchmark values for health and fitness screening and surveillance of children. These data complement a growing literature reporting growth percentiles across a range of different health measures, such as body mass index,[32] waist girth[33] and blood pressure,[28] and a range of other health-related fitness measures.[29 30] It also quantifies the magnitude and direction of sex- and age-related differences in children's health-related fitness and shows that boys consistently scored higher than girls on fitness tests (except on the sit-and-reach test of flexibility) and that boys experience larger age-related changes in fitness. The developmental patterns of children's fitness have been well studied and extensively reviewed (eg, for cardiovascular fitness, refer to Armstrong *et al*,[34] Krahenbuhl *et al*[35] and Rowland[36]; for muscular fitness, refer to Blimkie and Sale,[37] Froberg and Lammert[38] and De Ste Croix[39]). Although the underlying causes of sex- and age-related differences are clear for some fitness test performances, such as those for muscular strength, power and speed, which are largely explained by physical differences (eg, differences in muscle mass

Table 9 Hand-grip strength (kg) centile values and LMS summary statistics by sex and age in 9- to 15-year-old Australians (taken as the mean of both hands)

Age (year)	P_5	P_{10}	P_{20}	P_{30}	P_{40}	P_{50}	P_{60}	P_{70}	P_{80}	P_{90}	P_{95}	L	M	S
Boys														
9	11.5	12.5	13.8	14.8	15.6	16.4	17.2	18.1	19.2	20.8	22.1	0.600	16.415	0.197
10	13.1	14.3	15.9	17.0	18.0	19.0	19.9	21.0	22.2	23.9	25.4	0.728	18.967	0.198
11	14.5	15.9	17.7	19.0	20.1	21.2	22.3	23.5	24.9	26.8	28.5	0.764	21.217	0.200
12	15.4	17.0	18.9	20.3	21.5	22.7	23.8	25.1	26.6	28.7	30.5	0.747	22.655	0.203
13	17.5	19.3	21.5	23.1	24.5	25.8	27.2	28.6	30.4	32.8	34.9	0.738	25.819	0.205
14	20.8	22.9	25.5	27.4	29.1	30.7	32.4	34.1	36.2	39.1	41.6	0.742	30.731	0.207
15	24.6	27.1	30.3	32.6	34.6	36.5	38.4	40.5	43.0	46.5	49.5	0.752	36.517	0.207
Girls														
9	9.8	10.8	12.0	12.9	13.7	14.4	15.1	16.0	17.0	18.4	19.5	0.639	14.396	0.205
10	11.4	12.6	14.1	15.2	16.2	17.1	18.0	19.0	20.1	21.8	23.1	0.842	17.072	0.210
11	12.5	13.9	15.5	16.8	17.8	18.8	19.8	20.9	22.1	23.9	25.3	0.932	18.816	0.208
12	14.4	16.0	17.8	19.1	20.3	21.4	22.5	23.6	25.0	26.9	28.5	0.922	21.374	0.200
13	16.4	18.0	19.9	21.3	22.5	23.6	24.8	26.0	27.4	29.5	31.1	0.880	23.641	0.190
14	18.2	19.7	21.6	23.0	24.3	25.4	26.5	27.8	29.2	31.3	33.0	0.828	25.390	0.178
15	19.8	21.3	23.2	24.6	25.8	26.9	28.0	29.2	30.7	32.7	34.4	0.770	26.881	0.165

Percentile data were calculated from the 3 707 hand-grip strength performances collected between 1985 and 1999.
L, skew; M, median; P, percentile; S, coefficient of variation.

Table 10 Sit-and-reach (cm) centile values and LMS summary statistics by sex and age in 9- to 17-year-old Australians.

Age (y)	P_5	P_{10}	P_{20}	P_{30}	P_{40}	P_{50}	P_{60}	P_{70}	P_{80}	P_{90}	P_{95}	L	M	S
boys														
9	10.4	12.9	15.7	17.7	19.4	20.9	22.4	23.9	25.8	28.2	30.3	1.211	20.877	0.285
10	10.0	12.5	15.3	17.3	19.0	20.5	22.1	23.7	25.5	28.0	30.1	1.190	20.537	0.294
11	9.6	12.1	15.0	17.0	18.7	20.3	21.9	23.5	25.4	28.0	30.1	1.167	20.313	0.305
12	9.3	11.8	14.8	16.9	18.7	20.3	21.9	23.6	25.6	28.3	30.5	1.133	20.292	0.315
13	9.4	12.0	15.1	17.2	19.1	20.8	22.5	24.3	26.4	29.2	31.6	1.091	20.785	0.322
14	9.8	12.5	15.7	18.0	20.0	21.8	23.6	25.5	27.8	30.9	33.4	1.054	21.804	0.328
15	10.4	13.2	16.6	19.1	21.2	23.1	25.1	27.1	29.5	32.9	35.7	1.017	23.112	0.332
16	11.1	14.0	17.6	20.1	22.3	24.4	26.5	28.7	31.3	34.9	37.8	0.984	24.392	0.334
17	11.7	14.8	18.5	21.2	23.5	25.7	27.9	30.2	33.0	36.8	40.0	0.953	25.686	0.335
girls														
9	13.0	15.8	18.9	21.1	22.9	24.6	26.2	28.0	29.9	32.6	34.8	1.285	24.614	0.264
10	13.0	15.7	18.8	20.9	22.7	24.4	26.0	27.7	29.7	32.4	34.6	1.259	24.402	0.265
11	13.2	15.9	19.0	21.2	23.0	24.7	26.4	28.1	30.1	32.8	35.0	1.235	24.705	0.265
12	14.0	16.7	19.9	22.2	24.1	25.8	27.5	29.3	31.3	34.2	36.4	1.230	25.790	0.262
13	15.3	18.2	21.6	24.0	25.9	27.7	29.5	31.4	33.6	36.5	38.9	1.250	27.740	0.256
14	16.5	19.5	23.1	25.5	27.6	29.4	31.3	33.2	35.4	38.4	40.9	1.293	29.440	0.248
15	17.0	20.1	23.7	26.1	28.1	30.0	31.8	33.7	35.9	38.8	41.2	1.350	29.997	0.241
16	17.0	20.0	23.5	25.9	27.9	29.6	31.4	33.2	35.3	38.1	40.3	1.412	29.647	0.235
17	16.8	19.8	23.2	25.5	27.4	29.1	30.7	32.5	34.4	37.1	39.2	1.472	29.074	0.229

Note, percentile data were calculated from 9,124 sit-and-reach performances collected between 1985 and 2000; L = skew; M = median; S = coefficient of variation. Note, a score of "20 cm" corresponds to the participant reaching their toes.

or height), they are less clear for others, such as for cardiovascular endurance, which may be explained by physiological differences (eg, differences in mechanical efficiency and/or fractional utilisation).[15 36] It is, nonetheless, beyond the scope of this article to discuss the causes that underscore the sex- and age-related changes in fitness test performance.

International comparisons

Although several studies have previously compared the health-related fitness of Australian children with their sex- and age-matched international peers,[20 40] comparisons have only been made for cardiovascular fitness. Figure 6 compares the 20-m shuttle run, 50 m sprint, standing broad jump, hand-grip strength and sit-and-reach performance of 9–17-year-old Australians with 1 894 971 test results from sex-, age- and test-matched international children from 48 countries who have been measured using the same test protocols as those referenced in table 1 and described in Appendix 1. Figure 6 also shows typically small differences in health-related fitness between Australian and international children. Furthermore, the sex- and age-related differences in fitness of Australian children are strikingly similar to those observed in international children. Given that the differences are generally small, the normative centile data presented in this study could be used as approximate benchmark values for health-related fitness of international children.

Fitness thresholds for cardiometabolic risk

Fitness is widely recognised as a powerful marker of current and future cardiovascular, skeletal and mental health. Unfortunately, there are no universally accepted recommendations for health-related levels of fitness. In recent years however, sex- and age-specific threshold values for cardiovascular fitness (operationalised as mass-specific peak oxygen uptake in ml/kg/min) have been established for European and US children using linked cardiometabolic risk-based values from receiver operator characteristic curve analyses.[41–44] To estimate the prevalence of Australian children with 'healthy' cardiovascular fitness (ie, those above the thresholds), 'international' sex- and age-specific thresholds for 9–17-year-old children were estimated by determining best-fitting polynomial regression model (quadratic or cubic) relating age (predictor variable) to previously reported threshold values (response variable) in Adegboye *et al*,[41] Lobelo *et al*,[42] Ruiz *et al*[43] and Welk *et al*.[44] Separate models were generated for boys and girls. Peak oxygen uptake values in Australian children were estimated using 1.6 km run and 20 m shuttle run data and the Cureton *et al*[45] and Léger *et al*[46] regression equations, respectively.

Using these thresholds, about 71% of Australian boys (median ±95% CI: 71%±8%) and 77% of Australian girls (median ±95% CI: 77%±10%) apparently have 'healthy' cardiovascular fitness. Although in light of recent secular declines in cardiovascular fitness,[20 22 23 25] and with a median testing year of 1993 in this study's cardiovascular fitness dataset, it is likely that these prevalence rates somewhat overestimate those of today. These prevalence rates are better than (for girls), or similar to (for boys), those observed in European (61% of boys and 57% of girls)[29] and US (71% of boys and 69% of girls)[42] children. Geographical differences in prevalence rates may reflect differences in (a) threshold levels, (b) the year(s) of testing, (c) sampling methodology, (d) test methodology and (e) the way in which peak oxygen uptake was measured or estimated.[47]

Ultimately, it is important to remember that the normative data presented in this study show how well Australian children perform on health-related fitness tests relative to their sex- and age-matched peers. For example, using a percentile classification, children with fitness in the bottom 20% can be classified as having 'very low' fitness; those between the 20th and 40th percentiles as having 'low' fitness; those between the 40th and 60th percentiles as having 'average' fitness; those between the 60th and 80th percentiles as having 'high' fitness; and those

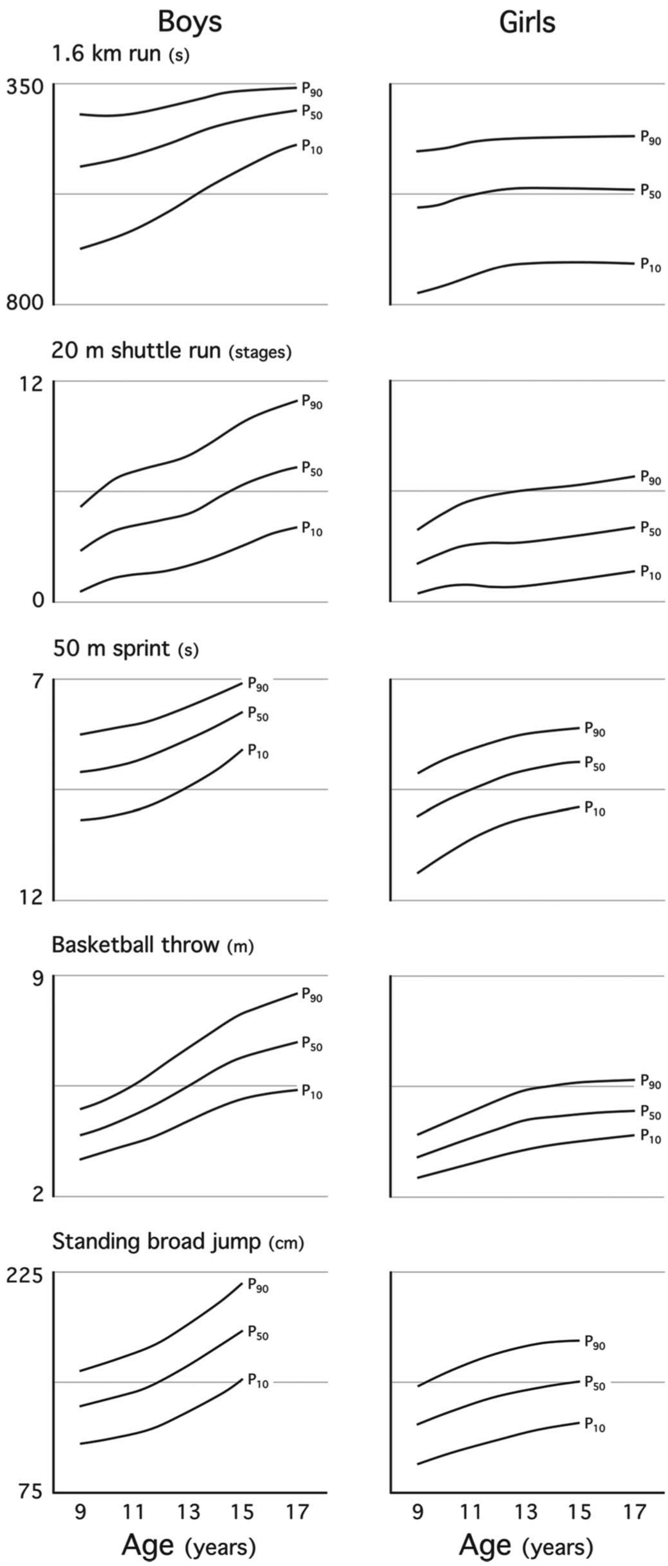

Figure 2 Smoothed centile curves (P_{10}, P_{50} and P_{90}) for (A) 1.6 km run (s), (B) 20 m shuttle run (number of completed stages), (C) 50 m sprint (s), (D) basketball throw (m) and (E) standing broad jump (cm).

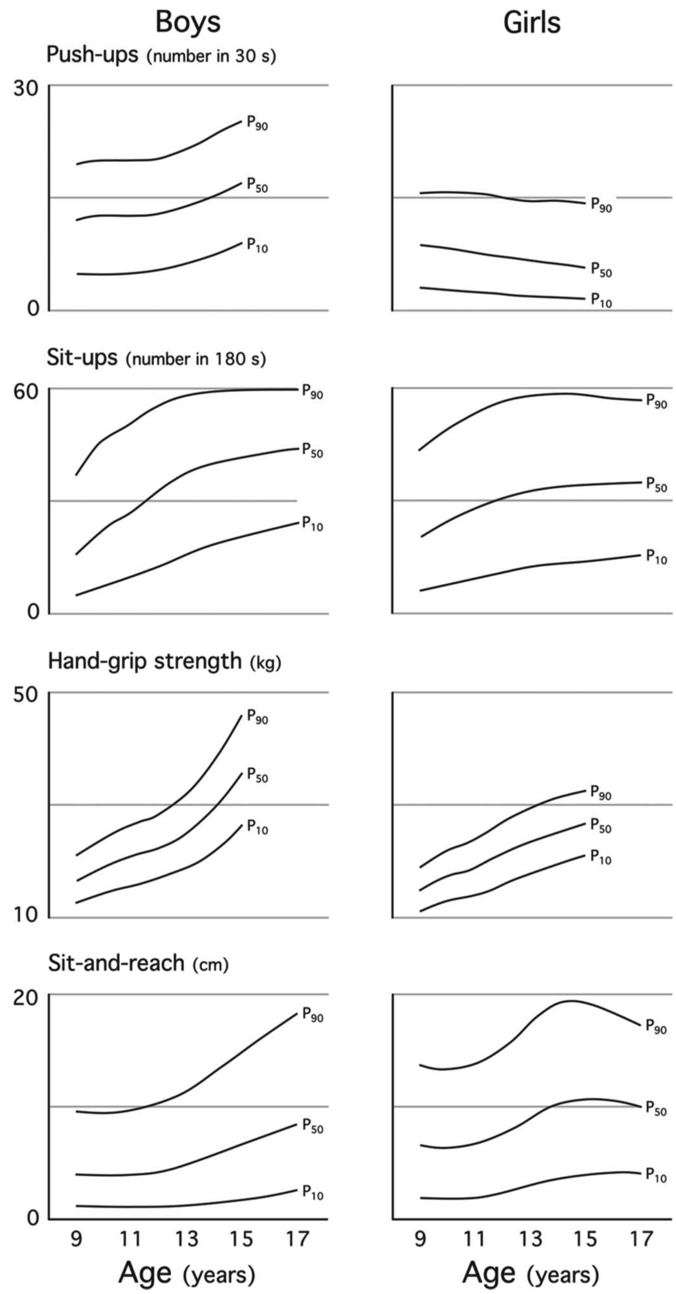

Figure 3 Smoothed centile curves (P_{10}, P_{50} and P_{90}) for (A) push-ups (number in 30 s), (B) sit-ups (number in 180 s), (C) hand-grip strength (kg) and (D) sit-and-reach (cm) tests.

above the 80th percentile as having 'very high' fitness. These data are not criterion-referenced in that they do not indicate whether children with 'very low' or 'low' (or any other classification for that matter) have 'unhealthy' cardiovascular fitness or increased cardiometabolic risk. Despite the fact that previous Australian evidence has linked low childhood cardiovascular fitness with increased cardiometabolic risk in adulthood,[48] future Australian studies are required to examine whether childhood thresholds for cardiovascular fitness (or other health-related fitness components) are significantly associated with clustered cardiometabolic risk (or other health outcomes, such as mental or skeletal health outcomes).

Strengths and limitations

Despite the fact that the last national fitness survey of Australian children was in 1985, this study provides the most up-to-date normative dataset for nine widely administered health-related fitness tests, using cumulated data from 85347 Australian children aged 9–17 years collected between 1985 and 2009. This

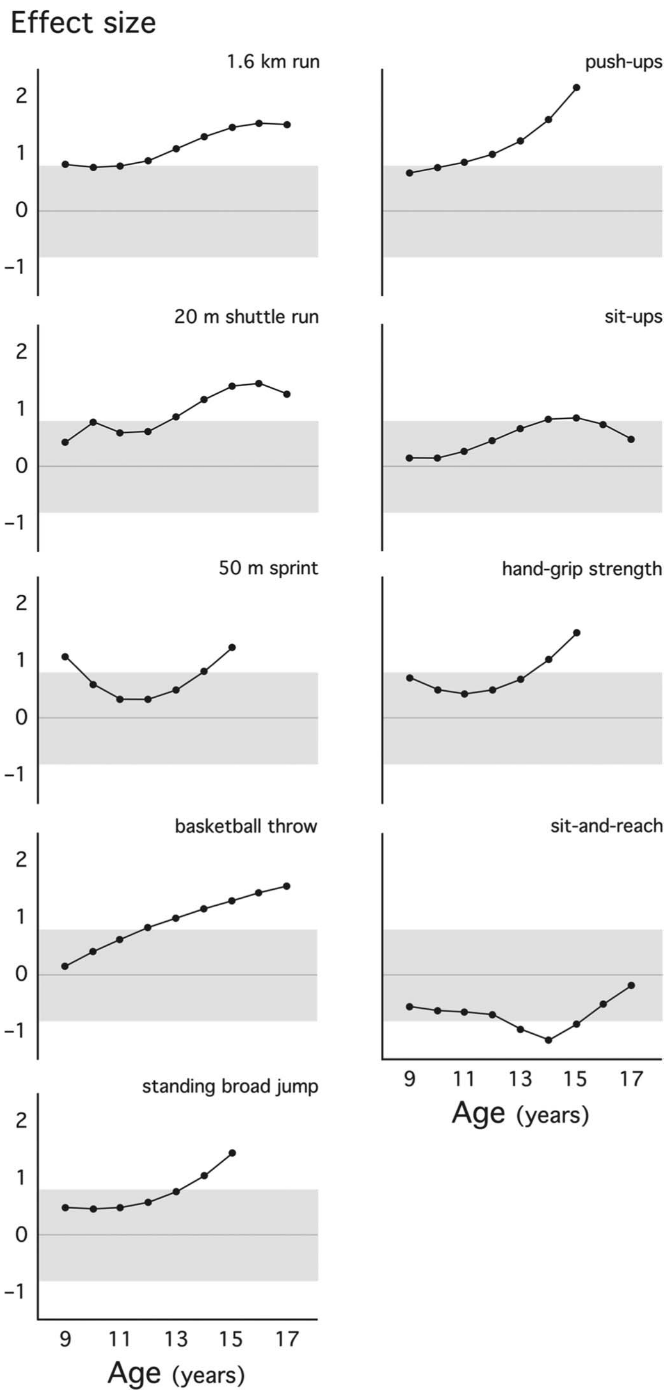

Figure 4 Sex-related differences in mean fitness expressed as effect sizes. Data are shown for 9–17-year-old children tested on the (A) 1.6 km run, (B) 20 m shuttle run, (c) 50 m sprint, (D) basketball throw, (E) standing broad jump, (F) push-ups, (G) sit-ups, (H) hand-grip strength and (I) sit-and-reach tests. The limits of the grey zone represent effects sizes of 0.8 and −0.8, beyond which large differences are observed.

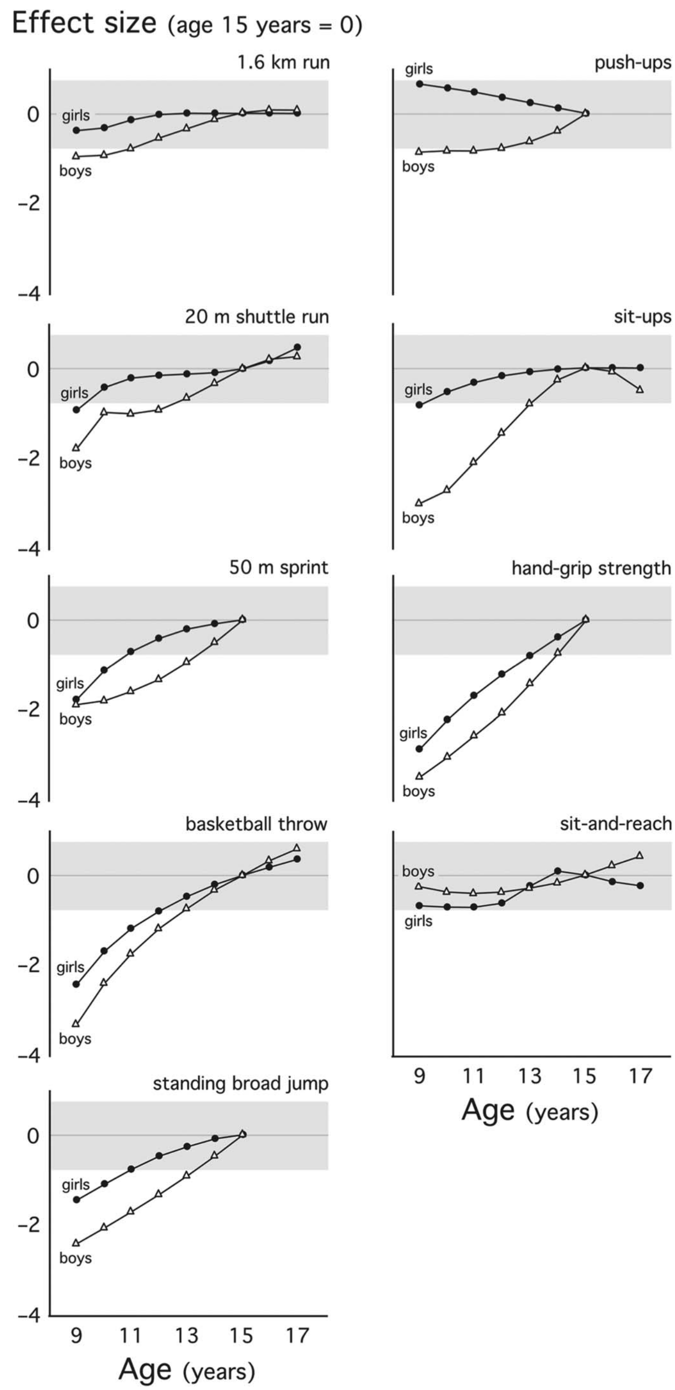

Figure 5 Age-related changes in mean fitness expressed as effect sizes standardised to an effect size of age 15 years=0. Data are shown for 9–17-year-old boys (triangles) and girls (circles) separately tested on the (A) 1.6 km run, (B) 20 m shuttle run, (C) 50 m sprint, (D) basketball throw, (E) standing broad jump, (F) push-ups, (G) sit-ups, (H) hand-grip strength and (I) sit-and-reach tests. The limits of the grey zone represent effects sizes of 0.8 and −0.8, beyond which large differences are observed.

study used a strict set of inclusion and exclusion criteria and rigorous initial data analysis procedures to systematically control for any factors (eg, differences in test methodology) that might have biased the normative values or the estimates of the sex- and age-related differences. It used a novel pseudo-data method to allow both descriptive and raw data to be merged before using the LMS method to create sex- and age-specific smoothed percentiles. It also quantified sex- and age-related differences as standardised effects sizes, allowing for comparison between sexes, among different ages, and with sex, age and test-matched international children.

However, this study is not without limitations. Only one of the 15 included studies was based on a nationally representative sample, which obviously raises the issue of representativeness. Most of the included studies used similar sampling frames

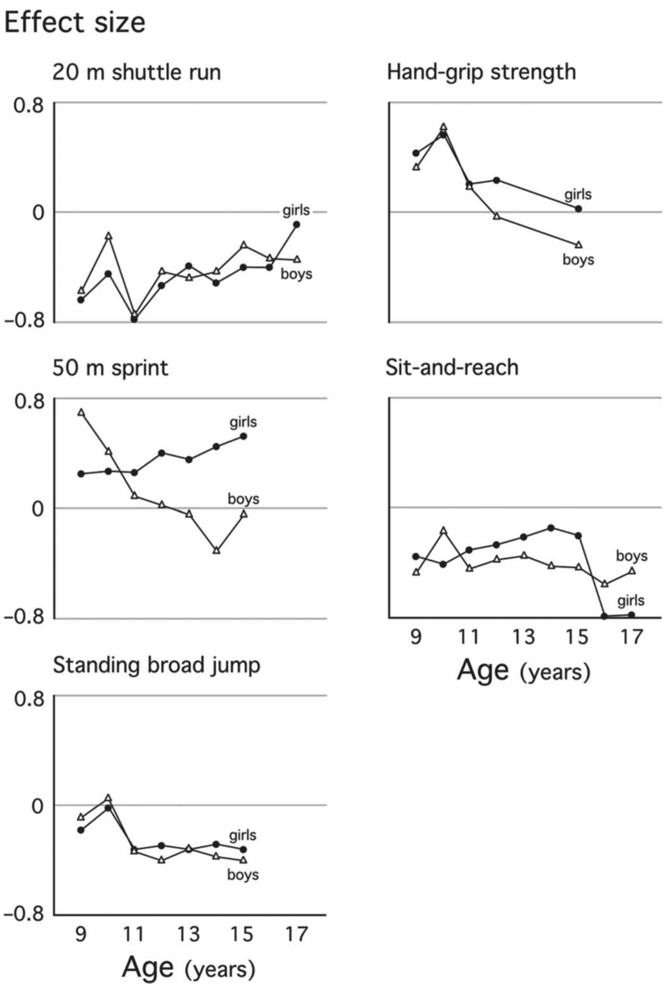

Figure 6 Sex- and age-specific effect sizes for (A) 20 m shuttle run, (B) 50 m sprint, (C) hand-grip strength, (D) sit-and-reach and (E) standing broad jump for 9–17-year-old Australian boys (triangles) and girls (circles) relative to their international peers. Positive effects indicate higher fitness scores for Australian children and negative effects indicate lower fitness scores. Comparative data represent n=284 508 20 m shuttle run performances,[28–30] n=1 216 452 50 m sprint performances,[18] n=126 361 hand-grip strength performances,[29] n=102 664 sit-and-reach performances,[29] and n=164 986 standing broad jump performances[29] of 9–17-year-old children from 48 international countries.

(table 1). Schools with a greater interest in sport and fitness may have been more willing to participate, and because participation at the individual level was voluntary, it is possible that children with low fitness levels chose not to participate. This might have resulted in fitness test performances unrepresentative of the population, but it should not have affected the sex- and age-related differences. Fitness data were also collected at different times during the 1985–2009 period, and given convincing evidence of recent temporal declines in some (but not all) components of Australian children's fitness,[23 49] it is possible that the normative data presented in this study represent a better 'health-related picture' than what would be observed today. A temporal analysis of the data accumulated in this study suggests that these normative data would probably overestimate the fitness of Australian children in 2009 by an average of 0.3 SDs or 13 percentile points, assuming of course that the observed temporal changes remained consistent across the entire 1985–2009 period. Nonetheless, these data represent the best available and most up-to-date health-related fitness data on Australian children. It must also be remembered that despite being simple, cheap, easy, reliable, reasonably valid and widely used alternatives of laboratory-based criterion measures, field tests are affected by factors other than underlying construct fitness. For example, validity data for field tests of cardiovascular fitness suggest that (at best) only 50–60% of the variance in field test performance is explained by the variance in underlying peak oxygen uptake, indicating that other physiological, physical, biomechanical, psychosocial and environmental factors also play a part.[15] In addition, although criterion-related validity has not been established for all of the included tests, face validity is generally accepted.[17] Most of the included tests are also considered to demonstrate good reliability, although tests requiring a reasonable degree of subjective judgement (eg, the subjective scoring of a properly performed sit-up or push-up) typically demonstrate poorer reliability.[14]

Conclusion

Physical fitness is considered to be an excellent marker of current and future health. In anticipation of a follow-up national fitness survey, this study provides the most up-to-date and most comprehensive set of sex- and age-specific normative centile values of health-related fitness of Australian children, which can be used as benchmark values for health and fitness screening and surveillance systems. These normative centile values will facilitate the identification of children with low fitness to set appropriate fitness goals, monitor individual changes in fitness and promote positive health behaviours. They will also facilitate the identification of children who possess specific fitness characteristics that may be considered important for sporting success, in the hope of recruiting the high achievers into elite sporting development programs.

Acknowledgements The authors thank the authors of the included studies for generously clarifying details of their studies and/or for providing raw data. The University of South Australia Divisional Development Research Scheme supported this study.

Correction notice This article has been corrected since it was published Online First. The authors have noticed that the normative data in Table 10 are incorrect. The correct table has been inserted.

Competing interests None.

Provenance and peer review Not commissioned; externally peer reviewed.

REFERENCES

1 Ortega FB, Ruiz JR, Castillo MJ, *et al*. Physical fitness in childhood and adolescence: a powerful marker of health. *Int J Obes (Lond)* 2008;32:1–11.
2 Ruiz JR, Castro-Piñero J, Artero EG, *et al*. Predictive validity of health-related fitness in youth: a systematic review. *Br J Sports Med* 2009;43:909–23.
3 Vicente-Rodriguez G, Ara I, Perez-Gomez J, *et al*. High femoral bone mineral density accretion in prepubertal soccer players. *Med Sci Sports Exerc* 2004;36:1789–95.
4 Kodama S, Saito K, Tanaka S, *et al*. Cardiorespiratory fitness as a quantitative predictor of all-cause mortality and cardiovascular events in healthy men and women: a meta-analysis. *JAMA* 2009;301:2024–35.
5 Lee CD, Blair SN. Cardiorespiratory fitness and stroke mortality in men. *Med Sci Sports Exerc* 2002;34:592–5.
6 Dishman RK, Washburn RA, Heath GW. *Physical Activity Epidemiology*. Champaign, IL: Human Kinetics 2004:358–9.
7 Gillespie LD, Robertson MC, Gillespie WJ, *et al*. Interventions for preventing falls in older people living in the community. *Cochrane Database Syst Rev* 2009;2:CD007146.
8 Katzmarzyk PT, Church TS, Janssen I, *et al*. Metabolic syndrome, obesity, and mortality: impact of cardiorespiratory fitness. *Diabetes Care* 2005;28:391–7.
9 Katzmarzyk PT, Church TS, Blair SN. Cardiorespiratory fitness attenuates the effects of the metabolic syndrome on all-cause and cardiovascular disease mortality in men. *Arch Intern Med* 2004;164:1092–7.
10 Andersen LB, Hasselstrøm H, Grønfeldt V, *et al*. The relationship between physical fitness and clustered risk, and tracking of clustered risk from adolescence to young

adulthood: eight years follow-up in the Danish Youth and Sport Study. *Int J Behav Nutr Phys Act* 2004;1:6.
11 Cleland VJ, Ball K, Magnussen C, *et al*. Socioeconomic position and the tracking of physical activity and cardiorespiratory fitness from childhood to adulthood. *Am J Epidemiol* 2009;170:1069–77.
12 Twisk JW, Kemper HC, van Mechelen W. Tracking of activity and fitness and the relationship with cardiovascular disease risk factors. *Med Sci Sports Exerc* 2000;32:1455–61.
13 Kristensen PL, Wedderkopp N, Møller NC, *et al*. Tracking and prevalence of cardiovascular disease risk factors across socio-economic classes: a longitudinal substudy of the European Youth Heart Study. *BMC Public Health* 2006;6:20.
14 Artero EG, España-Romero V, Castro-Piñero J, *et al*. Reliability of field-based fitness tests in youth. *Int J Sports Med* 2011;32:159–69.
15 Tomkinson GR, Olds TS. Field tests of fitness. In: Armstrong N, Van Mechelen W, eds. *Pediatric Exercise Science and Medicine*. Oxford: Oxford University Press 2008:109–28.
16 Castro-Piñero J, Artero EG, España-Romero V, *et al*. Criterion-related validity of field-based fitness tests in youth: a systematic review. *Br J Sports Med* 2010;44:934–43.
17 Ruiz JR, Castro-Piñero J, España-Romero V, *et al*. Field-based fitness assessment in young people: the ALPHA health-related fitness test battery for children and adolescents. *Br J Sports Med* 2011;45:518–24.
18 Council of Europe. *Eurofit: Handbook for the Eurofit Tests Of Physical Fitness*. Rome: Council of Europe 1988.
19 The Cooper Institute. *FITNESSGRAM/ACTIVITYGRAM Test Administration Manual*. Fourth edition. Champaign, IL: Human Kinetics 2007.
20 Olds TS, Tomkinson GR. The aerobic fitness of 9–15 year old South Australian children: norms, trends and international comparisons. *ACHPER Healthy Lifestyles Journal* 2003;50:25–30.
21 Pyke JE. *Australian Health And Fitness Survey 1985: The Fitness, Health And Physical Performance Of Australian School Students Aged 7–15 Years*. Parkside, SA: The Australian Council for Health, Physical Education and Recreation 1987.
22 Tomkinson GR, Olds TS. Secular changes in pediatric aerobic fitness test performance: the global picture. *Med Sport Sci* 2007;50:46–66.
23 Tomkinson GR, Olds TS. Secular changes in aerobic fitness test performance of Australasian children and adolescents. *Med Sport Sci* 2007;50:168–82.
24 Tomkinson GR. Global changes in anaerobic fitness test performance of children and adolescents (1958-2003). *Scand J Med Sci Sports* 2007;17:497–507.
25 Tomkinson GR, Léger LA, Olds TS, *et al*. Secular trends in the performance of children and adolescents (1980-2000): an analysis of 55 studies of the 20m shuttle run test in 11 countries. *Sports Med* 2003;33:285–300.
26 Cole TJ, Green PJ. Smoothing reference centile curves: the LMS method and penalized likelihood. *Stat Med* 1992;11:1305–19.
27 Pan H, Cole T. *User's Guide to Lms Chart Maker*. Council MR, ed. 1997–2005 Medical Research Council. UK: Medical Research Council 2005.
28 Jackson LV, Thalange NK, Cole TJ. Blood pressure centiles for Great Britain. *Arch Dis Child* 2007;92:298–303.
29 Ortega FB, Artero EG, Ruiz JR, *et al*. Physical fitness levels among European adolescents: the HELENA study. *Br J Sports Med* 2011;45:20–9.
30 Castro-Piñero J, González-Montesinos JL, Keating XD, *et al*. Percentile values for running sprint field tests in children ages 6-17 years: influence of weight status. *Res Q Exerc Sport* 2010;81:143–51.
31 Cohen J. *Statistical Power Analysis For The Behavioral Sciences*. Second edition. New Jersey: Lawrence Erlbaum 1988.
32 Cole TJ, Freeman JV, Preece MA. Body mass index reference curves for the UK, 1990. *Arch Dis Child* 1995;73:25–9.
33 Eisenmann JC. Waist circumference percentiles for 7- to 15-year-old Australian children. *Acta Paediatr* 2005;94:1182–5.
34 Armstrong N, McManus AM, Welsman JR. Aerobic fitness. In: Armstrong N, Van Mechelen W, eds. *Paediatric Exercise Science and Medicine*. Oxford: Oxford University Press 2008:269–82.
35 Krahenbuhl GS, Skinner JS, Kohrt WM. Developmental aspects of maximal aerobic power in children. *Exerc Sport Sci Rev* 1985;13:503–38.
36 Rowland TW. Evolution of maximal oxygen uptake in children. *Med Sport Sci* 2007;50:200–9.
37 Blimkie CJR, Sale DG. Strength development and trainability during childhood. In: Van Praagh E, eds. *Pediatric Anaerobic Performance*. Champaign, IL: Human Kinetics 1998:193–224.
38 Froberg K, Lammert O. Development of muscle strength during childhood. In: Bar-Or O, ed. *The Child and Adolescent Athlete*. Oxford: Blackwell Science 1996:42–53.
39 De Ste Croix MDA. Muscle strength. In: Armstrong N, Van Mechelen W, eds. *Paediatric Exercise Science and Medicine*. Second edition. Oxford: Oxford University Press 2008:199–212.
40 Olds T, Tomkinson G, Léger L, *et al*. 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;24:1025–38.
41 Adegboye AR, Anderssen SA, Froberg K, *et al*. Recommended aerobic fitness level for metabolic health in children and adolescents: a study of diagnostic accuracy. *Br J Sports Med* 2011;45:722–8.
42 Lobelo F, Pate RR, Dowda M, *et al*. Validity of cardiorespiratory fitness criterion-referenced standards for adolescents. *Med Sci Sports Exerc* 2009;41:1222–9.
43 Ruiz JR, Ortega FB, Rizzo NS, *et al*. High cardiovascular fitness is associated with low metabolic risk score in children: the European Youth Heart Study. *Pediatr Res* 2007;61:350–5.
44 Welk GJ, Laurson KR, Eisenmann JC, *et al*. Development of youth aerobic capacity standards using receiver operator characteristic curves. *Am J Prev Med* 2011;41: S111–6.
45 Cureton KJ, Sloniger MA, O'Bannon JP, *et al*. A generalized equation for prediction of VO2peak from 1-mile run/walk performance. *Med Sci Sports Exerc* 1995;27:445–51.
46 Léger L, Lambert J, Goulet A, *et al*. [Aerobic capacity of 6 to 17-year-old Quebecois–20 meter shuttle run test with 1 minute stages]. *Can J Appl Sport Sci* 1984;9:64–9.
47 Tomkinson G. Aerobic fitness thresholds for cardio metabolic health in children and adolescents. *Br J Sports Med* 2011;45:686–7.
48 Dwyer T, Magnussen CG, Schmidt MD, *et al*. Decline in physical fitness from childhood to adulthood associated with increased obesity and insulin resistance in adults. *Diabetes Care* 2009;32:683–7.
49 Tomkinson GR, Hamlin MJ, Olds TS. Secular changes in anaerobic test performance in Australasian children and adolescents. *Pediatr Exerc Sci* 2006;18:314–28.
50 Australian Council for Health, Physical Education and Recreation. *Australian Fitness Education Award: User's Manual And Curriculum Ideas.* Adelaide, SA: Australian Council for Health, Physical Education and Recreation 1996.
51 Barnett LM, Van Beurden E, Morgan PJ, *et al*. Does childhood motor skill proficiency predict adolescent fitness? *Med Sci Sports Exerc* 2008;40:2137–44.
52 Birchall J. Health related fitness testing. In: Went S, ed. *A Healthy Start: Holistic Approaches to Health Promotion in School Communities*. Second edition. Melbourne: Monash University 1992:251–65.
53 Booth M, Macaskill P, McLellan L, *et al*. *NSW Schools Fitness and Physical Activity Survey 1997*. Sydney: NSW Department of Education and Training, 1997.
54 Booth M, Okely AD, Denney-Wilson E, *et al*. *NSW Schools Physical Activity and Nutrition Survey (SPANS) 2004: Full Report*. Sydney: NSW Department of Health, 2006.
55 Burke V, Beilin LJ, Durkin K, *et al*. Television, computer use, physical activity, diet and fatness in Australian adolescents. *Int J Pediatr Obes* 2006;1:248–55.
56 Cooley D, McNaughton L. Aerobic fitness of Tasmanian secondary school children using the 20-m shuttle run test. *Percept Mot Skills* 1999;88:188–98.
57 Dollman J, Olds T, Norton K, *et al*. 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;11:106–21.
58 Hands B. *Fitness and motor skill levels of Western Australian Primary School Children*. Perth, WA: University of Western Australia 2000.
59 McNaughton L, Morgan R, Smith P, *et al*. An investigation into the fitness levels of Tasmanian primary schoolchildren. *ACHPER Healthy Lifestyles Journal* 1996;43:4–10.
60 Vandongen R, Jenner DA, Thompson C, *et al*. 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.