Exercise capacity in Dutch children; new reference values for the Bruce treadmill protocol.

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Short title: Exercise capacity in children

ABSTRACT

The Bruce treadmill protocol is suitable for children 4 years of age and older. Dutch reference values were established in 1987. We considered that children's exercise capacity has deteriorated due to changes in physical activity patterns and eating habits. We determined new reference values and evaluated determinants of exercise capacity. Healthy Dutch children (n = 267) aged 6 - 13 years participated in this cross-sectional observational study. The maximal endurance time on the treadmill was the criterion of exercise capacity. Furthermore, we obtained data on anthropometry, smoking habits, socioeconomic status, ethnicity, sports participation, and school transport habits. The maximal endurance time for children aged up till 10 was lower (up to 1.6 and 1.4 min in girls and boys, respectively) than previously published. Body mass index was negatively, and intense sports participation was positively associated with endurance time (β = -0.412 and 0.789, respectively; $p < 0.001$). In conclusion, exercise capacity seems to have deteriorated in Dutch children aged up till 10 years whereas the values from the older children are remarkably similar to those from the previous study.

INTRODUCTION

Exercise testing provides information on exercise capacity and facilitates assessment of pathophysiologic characteristics, effectiveness of medication, and risk of potential disease.[1] Because children have relatively undeveloped knee extensors, treadmill testing is preferred over cycle ergometry especially for those lower than 8 years of age.[1] The Bruce treadmill protocol is well fitted for children 4 years of age onwards[2] and is preferred to cycle ergometry for clinical exercise testing in children in the United States.[3] In the Netherlands, the Bruce treadmill protocol is used not only in clinical settings but also by local pediatric physical therapists.

Dutch reference values for the Bruce treadmill protocol were established in 1987.[4] It may be doubted, whether these values reflect contemporary exercise capacity of healthy Dutch children. We hypothesized that exercise capacity has deteriorated. This hypothesis is supported by Chatrath for urban American children: children in 2002 showed a shorter endurance time on the Bruce treadmill test than children tested in 1977.[5,6] They reported a strong inverse relationship between body mass index (BMI) and endurance time. A similar trend was observed in Danish children between 1985 - 1986 and 1997 - 1998.[7] In view of this hypothesis we set out to: (1) determine new reference values for exercise capacity as indicated with the Bruce treadmill test for healthy Dutch children; (2) compare these new reference values with the previously established reference values by Binkhorst et al.[4] and (3) evaluate height for age, BMI, smoking habits, ethnicity, socioeconomic status (SES), sports participation, and school transport habits as possible determinants of exercise capacity.

PARTICIPANTS AND METHODS

We recruited healthy children, aged 6 - 13 years, attending five primary and secondary schools in the Southwestern part of the Netherlands. The schools were located in both urban and suburban regions. Teachers distributed 455 information letters and pre-test questionnaires to their pupils.

Exclusion criteria were: impaired motor development, use of medication affecting exercise capacity, or pulmonary and cardiovascular disease. Furthermore, we excluded obese children [weight for height ratio above +2 standard deviation scores (SDS)[8]] from analysis. We aimed at studying 30 boys and 30 girls for each age band of 2 years.

Study design

We performed this cross-sectional observational study between July 2006 and January 2007. The children were tested in a quiet room at their own schools. A minority of children performed the test in the hospital's exercise room. Parents of all participants filled out a pre-test questionnaire. Parental estimation of their child's fitness level was classified as higher than, equal to or less than that for children of the same age.

The Erasmus MC Medical Ethical Review Board approved the study and we obtained written informed consent from all parents or guardians and for children aged 12 and 13 years also from the children.

The Bruce treadmill test

A motor-driven treadmill (En Mill, Enraf Nonius, Rotterdam, the Netherlands) was programmed for increases in angle of inclination and speed according to Bruce et al.[2] (Table 1). The children were permitted to hold on to the guardrail for maximally 5 seconds only to regain balance during changes of speed and angle of inclination. A physical therapist trained to apply Basic Life Support to children supervised all tests. We encouraged the children to perform to voluntary exhaustion. Thereafter the children continued walking at a slope of 0% and a speed of 2 km/h for 2 min. The maximal endurance time (in minutes, one decimal) served as criterion of exercise capacity. Before and during the test we monitored heart rate and transcutaneous oxygen saturation with a pulse Oximeter (MARS, motion artifact reduction system, type 2001, Respironics Novametrix, Murrysville, PA, USA). Heart rate of ≥ 185 beats per min (bpm)[9] or loss of coordination was considered to indicate maximal performance.

Determinants of exercise capacity

Pre-test questionnaire

The parental pre-test questionnaire included questions on means of school transport habits, one-way travel distance, sports participation, active and passive smoking, ethnic origin, and SES. Sports participation was classified into low (only school gymnastic lessons), moderate (gymnastic lessons and participation in organized sports up to 2 hours weekly) or high (gymnastic lessons and more than 2 hours of organized sports weekly). We classified ethnic origin using the definition of Statistics Netherlands into "Dutch", "Western background" or "non-Western background".[10] We assessed SES by questions about employment and education of both parents. SES was classified into: "low", "middle", and "high".[11] For children who cycled to school a weekly commuting distance (in km) was calculated by multiplying the one-way travel distance by 10.

Pre-test evaluation

A pre-test evaluation included measurement of height (cm) and weight (kg) using a stadiometer (Seca 206, Seca, Hamburg, Germany) and a scale (Beurer PS-16, Beurer, Ulm, Germany), respectively. The Dutch Growth Analyser, version 3.0 (Dutch Growth Foundation, Rotterdam, the Netherlands) served to calculate SDS for height, BMI, and weight for height on the basis of Dutch reference values published in 2000.[8]

Table 1 *Bruce treadmill protocol*

	Bruce		
Stage	Speed (km/h)	Grade (%)	Time (min)
I	2.7	10	3
II	4	12	3
III	5.4	14	3
IV	6.7	16	3
V	8	18	3
VI	8.8	20	3
VII	9.6	22	3

DATA ANALYSES

Data are presented for boys and girls separately. We performed a construction of age-related reference centiles according to Altman.[12] In brief: the endurance time is assumed to follow a normal distribution for a given age and sex. First the mean endurance time is modelled as a function of age. The absolute residuals of this regression are then regressed on age to provide an estimate of the standard deviation (SD) of the endurance time as a function of age. Means and SDs were combined to provide estimates for the centiles (centile = mean + Z x SD where Z is the corresponding centile of the standard normal distribution). We used a restricted cubic spline (with knots at the age of 7, 10, and 13) to obtain flexibility in the functional form of the relation of mean endurance time.[13] The SD was modelled using a linear model. When the slope of this model was not significant the SD was assumed to be constant.

Furthermore, we investigated whether differences in SDS endurance time could be explained by SDS height for age, SDS BMI, sports participation, school transport habits, smoking habits, ethnicity, or SES. We used linear regression analyses with the SDS of the endurance time as outcome variable in order to detect relevant determinants (i.e. bivariate significant) to include in multiple regression models. We present the regression coefficients (β) and explained variance (R^2) of the linear regression models.

Group comparisons (differences in the subject characteristics between boys and girls) were performed with the independent t-test, Mann-Whitney U test or Chi-square test where appropriate. Correlation coefficients between estimated levels of fitness and SDS of the endurance times were established with the Spearman's correlation test. Data presented are mean ± SD, unless stated otherwise. Statistical significance is accepted at a 1% level for all tests. Statistical analyses were performed using SPSS 14.0 for Windows.

Table 2 *Subject characteristics*

	Total	**Boys**	**Girls**
	n = 267	n = 133	n = 134
Height SD-scores, mean (SD)	0.17 (1.00)*	0.23 (0.83)	0.12 (1.12)†
Weight-for-height SD-scores, mean (SD)	0.01 (1.00)	0.06 (0.98)	-0.025 (1.04)
BMI SD-scores, mean (SD)	0.06 (1.00)	0.11 (0.98)	-0.003 (1.02)
Passive smoking, n (%)	34 (12.7)	16 (12.0)	18 (13.5)
SES			
high, n (%)	182 (68.2)	97 (73.0)	85 (63.4)
middle, n (%)	62 (23.2)	24 (18.0)	38 (28.4)
low, n (%)	22 (8.2)	12 (9.0)	10 (7.4)
missing, n (%)	1 (0.4)	--	1 (0.8)
Ethnic group			
Dutch, n (%)	222 (83.2)	118 (88.7)	104 (77.6)
Western background, n (%)	23 (8.6)	7 (5.3)	16 (11.9)
Non-Western background, n (%)	22 (8.2)	8 (6.0)	14 (10.5)
Sports participation			
high, n (%)	131 (49.1)	78 (59.6)	53 (39.6)
moderate, n (%)	100 (37.4)	35 (26.3)	65 (48.5)
low, n (%)	35 (13.1)	20 (15.1)	15 (11.2)
missing, n (%)	1 (0.4)	--	1 (0.7)
Home/school commuting			
by car or sitting at parent's bicycle, n (%)	37 (13.9)	20 (15.0)	17 (12.7)
walking or public transport, n (%)	80 (30.0)	40 (30.1)	40 (29.9)
cycling, n (%)	150 (56.1)	73 (54.9)	77 (57.4)
Parental estimation of fitness level			
better than peers, n (%)	44 (16.5)	24 (18.1)	20 (14.9)
similar to peers, n (%)	209 (78.3)	103 (77.4)	106 (79.1)
worse than peers, n (%)	10 (3.7)	4 (3.0)	6 (4.5)
missing, n (%)	4 (1.5)	2 (1.5)	2 (1.5)

Independent t-test
** significantly different from zero: p = 0.005,*
† significantly different from zero: p = 0.002

RESULTS

Three hundred thirty-two of the 455 invited children (73%) were willing to participate; 114 parents did not respond and nine refused to participate. Nine of these 332 children were not tested for medical reasons: six had pulmonary or cardiovascular disease, two had a broken arm, and one child underwent chemotherapy. Thirty-nine children were not tested for organizational reasons. Furthermore, 17 children (5%) were excluded from analysis because of obesity (n = 3), no maximal exercise performed (n = 2), muscular problems (n = 2), and inability to walk without holding the guardrail (n = 9). Thus, final analysis was on 267 children (59%; Table 2). There were no significant differences between boys and girls in any of the characteristics. None of the children reported to smoke.

Reference values for exercise capacity

Percentile scores for exercise capacity for the children are shown in Tables 3 and 4 for boys and girls, respectively. The age-related reference centiles are graphically shown in Figure 1 (a and b).

Heart rate at maximal performance reliably recorded for 185 children (69%) was a mean of 197 ± 8 bpm. Technical problems precluded reliably recording for the other 82 children. Still, for 74 of these children a heart rate of ≥ 185 bpm had been recorded just before maximal exercise. For none of the children the transcutaneous oxygen saturation was ≤ 94%. We found positive correlations between the estimated levels of exercise capacity and the endurance SD-scores ($r_s = 0.4$, $p < 0.001$).

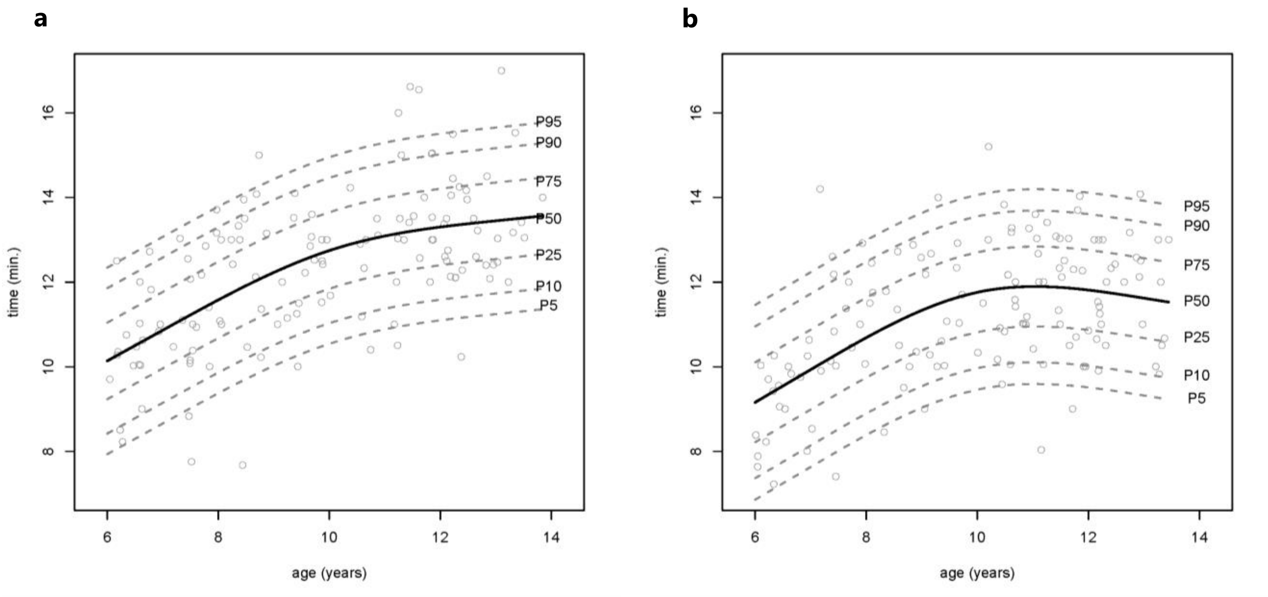

Figure 1 (a and b) *Maximal endurance time on the Bruce treadmill test for boys (a) and girls (b) (selected centiles). The open circles represent each individual subject*

Table 3 *Maximal endurance time in minutes for boys: centiles*

Age (yrs)	p 5	p 10	p 25	p 50	p 75	p 90	p 95	Maximum HR*
6.0	7.9	8.4	9.2	10.1	11.0	11.9	12.3	194 ± 11
6.5	8.3	8.8	9.6	10.5	11.4	12.2	12.7	202 ± 8
7.0	8.7	9.1	10.0	10.9	11.8	12.6	13.1	191 ± 9
7.5	9.0	9.5	10.3	11.2	12.1	12.9	13.4	197 ± 6
8.0	9.4	9.9	10.7	11.6	12.5	13.3	13.8	198 ± 14
8.5	9.7	10.2	11.0	11.9	12.8	13.6	14.1	188 ± 0
9.0	10.0	10.5	11.3	12.2	13.1	14.0	14.4	198 ± 9
9.5	10.3	10.8	11.6	12.5	13.4	14.2	14.7	194 ± 0
10.0	10.5	11.0	11.8	12.8	13.7	14.5	15.0	199 ± 8
10.5	10.7	11.2	12.0	12.9	13.8	14.7	15.2	193 ± 7
11.0	10.9	11.4	12.2	13.1	14.0	14.8	15.3	199 ± 10
11.5	11.0	11.5	12.3	13.2	14.1	14.9	15.4	201 ± 11
12.0	11.1	11.6	12.4	13.3	14.2	15.0	15.5	199 ± 6
12.5	11.2	11.7	12.5	13.4	14.3	15.1	15.6	192 ± 15
13.0	11.2	11.7	12.6	13.5	14.4	15.2	15.7	197 ± 5

** Maximum heart rate in bpm; mean ± 1 standard deviation (SD).*
Total n = 133; ages 6 and 7 years: n = 37; 8 and 9 years: n = 35; 10 and 11 years: n = 29;
12 and 13 years: n = 32. SD endurance time = 1.3 min

Table 4 *Maximal endurance time in minutes for girls: centiles*

Age (yrs)	p 5	p 10	p 25	p 50	p 75	p 90	p 95	Maximum HR*
6.0	6.9	7.4	8.2	9.2	10.1	11.0	11.5	195 ± 9
6.5	7.2	7.8	8.6	9.5	10.5	11.3	11.9	195 ± 5
7.0	7.6	8.1	9.0	9.9	10.9	11.7	12.2	191 ± 9
7.5	8.0	8.5	9.4	10.3	11.3	12.1	12.6	190 ± 12
8.0	8.4	8.9	9.7	10.7	11.6	12.5	13.0	195 ± 6
8.5	8.7	9.2	10.1	11.0	12.0	12.8	13.3	197 ± 7
9.0	9.0	9.5	10.4	11.3	12.3	13.1	13.6	201 ± 1
9.5	9.3	9.8	10.6	11.6	12.5	13.4	13.9	200 ± 13
10.0	9.5	10.0	10.8	11.8	12.7	13.6	14.1	202 ± 7
10.5	9.6	10.1	10.9	11.9	12.8	13.7	14.2	198 ± 7
11.0	9.6	10.1	10.9	11.9	12.8	13.7	14.2	201 ± 9
11.5	9.6	10.1	10.9	11.9	12.8	13.7	14.2	201 ± 6
12.0	9.5	10.0	10.9	11.8	12.8	13.6	14.1	202 ± 7
12.5	9.4	9.9	10.8	11.7	12.7	13.5	14.0	197 ± 8
13.0	9.3	9.8	10.7	11.6	12.6	13.4	13.9	197 ± 10

** Maximum heart rate bpm; mean ± 1 standard deviation (SD)*
Total n = 134; ages 6 and 7 years: n = 33; 8 and 9 years: n = 26; 10 and 11 years: n = 48;
12 and 13 years: n = 27. SD endurance time = 1.4 min

Comparison with previously established Dutch reference values

Figure 2 shows the p 50-centiles from our study plotted against values presented by Binkhorst et al.[4] Values for children up to the age of 9 and 10 years (girls and boys respectively) in the present study are lower than the historical values (up to 1.6 and 1.4 min in girls and boys, respectively). The difference was most striking in the youngest children. As Binkhorst et al. did not provide exact sample sizes for each age and gender band we present the comparison graphically.

Determinants of exercise capacity

Linear regression showed that SDS BMI, SES, and sports participation were related to endurance SDS (Table 5). Multiple regression showed that 27% of the variance in endurance SDS was explained by SDS BMI, SES, and sports participation. Intense sports participation and SDS BMI were best predictive. Furthermore we explored possible relations between age and BMI or sports participation. BMI scores did not correlate with age. Intensity of sports participation correlated positively with age ($r_s = 0.24$; $p < 0.001$).

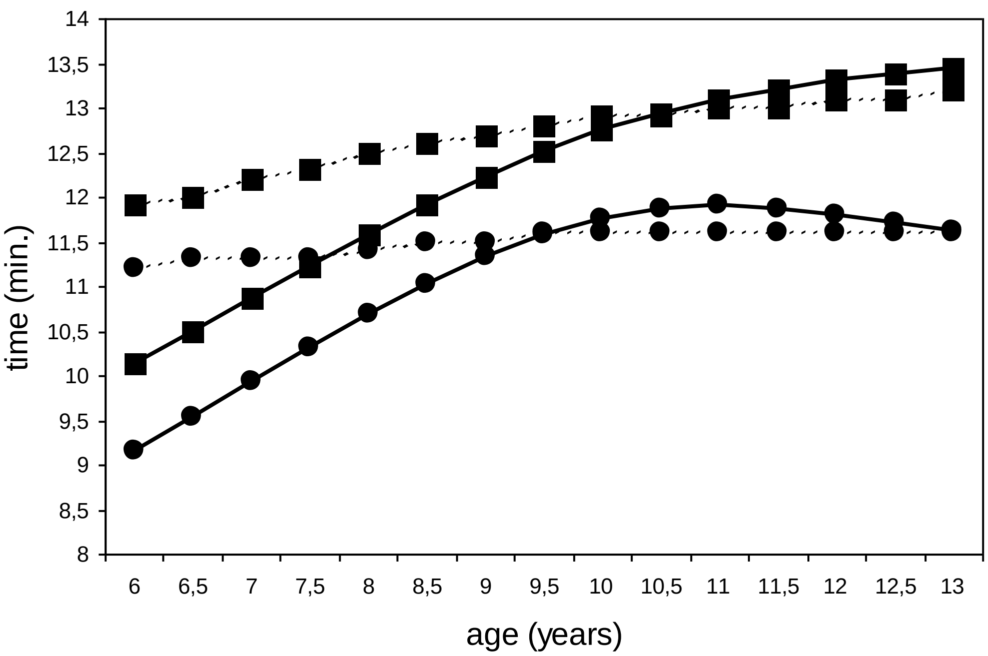

Figure 2 *Bruce protocol; endurance times in the current study (solid lines) and in the study of Binkhorst et al.[4] (dashed lines). Data from 6 to 13 years old boys (squares) and girls (circles) are shown*

Table 5 *Regression models for determinants affecting exercise capacity*

Independent variables	SDS endurance time		
	β	**p-value**	**R²**
SDS BMI	-0.384	< 0.001*	0.143
SDS height for age	-0.023	0.713	0.001
Passive smoking	-0.433	0.019	0.020
SES		0.009*	0.035
SES (difference 0 and 1)	-0.011	0.963	
SES (difference 0 and 2)	0.399	0.077	
Ethnicity		0.337	0.008
Ethnicity (difference 0 and 1)	-0.175	0.430	
Ethnicity (difference 0 and 2)	-0.298	0.189	
Sports participation		< 0.001*	0.085
Sports participation (difference 0 and 1)	0.033	0.864	
Sports participation (difference 0 and 2)	0.613	0.001*	
Home/school commuting		0.081	0.019
Home/school (difference 0 and 1)	0.451	0.025	
Home/school (difference 0 and 2)	0.311	0.093	
Multiple			
SDS BMI, SES, Sports participation		< 0.001*	0.268
SDS BMI	-0.412	< 0.001*	
SES (difference 0 and 1)	-0.093	0.670	
SES (difference 0 and 2)	0.196	0.328	
Sports participation (difference 0 and 1)	0.220	0.207	
Sports participation (difference 0 and 2)	0.786	< 0.001*	

** = significant; SDS = standard deviation scores; β = regression coefficient; R² = explained variance; Passive smoking: no (0), yes (1); SES (socioeconomic status): low (0), middle (1), high (2); Ethnicity: Dutch (0), Western background (1) and non-Western background (2); Sports participation: low (0), middle (1), high (2); Home/school commuting: car or sitting at parent's bicycle (0), walking or public transport (1), cycling themselves (2)*

DISCUSSION

The present study provides an update of children's reference values for the Bruce exercise test. An update was felt necessary as the presently used values date from 1987 and children's activity levels are thought to have dropped. Endurance times for children up to the age of 9 and 10 years (girls and boys, respectively) in the present study were indeed lower than those for the children studied in 1987.[4] However, the values from the older children were remarkably similar to those from the previous study. BMI was negatively associated, and intense sports participation was positively associated with maximal endurance time.

The sample of 267 healthy children was representative of the Dutch population with respect to ethnicity.[14] The sample included 59% of all invited children. Since background data on non-participants are lacking, some selection bias cannot be ruled out. Nevertheless, as the large majority of parents estimated their child's fitness level similar to that of age peers, a selection bias towards high fitness levels seems unlikely. Furthermore, a relatively large proportion of the sample was classified as high SES. Because we found a rather low but positive interaction between SES and SDS endurance time, we assume that children with lower SES may perform slightly worse. This would suggest that inclusion of more children from low SES families would have resulted in lower exercise capacity.

Although children in the study of Binkhorst et al.[4] were tested under slightly different conditions, we do not expect the differences between the study conditions to interfere with the main conclusion of our study. For example, children in the study of Binkhorst et al. had been given the opportunity to practice walking on the treadmill. We did not arrange opportunity to practice, because the Bruce protocol starts with walking for 3 min at a low speed, which provides for warming up and getting used to the treadmill. Furthermore, we also did not measure gas exchange parameters. Firstly, wearing a mask may lead to loss of cooperation and to submaximal results, especially in the younger children. Secondly, Cumming et al.[5] reported a strong correlation between the maximal endurance time and maximal oxygen uptake. They concluded that maximal endurance time might be used as a sole criterion of exercise capacity. We selected the present study design because our study conditions are in accordance with the everyday practice applied by pediatric physical therapists.

Two studies in North-American children and one in Italian children and adolescents report on exercise testing by the Bruce protocol in large samples as well (Table 6).[5,6,15] We found lower maximal endurance times, especially in the younger children, than did Cumming et al.,[5] and Maffulli et al.[15] Also Wedderkopp et al.[7] and Tomkinson and Olds[16] suggested this secular trend in exercise capacity in children.

We assume that both increased obesity and lower level of physical activity may explain the deterioration in exercise capacity.[17-19] In the Netherlands, children up to 7 years of age spend more time watching television than 5 years earlier and 2% of all children aged 3 years and over never play outdoors.[20] More and more children in the United Kingdom and Australia are being taken to school by car[21,22] and we assume that this holds true for the Netherlands as well. On the other hand, Metcalf found that the school run does not affect overall physical activity of 5-year-olds.[21]

Table 6 *Comparison of our results with previously published data on the Bruce treadmill protocol in children*

Age groups (years)	Binkhorst[4] n = 336*	Cumming[5] n = 177	Maffulli[15] n = 160	Chatrath[6] n = 236	Current study n = 267
Boys					
6 - 7	12.1 ± 1.5	11.8 ± 1.6	14.0 ± 1.8	9.6 ± 2.3	10.7± 1.3
8 - 9	12.7 ± 1.5	12.6 ± 2.3	15.2 ± 1.3	10.2 ± 2.5	12.1 ± 1.3
10 - 11	13.0 ± 1.5	12.7 ± 1.9†	15.4 ± 2.5	10.7 ± 2.1†	13.0 ± 1.3
12 - 13	13.2 ± 1.5		17.1 ± 2.2		13.4 ± 1.3
Girls					
6 - 7	11.3 ± 1.1	11.2 ± 1.5	12.7 ± 1.6	8.7 ± 2.0	9.7 ± 1.4
8 - 9	11.6 ± 1.1	11.8 ± 1.6	13.6 ± 2.3	9.8 ± 1.6	11.2 ± 1.4
10 - 11	11.6 ± 1.1	12.3 ± 1.4†	14.8 ± 1.2	10.2 ± 1.9†	11.8 ± 1.4
12 - 13	11.6 ± 1.1		14.0 ± 2.7		11.7 ± 1.4

Mean (± 1 SD) endurance time (min)
** 336 is the total study population (4 - 18-year-olds), the number of 6 - 13-year-olds is unclear.*
† age group 10 - 12 years

The cross-sectional design of our study does not allow to establish causal relations explaining the deteriorated exercise capacity in the youngest children. Attempts can be made to reverse the downward trend, but even individual life style recommendations have met with little success. It would seem therefore, that the best approach is creating better opportunities for children to be physically active in their daily environments (e.g. schools, roads, sports), stimulated by policy changes that aim at better eating habits.

Exercise capacity for older children does not seem to have changed, probably as a result of increasing sports participation during the past years and stabilization of time spent watching television.[20,23] Furthermore, members of sports clubs are the most likely to play outdoors.[20] In our study, the travel distance by bicycle correlated positively with age. Thus, older children seem to exert more physical exercise during home/school commuting.

Children from a large U.S. metropolitan area referred to a pediatric cardiology clinic but proven to be without cardiac abnormalities[6] performed worse than the children in our study. This may be explained by the inclusion of obese children in their sample (15% of the children had a BMI > 95th percentile). In our study, the three children with obesity were excluded from analysis.

Children in our study were permitted to hold on to the guardrail for maximally 5 seconds only to regain balance during changes of speed and angle of inclination. We refrained from using a harness because in the Bruce protocol the belt speed is slow and using a harness may lead to loss of cooperation and to submaximal results. Nine of the 6-year-olds (eight girls and one boy) were not able to perform without holding the guardrails and reached longer endurance time than did their age peers. For the eight girls this was 10.7 against 9.2 min (p = 0.003). This finding confirms that holding the guardrail adds to the endurance time.[5] Thus, the reference values established in the current study are only applicable for children who are able to walk without holding the guardrail, apart from brief moments to regain balance during changes of speed and angle of inclination.

PERSPECTIVES

Our hypothesis that exercise capacity might have deteriorated over the years was confirmed for children aged 6 - 10 years. We assume that a change in lifestyle with younger children spending more leisure time playing computer games and/or watching television may be important.[17,19,20] For older children exercise capacity does not seem to have changed over the years probably as a result of increasing sports participation and stabilization of time spent watching television[20,23] (Figure 2). Younger children (up from the age of 4 years) are assumed to be able to perform the Bruce treadmill test too, but may need a slight modification of the protocol, i.e. holding the rail. Since intense sports participation interacts positively and BMI interacts negatively with exercise capacity, recommendations targeted at improvement of daily environment and a healthy eating pattern may be important to improve children's exercise capacity.

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