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Endurance, Explosive Power, and Muscle Strength in Relation to Body Mass Index and Physical Fitness in Greek Children Aged 7–10 Years

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We aimed to model endurance, explosive power, and muscle strength in relation to body mass index (BMI) and physical-fitness tests in Greek children aged 7–10 years old. In the present large epidemiological study, anthropometric measurements and physical-fitness tests (i.e., multistage shuttle run, vertical jump, standing long jump, small ball throw and 30-m sprint) from 141,169 children were analyzed. Age- and sex-specific normative values for physical fitness tests were expressed as tabulated percentiles using the LMS statistical method. The correlation coefficients between BMI and performances were negative and significant for both sexes ($p < .01$) in all physical-fitness tests. The only exception was a positive correlation between ball throw and BMI ($p < .01$). Only 2.9% and 4.0% of boys and girls respectively, passed the upper quartiles in all tests. The performance in speed may serve as a predictive factor explaining, at least in part, the performance in aerobic endurance and explosive power in children aged 7–10 years. The presented population-based data for physical-fitness tests revealed that only a small percentage of these children are in the upper quartiles in all tests. Furthermore, the data suggests that speed performance can be used to predict physical fitness.

Physical fitness refers to the “ability to carry out daily tasks with vigor and alertness, without undue fatigue and with ample energy to enjoy leisure-time pursuits and to meet unforeseen emergencies” (17). Sufficient fitness level in childhood is needed to carry forward favorable behavioral and biological effects into later life (16). Accumulating epidemiologic evidence reveals that improvement in physical fitness, mainly aerobic capacity, is related to better health in children (3,8,10,22) in a dose-response fashion (4). At this point, it should be highlighted the established close relationship between aerobic capacity and sprint performance. Speed is an important parameter for the improvement of aerobic performance, strongly related with parameters like maximal oxygen uptake, oxygen uptake at the ventilatory threshold and velocity at the onset of blood-lactate accumulation (6,20). Moreover,

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subjects with high physical fitness during adolescence may have lower levels of body fatness as adults (7). In contrast, low levels of physical fitness in children are associated with a number of risk factors such as hypertension, hyperlipidemia, and obesity (4). Among adults, a meta-analysis showed that the relative risk for cardiovascular disease was higher among those who were below the 25th percentile of the fitness distribution compared with those in higher percentiles (26). To prevent early development of cardiovascular risk factors in childhood, preventive strategies must incorporate age- and sex-specific physical-fitness levels for children.

Very limited data on physical-fitness levels are available for Greek children (11,14,24). Therefore, the aim of the present work was to evaluate the distribution of age- and sex- specific physical-fitness tests measurements in 7- to 10-year-old children and to fit equations that relate endurance, explosive power, and strength level with body mass index (BMI) and physical-fitness tests.

Methods and Procedures

Participants

Population-based data were derived from a national school-based health survey. Specifically, anthropometric (e.g., weight, height) and physical-fitness data along with information on age and sex were collected from children attending 2nd (7.0–7.9 years old) and 3rd (8.0–8.9 years old) class of primary education in almost all Greek schools (>85% of all schools). The schools that did not participate were from borderland areas with small numbers of children. Data from children attending 4th grade (9.0–9.9 years old) were derived from a representative sample of children attending elementary schools randomly selected from the whole country. Distribution between rural and urban areas was based on the Hellenic National Commitment criteria (21). A total of 141,169 children aged 7–10 years (51% boys and 49% girls) participated in the study (Table 1).

Study Approval

Ethical approval for the health survey was granted by the ethical review board of the Ministry of Education and the ethical committee of Harokopio University.

Fitness Tests

In each school, two trained physical-education professionals administered five fitness tests. Vertical jump (VJ; jump from a squatting position at the start) and standing long jump (SLJ; jump as far as possible from a standing position at the start) both assessed lower-body explosive power. Also administered were the small-ball throw (SBT; 1 kg with both hands in a standing position) to assess upper-body explosive strength, 30-m sprint (30mS; from a standing start) to evaluate speed, and the multistage 20-m shuttle run (20mSRT) to estimate maximal oxygen consumption (VO_{2max}) using the formulas proposed by Leger et al. (12,13). The 20mSRT test consists of measuring the number of laps completed by subjects running up and down between two lines, set 20 m apart, at an initial speed of 8.5 kph which increases by 0.5 kph every minute, using a prerecorded audio tape.

Table 1 Percentiles of Physical Performance for Fitness Tests by Sex and Age

			Boys					Girls				
Age (yr)	*n*	Centile	Sprint [30 m]	Shuttle run 20 m (stages)	Jump vertical (cm)	Throw small ball (m)	Standing long jump (cm)	Sprint [30 m]	Shuttle run 20m (stages)	Jump vertical (cm)	Throw small ball (m)	Standing long jump (cm)
8	33,130 boys	P10	7.3	1.1	15	3.0	67.6	7.69	1.1	13	2.5	64.7
	31,990 girls	P20	6.99	1.6	17	3.2	74.2	7.32	1.4	15	2.8	71.0
		P25	6.86	1.7	18	3.4	77.5	7.2	1.6	15	3.0	71.0
		P30	6.75	1.9	18	3.5	77.5	7.1	1.7	16	3.0	74.2
		P40	6.57	2.3	20	3.8	84.1	6.91	2.0	18	3.2	80.5
		P50	6.41	2.7	20	4.0	84.1	6.75	2.3	19	3.4	83.7
		P60	6.27	3.1	22	4.2	90.7	6.59	2.6	20	3.6	86.8
		P70	6.13	3.7	23	4.4	94.0	6.42	3.0	21	3.9	90.0
		P75	6.06	4.1	25	4.6	100.6	6.35	3.1	22	4.0	93.1
		P80	6.0	4.6	25	4.7	100.6	6.25	3.6	23	4.12	96.3
		P90	5.8	5.7	27	5.1	107.1	6.03	4.6	25	4.5	102.6
9	33,430 boys	P10	6.9	1.3	15	3.4	67.6	7.22	1.3	13	3.0	64.7
	31,875 girls	P20	6.62	1.7	18	3.9	76.8	6.93	1.7	15	3.3	71.0
		P25	6.51	2.0	18	4.0	77.5	6.81	1.9	16	3.4	74.2
		P30	6.41	2.3	20	4.1	84.1	6.72	2.0	17	3.6	77.4
		P40	6.26	2.9	20	4.3	84.1	6.56	2.3	19	3.8	83.7

		P50	6.14	3.3	22	4.6	90.7	6.41	2.7	20	4.0	86.8
		P60	6.0	3.9	23	4.9	94.0	6.28	3.0	21	4.2	90.0
		P70	5.9	4.6	25	5.1	100.6	6.14	3.6	22	4.5	93.1
		P75	5.81	4.9	25	5.2	100.6	6.07	3.7	23	4.6	96.3
		P80	5.75	5.3	26	5.4	103.8	5.99	4.1	25	4.8	102.6
		P90	5.54	6.4	29	5.9	113.7	5.79	5.1	26	5.3	105.8
10	5,526 boys 5,218 girls	P10	6.67	1.3	17	4.0	74.2	6.97	1.4	15	3.5	71.0
		P20	6.36	2.0	20	4.4	84.1	6.66	1.9	17	4.0	77.4
		P25	6.27	2.4	20	4.6	84.1	6.56	2.1	18	4.0	80.5
		P30	6.18	2.6	20	4.8	84.1	6.45	2.3	19	4.2	83.7
		P40	6.03	3.3	22	5.0	90.7	6.3	2.6	20	4.4	86.8
		P50	5.9	3.9	24	5.2	97.3	6.17	3.0	21	4.7	90.0
		P60	5.8	4.6	25	5.6	100.6	6.04	3.4	23	5.0	96.3
		P70	5.65	5.1	26	5.8	103.8	5.9	4.0	25	5.2	102.6
		P75	5.58	5.6	27	6.0	107.1	5.84	4.3	25	5.4	102.6
		P80	5.5	5.9	28	6.2	111.8	5.76	4.7	26	5.6	105.8
		P90	5.32	7.1	30	6.7	117.7	5.58	5.7	28	6.2	114.6

These five widely used fitness tests were selected as being representative of explosive, anaerobic, and aerobic performance. Repeat tests (2 trials) were allowed for the VJ, SLJ, SBT, and 30mS, with the best performance of each recorded.

Anthropometric Measurements

Each child's height and weight were measured in the morning without shoes, using a standardized procedure. Weight was measured with electronic scales with a precision of 100 g. Standing height was determined to the nearest 0.5 cm with the child's weight being equally distributed on the two feet, head back, and buttock on the vertical land of the height gauge. BMI was calculated as the ratio of body weight (in kg) to the square of height (in m, kg/m^2).

Data Analysis

Percentile values (10th, 20th, 25th, 30th, 40th, 50th, 60th, 70th, 75th, 80th, and 90th) by sex and age were calculated. Descriptive information on fitness-test performances are presented as means ± *SD*. The results of each fitness-test performance with quartiles by age and sex were also calculated. Children were classified as having a score in the lower–poor (1st), middle–good (2nd–3rd), and upper–excellent (4th) quartiles of the distribution. Children in the first quartile of the tests were classified as having poor performance. Comparisons of the physical-fitness-test performance data between boys and girls were performed using the independent samples *t* test, after testing for equality of variances using the Levene test. Comparisons of the categorical variables (i.e., sex and quartiles of performances) were performed using the Pearson's chi-square test.

Linear regression analysis was performed to examine the association of various potential predictors (i.e., age, sex, area, BMI, VJ, SBT, 30mS, and 20mSRT) of aerobic endurance, explosive power, and upper-body explosive strength. The results from the regression models are presented as B coefficients and standard error of the coefficient. Normality of the residuals was graphically assessed through P-P plots of standardized residuals. Colinearity was tested using the VIF criterion (values >4 indicate presence of colinearity and the variable excluded from the model). The assumptions of linearity for the continuous independent variables and constant variance of the standardized residuals were assessed through plotting the residuals against the fitted values. We also calculated the R^2 to find how well each fitted model predicts the dependent variables. To validate the estimated equations, the following procedure was applied: the total sample was randomly split to a training subsample of 80% of the entire cohort that was used to re-estimate the equations and the remaining 20%, which was used as the validation sample. Both training and validation samples had the same allocation of sex and age as the total sample. Based on the training sample, the regression equations were estimated and used to predict the sex-specific physical-performance outcomes. Based on these re-estimated equations, the sex-specific physical-performance outcomes of the validation sample were recalculated. The validation statistics included the calculation of the Pearson correlation coefficients *r*, the independent samples *t* test, and their 95% CI as well as the percent coefficient of variation (CV), between the measured and the predicted values of the validation sample. Statistical significance level from two-sided hypotheses was set at $p < .05$. All statistical analyses were performed using the SPSS version 18.0 software for Windows (SPSS Inc., Chicago, IL, USA).

Results

Table 1 presents the percentile for the five fitness-test performances by sex and age. For each of the fitness tests, performance was better in boys compared with girls ($p < .001$). Moreover, older boys and girls had better performances than younger ones ($p < .001$).

The correlation coefficients between BMI and performances were negative and significant ($p < .01$) in all physical-fitness tests for both sexes with the exception of a positive correlation between ball-throw test and BMI ($p < .01$; Table 2). The correlations between the various physical-fitness tests are also presented in Table 2. The highest correlation coefficients were observed between anaerobic speed (30mS) and all the other tests for both sexes (r varied between 0.42–0.46, all Ps < .001).

Table 2 Partial Correlation Coefficients Between Body Mass Index (BMI) and Physical Fitness Tests Performances by Sex, Adjusted for Age

	Shuttle run	Sprint 30 m	Vertical jump	Long jump	Ball throw
Boys					
BMI (kg/m²)	–.27	–.28	–.22	–.22	–.17
shuttle run (stages)		–.44	.34	.34	.27
sprint 30 m			–.46	–.46	–.42
vertical jump (cm)				1.0	.34
long jump (cm)					.34
ball throw (m)					
Girls					
BMI (kg/m²)	–.25	0.23	–.17	–.17	.18
shuttle run (stages)		–0.42	.31	.31	.28
sprint 30 m			–.42	–.42	–.42
vertical jump (cm)				1.0	.32
long jump (cm)					.32
ball throw (m)					

Note. All p-values <.0001

Taking all five fitness tests together, we calculated the proportion of children achieved the higher-excellent quartile in all fitness tests (Table 3). Only 2.9% and 4.0% of boys and girls, respectively, were classified in the upper quartile in all tests.

Table 4 presents linear regression models that evaluate factors associated with physical performance. In boys, the highest increase (11.5%, $p < .001$) in the ability of the model to explain aerobic endurance was observed when the speed test was added to age, BMI, and area of living; the corresponding increase for girls was 11.3%

Table 3 Percentiles of Children 8–10 Years Old with Excellent Performance (Upper Quartile) in Combination of Physical Fitness Tests by Sex

	Sprint 30 m	Shuttle run[a]	Vertical jump[a]	Long jump[a]	Ball throw[a]
Boys					
sprint 30 m	24.9	11.7	6.6	4.3	2.9
shuttle run (stages)		25.3	11.0	8.0	4.0
vertical jump (cm)			27.0	18.4	7.8
long jump (cm)				27.0	7.9
ball throw (m)					25.9
Girls					
sprint 30 m	25.0	11.8	6.7	5.6	4.0
shuttle run (stages)		26.5	11.3	11.3	5.8
vertical jump (cm)			27.7	27.6	11.5
long jump (cm)				27.7	11.5
ball throw (m)					27.6

[a] The percentiles have derived from the addition of the excellent performances in combination of two (e.g. sprint 30m and shuttle run), three (e.g. sprint 30 m and shuttle run and vertical jump), four (e.g. sprint 30 m and shuttle run and vertical jump and long jump), or five tests (e.g. sprint 30 m and shuttle run and vertical jump and long jump and ball throw).

($p < .001$). Regarding explosive power, the highest increase (13.5% and 12.1% for boys and girls, respectively $p < .001$) in the explanatory ability of the model was observed when the speed test was added to age, BMI, and area of living. Similarly, in the model for upper-body explosive strength, the highest increase (11% and 10% for boys and girls, respectively, $p < .001$) in the explanatory ability of the model was observed when the speed test was introduced in the model (Table 4). Moreover, as it can be seen from the validation analysis of the estimated regression equations (see Methods section), the majority of the equations presented high validity (i.e., moderate to good correlation coefficients, mean differences between the measured and the estimated performance test almost equal to zero, with 95%CI close to zero, and low, i.e., <10%, coefficients of variations).

Discussion

The aims of the current study were to establish sex- and age- specific physical-fitness normative values for Greek children aged 7–10 years old and to develop equations that model endurance, explosive power, and strength level in relation to BMI and physical-fitness tests. To the best of our knowledge, this is the first study to show that speed performance can be used as a predictive tool for performance in aerobic endurance and explosive power (upper and lower body) in large epidemiological studies of children. We provide evidence that the 30mS, a physical test easy to perform in a school setting, can be used to measure physical performance and monitor possible modifications to promote physical activity and a healthy lifestyle.

Sprint ability is considered as an important factor, which affects aerobic performance in many activities, e.g., team sports. These sports require many bursts of speed during the activity. Therefore, high sprinting ability gives the athlete an additional advantage. Moreover, it has been documented that sprint ability is strongly correlated with physiological variables related to aerobic fitness (e.g., minimum velocity needed to reach VO_{2max} and velocity at the onset of blood-lactate accumulation) therefore is considered as a crucial parameter for achieving high aerobic performance (6,23).

Low levels of physical fitness have been associated with many serious health problems. Low physical activity alone or in combination with obesity increases the risk of developing hypertension, diabetes, metabolic syndrome and cardiovascular disease (4,25). Furthermore, the detrimental effects of sedentary lifestyle to health are observed even in young children between the age of 6 and 9 years (1). The results from the aforementioned studies suggest that physical fitness may have an important cardio-protective role in children, while on the contrary, low physical levels have been associated with high cardio-metabolic risk in youth (2,5). However, only a very small percentage of children meet the criteria for being sufficiently physically active for their age.

Our data are in accordance with results from a previous, large epidemiological study from our laboratory, which indicated that only a very small percent of children were classified in the upper-excellent quartile of physical tests (22). These data also revealed a concomitant increase in overweight and obese children. This observed ongoing decrease in children's physical activity is considered a main reason for the epidemic of childhood obesity and also may partially explain why

Table 4 Equations Predict Physical Performance of Greek Children 7–10 Years Old and Validation Report.

			Results from the validation procedure between the measured and the calculated values in the validation sample		
Equations for Aerobic Endurance (Pal Stages)		R^2	*r*	*t* test (95%CI)	CV
Boys					
equation 1	10.30 + 0.24 × Age*–0.10 × BMI*+0.46×Area*–1.12×Speed*	.225	.47	0 (–.04, 0.04)	2%
equation 2	2.43 + 0.24 × Age*–0.20×BMI*+0.486 × Area*+0.54 × Ball*	.173	.41	0 (–.04, 0.04)	5%
equation 3	0.001 + 0.43 × Age*–0.13 × BMI* + 0.375 × Area* + 0.09 × Jump*	.172	.43	0 (–.05, 0.03)	2%
equation 4	1.37 + 0.58 × Age*–0.17 × BMI* + 0.50 × Area*	.110	.33	0 (–.04, 0.05)	5%
Girls					
equation 1	8.00 + 0.18 × Age*–0.08 × BMI* + 0.39 × Area*–0.80 × Speed*	.210	.46	0 (–.04, 0.03)	2%
equation 2	2.08 + 0.17 × Age*–0.14 × BMI* + 0.38 × Area* + 0.45 × Ball*	.162	.39	0 (–.04, 0.03)	3%
equation 3	0.12 + 0.34 × Age*–0.10 × BMI* + 0.36 × Area* + 0.07 × Jump*	.155	.39	0 (–.02, 0.05)	1%
equation 4	1.06 + 0.44 × Age*–0.12 × BMI* + 0.44 × Area*	.097	.29	0 (–.03, 0.04)	4%
Equations for Explosive Power (Vertical Jump in Cm)					
Boys					
equation 1	42.06 + 0.54 × Age*–0.19 × BMI* + 1.23 × Area*–3.43 × Speed*	.222	.47	0 (–.09, 0.13)	3%
equation 2	18.60 + 0.37 × Age*–0.49 × BMI* + 1.41 × Area* + 1.91 × Ball*	.188	.45	0 (–.08, 0.15)	1%
equation 3	13.70 + 1.16 × Age*–0.26 × BMI* + 1.01 × Area* + 0.74 × Aerobic*	.150	.41	0 (–.08, 0.15)	2%
equation 4	14.74 + 1.59 × Age*–0.39 × BMI* + 1.40 × Area*	.086	.31	0 (–.08, 0.16)	2%

Girls					
equation 1	37.49 + 0.43 × Age*–0.14 × BMI* + 0.92 × Area*–2.86 × Speed*	.181	.41	0 (–.08, 0.15)	2%
equation 2	16.95 + 0.26 × Age*–0.37 × BMI* + 0.99 × Area* + 1.82 × Ball*	.150	.39	0 (–.10, 0.12)	7%
equation 3	11.91 + 0.97 × Age*–0.17 × BMI* + 0.72 × Area* + 0.88 × Aerobic*	.121	.34	0 (–.08, 0.15)	2%
equation 4	12.83 + 1.39 × Age*–0.28 × BMI*+ 1.10 × Area*	.060	.23	0 (–.08, 0.16)	2%
Equations for Upper Body Explosive Strength (Small Ball Throw in m)					
Boys					
equation 1	2.81 + 0.44 × Age* + 0.08 × BMI*–0.01 × Area*–0.60 × Speed*	.367	.61	0 (–.02, 0.02)	3%
equation 2	–2.81 + 0.53 × Age* + 0.07 × BMI*–0.06 × Area* + 0.05 × Jump*	.340	.57	0 (–.02, 0.02)	3%
equation 3	–2.12 + 0.55 × Age* + 0.07 × BMI* + 0.13 × Aerobic*	.310	.56	0 (–.02, 0.02)	12%
equation 4	–1.99 + 0.63 × Age* + 0.05 × BMI*	.257	.51	0 (–.02, 0.02)	9%
Girls					
equation 1	2.04 + 0.43 × Age* + 0.07 × BMI* + 0.058 × Area*–0.49 × Speed*	.358	.59	0 (–.00, 0.04)	5%
equation 2	–2.906 + 0.53 × Age* + 0.66 × BMI* + 0.04 × Area* + 0.05 × Jump*	.338	.59	0 (–.01, 0.04)	6%
equation 3	–2.38 + 0.53 × Age* + 0.07 × BMI*–0.16 × Aerobic*	.313	.55	0 (–.00, 0.04)	5%
equation 4	–2.21 + 0.60 × Age* + 0.05 × BMI* + 0.09 × Area*	.258	.49	0 (–.00, 0.04)	9%

Note. Results from the equations' validation procedure include r = correlation coefficients, independent samples t test and 95% CIs between the measured (in a training random subsample of the 80% of the total sample) and the predicted by the equations values of the performance tests in the validation subsample (in the 20% of the total sample) and the CV = percent coefficient of variation of the validation sample. Speed: 30-m sprint test, ball: small ball throw, aerobic: shuttle run 20 m, jump: vertical jump, area: area of living (urban or rural)

*$p < .05$

Greece ranks among the countries with the highest prevalence of excess weight in children in Europe (9).

Moreover, there is a clear association between children's performance and BMI, also confirmed by other related studies (15,19,24). With the exception of the medicine-ball throw, in which high BMI resulted in better performance in upper-body explosive strength (presumably due to the confounding muscle and fat in BMI), in all remaining physical tests, BMI revealed a clear negative correlation with performance. Thus, it is obvious that excess weight is a disadvantageous parameter for performance, particularly for weight-bearing activities like running and jumping.

Strengths and Limitations of the Study

Our study has several strengths. The sample is representative of national gender and geographical representation as we studied almost all 7- to 10-year-old children in Greece. The study was performed in children 7–10 years; this is an advantageous age at which to apply effective prevention strategies for improving physical-fitness levels. Finally, the presented data are derived using the same standardized procedures in all schools.

There are also several limitations in our study design. Although a common, validated protocol was used to evaluate fitness tests in all schools, a large number of experienced, professional physical educators participated as evaluators in the study. To minimize the variability among the different experimenters, all educators received a 30-min lecture before every battery of tests, during which they received specific instructions. The selection of appropriate cut-off points for the fitness tests is another potential limitation. Although our choice for the quartile ranks in fitness tests is arbitrary, the National Children and Youth Fitness Study II suggested that test scores above the 25th percentile (the poor quartile) should be considered acceptable from a health perspective (18). Finally, the cross-sectional design of our study cannot provide causal relationships but only hypotheses for further research.

Conclusion

In conclusion, the presented population-based data for physical-fitness tests in almost all children aged 7–10 years attending school in Greece revealed that only a small percentage of children are classified as being in the upper quartiles in all tests. Furthermore, performance in the speed test can be used to predict physical fitness.

Disclosure

The authors declared no conflict of interest.

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