WEIGHT STATUS, BMI AND PHYSICAL FITNESS IN POLISH YOUTH: RELATIONSHIPS BETWEEN 1986 AND 2016

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Abstract

Background: One of the components affecting the level of health is physical fitness and diets, which is also considered the foundation of a healthy lifestyle. **Methods:** Samples by survey ranged from 871 to 1,417 (boys) and from 843 to 1,326 (girls). Speed (5 m run), agility (figure-8-run), explosive power (vertical jump), flexibility (stand and reach) and cardiovascular fitness (step test) were measured. The Body Mass Index (BMI) of each student was classified as Thin, Normal weight or Overweight/Obese (Owt/Ob) relative to International Obesity Task Force (IOTF) criteria. Fitness items were compared among weight status groups and across surveys with sex-specific analyses of covariance. Regressions of each fitness item on the BMI in the four surveys were done using linear and nonlinear quadratic models. **Results:** Performances on all fitness tests except flexibility were poorer among Owt/Ob compared to Normal and Thin youth, but performances on fitness tests within weight status groups did not differ consistently across surveys. **Conclusions:** Relationships between the BMI and fitness tests varied across surveys, but suggested reasonably consistent cur-vilinear relationships between fitness tests and the BMI among boys more so than girls.

***Keywords**: overweight; obesity; thinness; step test, speed; vertical jump*

Introduction

The lifestyle changes associated with diets of fast foods, reduced physical activity and increased sedentary behaviors (physical inactivity) are often indicated as major factors associated with the increasing prevalence of overweight and obesity among children and adolescents (Hu, 2011; Lobstein et al., 2004). Reduced habitual physical activity and increased sedentary time are also associated with declines in physical fitness, while overweight and obesity are specifically associated with reduced levels of fitness, especially items which require the projection or movement of the body as in jumps and runs (Arnaoutis et al., 2018; Chwałczyńska et al., 2017; Fairchild et al., 2016; Huang & Malina, 2007; Lopes et al., 2012). Reduced body mass reflected in a low Body Mass Index (BMI) may also negatively influence fitness, but studies addressing the relationship between thinness and fitness are relatively limited (Bovet et al., 2007; Xu et al., 2020).

Several studies have considered relationships between fitness across the total spectrum of the BMI among children and adolescence. Results generally suggest a curvilinear relationship; children and youth with a normal BMI tend to have better results in several fitness items compared to those with a low or high BMI (Huang & Malina, 2007, 2010; Kwieciński et al., 2018; Lopes et al., 2019; Zenić et al., 2013). Exceptions to the trends are tests of the flexed arm hang in which thin children and youth generally perform better (Artero et al., 2010; Monyeki et al., 2012), and some endurance items in which thin children and youth tended to perform at higher level (Xu et al., 2020).

In the context of the preceding, the purpose of the present study is twofold: first, to compare the fitness of Thin, Normal weight and Overweight/Obese youth

7-15 years of age across four surveys spanning 1986 through 2006, and second, to evaluate relationships between each fitness item and the BMI in the four surveys. A curvilinear relationship between the BMI and fitness test performances is hypothesized.

Methods

The growth status and physical fitness of children and adolescents attending schools in ten rural communities in the province of Poznań was evaluated in the 1985/1986 school year (Strzelczyk, 1995). The communities were selected in cooperation with the provincial Board of Education and Development in Poznań to represent different regions of the province. Population sizes varied between 4642 and 9850. School youth in the ten communities were surveyed again in 1996, 2006 and 2016. (Bartkowiak, Konarski, Strzelczyk, Janowski, Karpowicz, et al., 2021; Bartkowiak, Konarski, Strzelczyk, Janowski, & Malina, 2021) The communities were not involved in previous secular trend research in Poland.

Ethics.

The initial survey was approved by the provincial Board of Education and Development and educational authorities of each community, while subsequent surveys were approved by the Human Ethics Research Committee of the Karol Marcinkowski Medical University in Poznań (907/16 for 2016) and educational authorities of each community. Parents/legal guardians provided written informed consent, and the youth provided assent for their participation. The surveys were conducted by faculty and staff of the University of Physical Education in Poznań with the assistance of teachers at each school.

Sample.

Numbers of school youth 7-15 years across surveys were 1,417 boys and 1,326 girls in 1986, 979 boys and 947 girls in 1996, 871 boys and 843 girls in 2006, and 1,189 boys and 1,105 girls in 2016.

Weight Status.

Height (0.1 cm) and weight (0.1 kg) were measured during the school day in the gymnasium of each community (Bartkowiak et al., 2021a). The BMI (kg/m^2) was used to classify each student as severely, moderately or mildly thin, normal weight, overweight or obese using age- and sex-specific IOTF cut-offs (Cole et al., 2000, 2007). Numbers of severely and moderately thin and of obese youth were relatively limited (Bartkowiak et al., 2021c). The former were thus combined with mildly thin youth into a single group (Thin), while the latter were combined with overweight youth into a single group (Owt/Ob).

Fitness.

Five tests of physical fitness were administered in each survey. Details of the tests, each of which evaluated a specific component of fitness, have been previously described (Bartkowiak et al., 2021c). The tests were administered in the following order: speed - 5-meter run [m/s]; explosive power - vertical jump [cm]; flexibility - stand and reach with a forward bend [cm]; agility - figure-of-eight run [s]; and cardiovascular (CV) fitness – modified Harvard step test expressed as an index [pts].

Analysis.

To account for variable numbers of subjects by single year CA groups, boys and girls in each survey were respectively combined into three CA groups for analysis: (1) 7-9 years (6.50-9.49 years) - middle childhood in both sexes; (2) 10-12 years (9.50-12.49 years) - transition into puberty and mid-puberty (most girls) and transition into puberty (most boys); and (3) 13-15 years (12.50-15.49 years) - late adolescence (most girls) and the interval of the growth spurt (most boys). Sex-specific analyses were done in each CA group.

First, performances on each fitness test were compared among Thin, Normal weight and Owt/Ob youth within and among surveys using analysis of covariance (ANCOVA) with age and age^2 as covariates. The covariates adjust for potential linear and non-linear effects in CA distributions. Second, sex-specific regressions of each fitness test on the BMI were done by survey using linear and nonlinear quadratic models. The test was the dependent variable; the BMI was the independent variable in the linear model, while the BMI and BMI^2 were independent variables in the quadratic model. With the linear model,

$$\text{fitness item} = a + b*BMI;$$

and with the nonlinear quadratic model,

$$\text{fitness item} = a + b*BMI + c*BMI^2$$

where a (intercept), b (linear coefficient), and c (non-linear coefficient) are constants.

Results

Results of the ANCOVAs are summarized in Table 1. Fitness test performances differ significantly among the three weight status groups of boys and girls, with the exception of flexibility among boys 7-9 years and boys and girls 10-12 years. Performances also differ significantly among surveys except for CV fitness among boys 7-9 and 13-15 years and explosive power among girls 13-15 years. However, interactions between weight status and year of survey are not consistently different and show no clear pattern among fitness test in both sexes.

Table 1. Results (F values and eta^2 [η_p^2]) of sex and age group specific univariate analyses of covariance (age, age^2 as covariates) of the influence of weight status (thin, normal, owt/ob) and year (1986, 1996, 2006, 2016), and their interactions for each fitness test

	BOYS						GIRLS					
	Weight Status		Year		Wt St x Year		Weight Status		Year		Wt St x Year	
7-9 yrs	F	η_p^2	F	η_p^2	F	η_p^2	F	η_p^2	F	η_p^2	F	η_p^2
Speed	21.15***	0.03	75.50**	0.15	1.45	0.01	12.21***	0.02	122.01***	0.22	1.35	0.01
Agility	5.62**	0.01	7.71***	0.02	2.08*	0.01	3.64*	0.01	3.81**	0.01	1.34	0.01
Power†	18.87***	0.03	5.38**	0.01	0.27	0.00	10.81***	0.02	4.60**	0.01	3.27**	0.02
Flexibility	0.68	0.00	26.16***	0.06	2.34*	0.01	4.17**	0.01	18.38***	0.04	2.41*	0.01
CV Fitness	12.27***	0.02	0.03	0.00	1.75	0.01	8.03***	0.01	4.79**	0.01	2.27*	0.01
10-12 yrs												
Speed	58.63***	0.07	64.62***	0.10	0.66	0.00	38.73***	0.05	105.11***	0.17	2.40*	0.01
Agility	31.13***	0.04	7.56***	0.01	0.33	0.00	13.35***	0.02	9.66***	0.02	1.08	0.00
Power†	67.17***	0.07	13.46***	0.02	0.91	0.00	40.39***	0.05	6.57***	0.01	2.10*	0.01
Flexibility	0.20	0.00	29.98***	0.05	1.72	0.01	1.39	0.00	8.19***	0.02	1.28	0.01
CV Fitness	35.67***	0.04	4.18**	0.01	1.84	0.01	6.36**	0.01	3.96**	0.01	1.19	0.00
13-15 yrs												
Speed	32.95***	0.04	53.75***	0.10	0.49	0.00	31.35***	0.05	75.07***	0.15	0.95	0.00
Agility	36.23***	0.05	15.45***	0.03	2.72*	0.01	12.85***	0.02	3.77**	0.01	1.69	0.01
Power†	28.05***	0.04	14.59***	0.03	1.96	0.01	30.45***	0.05	0.73	0.00	0.57	0.00
Flexibility	13.29***	0.02	11.36***	0.02	1.32	0.01	7.96***	0.01	3.50*	0.01	1.05	0.01
CV Fitness	20.41***	0.03	0.38	0.00	0.53	0.00	7.39***	0.01	15.11***	0.03	2.71*	0.01

*$p \leq 0.05$, **$p \leq 0.01$, ***$p \leq 0.001$, † - Explosive Power

Age-adjusted means, standard errors, 95% confidence intervals and significant post-hoc comparisons between weight status groups within survey (year) and between surveys within weight status group for each fitness test by age group are summarized in Tables 2 (boys) and 3 (girls). Of note, a lower time in the agility test indicates a better performance, while higher scores in the other tests indicate better performances. Although not consistent for all comparisons, post hoc comparisons suggest poorer performances on all fitness tests except flexibility among Owt/Ob compared to Normal and Thin boys (Table 2). Comparisons of fitness performances within weight status groups across surveys, however, are variable except for speed. Running speed is generally similar between 1986 and 1996 and between 2006 and 2016, but is significantly better in 1986 and 1996 compared to 2006 and 2016. CV fitness is also better in the two younger age groups in 1986.

Corresponding post hoc comparisons among girls, indicate consistently poorer performances in explosive power among Owt/Ob girls 10-12 and 13-15 years, while performances of Thin and Normal girls do not consistently differ (Table 3). Running speed in girls shows a pattern that is similar to that in boys, i.e., similar performances 1986 and 1996 and in 2006 and 2016, but significantly better performances in 1986 and 1996 compared to 2006 and 2016. Performances on the other fitness tests within weight status groups are, as in boys, variable across surveys and show no consistent trends.
Results of the regression analyses are summarized in Tables 4 (boys) and 5 (girls).

Most of the regressions have a very low explained variance (R^2) and several are not significant. Relationships between the BMI and fitness performances also vary across the four surveys. Nevertheless, the quadratic coefficients are significant in some models, indicating that the association between the BMI and the specific fitness test is curvilinear. This suggests that better performances are generally attained by youth with BMIs in the mid-range of the distribution, while performances of those at the low and high tails of the BMI distribution are lower. This is apparent for relationships between the BMI and speed, agility and explosive power in the 1986 survey except among girls 7-9 years. On the other hand, a curvilinear relationship is suggested across the four surveys for all tests except CV fitness among boys 13-15 years. Though significant, the explained variances are low. Note, however, that the standardized regression coefficient should vary between -1 and 1, but values < -1 and > 1 may occur when there is collinearity between the independent variables. The latter often occurs when the model includes x and x^2. Overall, the hypothesis of a curvilinear association between the BMI and fitness test performances was partially supported.

Discussion

Comparison among weight status groups indicated, on average, poorer performances on all fitness tests except flexibility among Owt/Ob compared to Normal and Thin boys and girls. On the other hand, performances on the five fitness tests were generally similar within the samples of Thin, Normal weight and Owt/Ob youth across the four surveys. By inference, there were no consistent secular trends in fitness performances within weight status groups.
Results of the regression analyses were quite variable (Tables 4 and 5) and likely reflected the concentration of the sample within the normal weight range with proportionally fewer youth at the extremes of the BMI distributions. At the low end of the BMI range, the prevalence of severe and moderate thinness was very low across the four surveys in both boys and girls, while the prevalence of mild thinness was relatively low in all surveys except among boys and girls 7-9 years in 1986. On the other hand, the prevalence of overweight was higher in 2006 and 2016 compared to 1986 and 1996 among boys and girls in the three age groups, while the prevalence of obesity was low (Bartkowiak et al., 2021b). The relatively low prevalence at both extremes of the BMI distributions in the three age groups translated into a limited range of BMIs, which likely influenced the relationships between the BMI and each fitness test and in turn the quadratic regressions.

Nevertheless, results of the regression analyses in the present study were reasonably consistent with trends suggested in the literature. For example, results for the rural youth 13-15 years in 2006 and 2016 were generally consistent with a similar analysis of relationships between the BMI and fitness among school youth 13-15 years resident in an urban-rural administrative district about 110-120 km east-southeast of Poznań (Kwieciński et al., 2018). Although different fitness tests were used, the results were consistent in showing curvilinear relationships with the BMI for tests of speed (50 m dash, 5 m sprint), agility (shuttle run, figure-8-run), and explosive power (standing long jump, vertical jump) in both sexes. For flexibility (standing forward bend/reach), results were curvilinear in boys and linear in girls in both studies. In contrast, results varied for the tests of cardiovascular endurance, 1000 m (boys) and 800 m (girls) runs compared to the step test (present study).

A curvilinear relationship was noted for the vertical jump in the rural Polish school youth in the three age groups in 1996 and for the standing long jump in a 1997 national sample of Taiwan girls 9-10, 11-12 and 13-15 years and boys 11-12 and 13-15 years of age (Huang and Malina, 2010), the relationship was linear among Taiwan boys 9-10 years. For CV fitness, curvilinear relationships were noted for the 800 (girls) and 1600 (boys) meter run-walk in Taiwan youth and for the step test in Polish youth 13-15 years. Linear relationships in both studies were noted for the 800 meter run-walk in Taiwan youth 9-10 years and for the step test in Polish youth 7-9 years, while results were variable among Taiwan youth 11-12 years and Polish youth 10-12 years. On the other hand, results in the two studies varied for flexibility, curvilinear for the sit and reach for Taiwan boys and girls, but variable for the stand and reach in Polish youth.

Table 2. Age-adjusted means (M) and standard errors (SE) based on age-group specific ANCOVAs (age, age2 as covariates) and significant post hoc comparisons (SPHC, p<0.05) between weight status groups within survey (right column) and between surveys within weight status group (horizontal) for each fitness test among BOYS.

Speed – 5 m dash (m/s)

		Thin (T)			Normal (N)			Owt/Ob (O)			
Age Group	Year	M	SE	95% CI	M	SE	95% CI	M	SE	95% CI	SPHC
7-9 yrs	1986	4.0	0.3	3.97-4.09	4.1	0.2	4.10-4.17	3.9	0.5	3.83-4.01	N>T=O
	1996	3.9	0.7	3.73-3.99	3.9	0.2	3.90-3.97	3.8	0.5	3.75-3.94	
	2006	3.6	0.9	3.46-3.81	3.7	0.2	3.65-3.74	3.6	0.4	3.50-3.65	
	2016	3.7	0.4	3.65-3.82	3.7	0.2	3.67-3.74	3.5	0.3	3.49-3.60	T=N>O
	SPHC	86>06=16			86>96>06=16			86=96>06=16			
10-12 yrs	1986	4.4	0.4	4.31-4.47	4.4	0.1	4.38-4.44	4.2	0.4	4.08-4.23	T=N>O
	1996	4.3	0.5	4.18-4.35	4.2	0.2	4.19-4.26	4.0	0.4	3.94-4.10	T=N>O
	2006	4.1	0.5	3.95-4.15	4.0	0.2	4.01-4.08	3.8	0.3	3.78-3.90	T=N>O
	2016	4.1	0.5	3.98-4.18	4.0	0.2	4.01-4.08	3.9	0.3	3.83-3.93	T=N>O
	SPHC	86>06=16			86>96>06=16			86>06=16			
13-15 yrs	1986	4.7	0.5	4.59-4.77	4.7	0.2	4.72-4.78	4.6	0.5	4.47-4.65	N>O
	1996	4.4	0.5	4.33-4.53	4.5	0.2	4.41-4.53	4.2	0.5	4.15-4.34	N>O
	2006	4.2	0.6	4.12-4.36	4.4	0.2	4.34-4.42	4.2	0.4	4.13-4.31	N>O
	2016	4.3	0.6	4.22-4.44	4.4	0.2	4.38-4.45	4.2	0.3	4.15-4.28	N>O
	SPHC	86>06=16			86>96=06=16			86>96=06=16			

Agility – figure-of-eight run (s)†

		Thin (T)			Normal (N)			Owt/Ob (O)			
Age Group	Year	M	SE	95% CI	M	SE	95% CI	M	SE	95% CI	SPHC
7-9 yrs	1986	18.7	0.2	18.3-19.2	18.0	0.1	17.8-18.2	18.5	0.3	17.9-19.1	N>O=T
	1996	18.4	0.4	17.5-19.3	17.7	0.1	17.4-17.9	18.3	0.3	17.7-19.0	
	2006	16.8	0.6	15.7-17.9	17.5	0.1	17.2-17.8	17.7	0.3	17.3-18.2	
	2016	17.4	0.3	16.8-17.9	17.7	0.1	17.5-17.9	18.3	0.2	18.0-18.7	T=N>O
	SPHC	06=16>86									
10-12 yrs	1986	16.3	0.2	15.9-16.7	16.4	0.7	16.3-16.5	17.1	0.2	16.7-19.1	T=N>O
	1996	16.0	0.2	15.5-16.4	15.8	0.8	15.6-16.0	16.5	0.2	16.1-16.9	N>O
	2006	16.0	0.3	15.5-16.5	15.9	0.9	15.7-16.1	16.8	0.2	16.5-17.1	N=T>O
	2016	15.6	0.3	15.1-16.1	15.8	0.9	15.6-16.0	16.6	0.1	16.3-16.8	T=N>O
	SPHC	86>96=06=16									
13-15 yrs	1986	15.4	0.2	15.1-15.8	15.6	0.1	15.5-15.7	16.2	0.2	15.8-16.6	T=N>O
	1996	15.1	0.2	14.7-15.5	15.0	0.1	14.9-15.2	15.6	0.2	15.2-15.9	N>O
	2006	14.4	0.2	13.9-14.8	14.7	0.1	14.5-14.8	15.7	0.2	15.4-16.1	T=N>O
	2016	15.2	0.2	14.8-15.6	14.5	0.1	14.4-14.7	15.4	0.1	15.2-15.7	N>T=O
	SPHC	86>06			86>96>06=16			86>16			

Explosive Power – vertical jump (cm)

		Thin (T)			Normal (N)			Owt/Ob (O)			
Age Group	Year	M	SE	95% CI	M	SE	95% CI	M	SE	95% CI	SPHC
7-9 yrs	1986	20.2	0.5	19.2-21.2	21.1	0.3	20.6-21.6	19.2	0.8	17.7-20.7	
	1996	20.4	1.1	18.2-22.5	22.5	0.3	21.9-23.1	20.4	0.8	18.8-21.9	

	2006	22.1	1.4	19.3-25.0	24.0	0.4	23.2-24.7	21.8	0.6	20.5-23.0	
	N>O										
	2016	21.5	0.7	20.1-22.9	22.3	0.3	21.8-22.9	20.0	0.5	19.1-20.9	
	SPHC		06>96=16=86								
10-12 yrs	1986	27.6	0.7	26.2-29.1	26.8	0.3	26.3-27.3	22.2	0.7	20.8-23.6	
	T=N>O										
	1996	28.9	0.8	27.3-30.5	29.0	0.3	28.4-29.6	25.0	0.8	23.5-26.5	
	N=N>O										
	2006	30.1	0.9	28.3-31.9	29.5	0.3	28.9-30.2	26.2	0.6	25.1-27.3	
	T=N>O										
	2016	30.7	0.9	28.9-32.6	28.3	0.3	27.6-28.9	24.6	0.5	23.6-25.5	
	T=N>O										
	SPHC		86<96=06	86<06							
13-15 yrs	1986	35.0	1.0	33.0-37.0	35.9	0.4	35.2-36.6	31.5	1.1	29.5-33.6	
	N>O										
	1996	35.3	1.1	33.1-37.6	37.6	0.4	36.7-38.4	34.4	1.0	32.4-36.4	
	N>O										
	2006	38.2	1.4	35.5-40.9	40.5	0.5	39.5-41.4	39.0	1.0	37.0-40.9	
	2016	35.3	1.3	32.8-37.7	39.1	0.4	38.2-39.9	33.6	0.7	32.2-35.0	
	N>T=O										
	SPHC		86<96<06=16		86=96<06						

Flexibility – forward bend (cm)

	Thin (T)	Normal (N)	Owt/Ob (O)								
Age Group	Year	M	SE	95% CI	M	SE	95% CI	M	SE	95% CI	SPHC
7-9 yrs	1986	50.7	0.6	49.5-51.9	51.1	0.3	50.5-51.7	52.3	0.9	50.5-54.1	
	1996	48.5	1.3	45.9-51.1	48.8	0.4	48.1-49.5	49.3	1.0	47.4-51.2	
	2006	47.8	1.8	44.4-51.3	47.0	0.4	46.1-47.9	49.0	0.8	47.5-50.5	
	2016	47.1	0.9	45.4-48.8	47.4	0.4	46.7-48.1	45.7	0.6	44.6-46.8	
	SPHC	86>16	86>96=16=06		86>16						
10-12 yrs	1986	50.9	0.9	49.1-52.6	51.5	0.3	50.9-52.1	53.0	0.9	51.3-54.7	
	1996	49.7	1.0	47.7-51.6	49.8	0.4	49.1-50.5	50.1	0.9	48.2-51.9	
	2006	48.3	1.1	46.1-50.5	48.2	0.4	47.4-48.9	46.3	0.7	45.0-47.6	
	2016	45.9	1.1	43.7-48.1	46.4	0.4	45.6-47.1	47.0	0.6	45.9-48.2	
	SPHC	86>16	86>96>06>16		86=96>06=16						
13-15 yrs	1986	52.3	1.1	20.2-54.4	53.4	0.4	52.7-54.1	53.0	1.1	50.9-55.2	
	1996	49.6	1.2	47.2-51.9	52.5	0.4	51.6-53.4	53.3	1.1	51.2-55.4	
	2006	46.5	1.4	43.7-49.3	52.0	0.5	51.0-52.9	51.6	1.0	49.6-53.6	
	N=O>T										
	2016	46.6	1.3	44.0-49.1	50.6	0.4	49.8-51.5	49.5	0.7	48.0-50.9	
	N>T										
	SPHC	86>06	86>16								

CV Fitness - step test index

	Thin (T)	Normal (N)	Owt/Ob (O)								
Age Group	Year	M	SE	95% CI	M	SE	95% CI	M	SE	95% CI	SPHC
7-9 yrs	1986	53.2	0.9	51.4-54.9	51.7	0.4	50.8-52.6	46.3	1.3	43.7-49.0	
	T=N>O										
	1996	53.1	1.9	49.3-56.8	49.5	0.5	48.5-50.6	47.8	1.4	45.0-50.5	
	2006	51.5	2.5	46.6-56.5	51.1	0.6	49.8-52.3	48.3	1.1	46.2-50.5	
	2016	49.9	1.2	47.5-52.4	51.5	0.5	50.5-52.5	49.3	0.8	47.7-50.8	
	SPHC		86>96								
10-12 yrs	1986	54.9	1.1	52.5-57.0	52.5	0.4	51.8-53.3	46.1	1.1	43.9-48.3	
	T=N>O										
	1996	49.4	1.3	46.9-51.9	50.8	0.5	49.8-51.7	45.7	1.2	43.3-48.0	
	N>O										
	2006	50.6	1.4	47.8-53.4	49.7	0.5	48.7-50.7	47.1	0.9	45.4-48.8	
	2016	52.3	1.5	49.4-52.4	51.7	0.5	50.7-52.7	47.7	0.8	46.2-49.2	
	T=N>O										
	SPHC	86>96	86>06								

13-15 yrs	1986 T=N>O	52.4	1.3	49.8-55.1	50.8	0.5	49.9-51.7	45.5	1.4	42.8-48.3
	1996 T=N>O	52.6	1.5	49.6-55.5	52.0	0.6	50.9-53.2	46.9	1.4	44.3-49.6
	2006	51.6	1.8	48.0-55.1	50.2	0.6	49.0-51.4	48.0	1.3	45.5-50.5
	2016 N>O SPHC	52.4	1.7	49.1-55.6	51.2	0.6	50.2-52.3	47.3	0.9	45.5-49.1

†a lower time in the agility test indicates a better performance

Table 4. Results of the regressions by year of each test (dependent variable) on the BMI (independent variable) with two models: linear (fitness = a + b * BMI) and nonlinear quadratic (fitness = a + b * BMI + c * BMI^2), where a, b and c are constants: BOYS

		Linear Model				Quadratic Model				
Age	Year	R^2	a	b	F	R^2	a	b	c	F
Speed - 5 m dash (m/sec)										
7-9	1986	0.00	4.15	-0.02		0.05	1.63	2.25**	-2.28**	**
	1996	0.00	4.03	-0.05		0.03	2.01	1.28*	-1.63*	*
	2006	0.02	3.85	-0.13		0.03	3.04	0.91	-1.05	
	2016	0.03	4.01	-0.18		0.04	3.41	0.39	-0.57	*
10-12	1986	0.02	4.69	-0.15**	**	0.06	2.45	1.93**	-2.00**	**
	1996	0.05	4.63	-0.22**	**	0.05	4.41	-0.02	-0.21	**
	2006	0.05	4.41	-0.23**	**	0.05	4.46	-0.27	0.05	**
	2016	0.04	4.37	-0.20**	**	0.05	3.63	0.55	-0.75	**
13-15	1986	0.00	4.70	0.01		0.07	1.76	2.53**	-2.54**	**
	1996	0.01	4.68	-0.11*	*	0.06	2.13	1.88**	-1.99**	**
	2006	0.00	4.40	-0.03		0.09	1.76	2.44**	-2.48**	**
	2016	0.02	4.66	-0.15**	**	0.04	3.34	1.15**	-1.30**	**
Agility - figure-of-eight run (sec)†										
7-9	1986	0.01	19.46	-0.08		0.04	33.67	-1.81**	1.74**	**
	1996	0.00	17.61	0.02		0.01	24.81	-0.99	1.02	
	2006	0.00	17.18	0.03		0.00	17.71	-0.07	0.10	
	2016	0.16	16.40	0.13*		0.03	23.13	-0.93*	1.07*	
10-12	1986	0.01	15.68	0.07		0.02	23.36	-1.27**	1.35**	**
	1996	0.03	14.60	0.17**	**	0.04	16.80	-0.36	0.54	**
	2006	0.06	13.92	0.24**	**	0.08	20.08	-1.03*	1.28**	**
	2016	0.05	14.07	0.21**	**	0.05	16.24	-0.25	0.47	**
13-15	1986	0.01	14.52	0.12	**	0.02	18.69	-0.72	0.85	**
	1996	0.01	14.36	0.12*	*	0.07	21.96	-2.11**	2.24**	**
	2006	0.07	12.67	0.26**	**	0.09	18.84	-1.15*	1.42**	**
	2016	0.03	13.44	0.18**	**	0.04	17.36	-0.82	0.99*	**
Explosive Power - vertical jump (cm)										
7-9	1986	0.00	21.76	-0.02		0.03	-9.97	1.63**	-1.67**	**
	1996	0.00	22.04	0.00		0.01	0.44	1.15	-1.15	
	2006	0.01	26.77	-0.11		0.03	5.40	1.19	-1.30	
	2016	0.01	24.29	-0.10		0.03	3.22	1.32**	-1.42**	*
10-12	1986	0.01	30.19	-0.09*	*	0.03	-3.99	1.45**	-1.55**	**
	1996	0.05	35.77	-0.23**	**	0.07	22.19	0.55	-0.78*	**
	2006	0.05	36.24	-0.23**	**	0.05	29.90	0.14	-0.38	**
	2016	0.09	37.60	-0.29**	**	0.09	40.06	-0.43	0.14	**
13-15	1986	0.00	34.85	0.01		0.08	-42.11	2.74**	-2.75**	**
	1996	0.00	38.93	-0.05		0.07	-19.07	2.31**	-2.38**	**
	2006	0.00	37.27	0.06		0.06	-14.67	2.02**	-1.97**	**
	2016	0.01	43.12	-0.11*	*	0.07	-5.97	1.91**	-2.03**	**
Flexibility - forward bend (cm)										
7-9	1986	0.05	48.31	0.07		0.09	35.20	0.69	-0.63	
	1996	0.00	47.30	0.04		0.00	42.99	0.23	-0.20	
	2006	0.03	42.38	0.16*		0.03	32.80	0.70	-0.54	
	2016	0.04	49.13	-0.07	*	0.01	63.18	-0.84	0.78*	
10-12	1986	0.03	44.51	0.16**	**	0.03	29.43	0.80	-0.65**	
	1996	0.00	47.89	0.05		0.01	36.10	0.64	-0.59	
	2006	0.00	50.21	-0.06		0.01	41.69	0.35	-0.41	
	2016	0.00	44.74	0.05		0.00	47.14	-0.08	0.13	
13-15	1986	0.00	49.93	0.06		0.02	21.86	1.15*	-1.10*	*
	1996	0.02	45.97	0.14*	*	0.04	13.09	1.54**	-1.41**	**
	2006	0.03	43.47	0.17**	**	0.10	-11.39	2.36**	2.20**	**
	2016	0.01	44.99	0.12*	*	0.04	9.61	1.57**	-1.46**	**
CV Fitness (step test index)										
7-9	1986	0.04	63.64	-0.19**	**	0.04	16.80	0.19	-0.38	**
	1996	0.02	57.37	-0.14		0.02	54.98	-0.06	-0.08	

	2006	0.29	57.79	-0.17*		0.03	61.89	-0.34	0.18	
	2016	0.01	55.34	-0.10	*	0.02	36.90	0.65	-0.75	*
10-12	1986	0.09	70.99	-0.31**	**	0.10	57.54	0.11	-0.42	**
	1996	0.04	59.18	-0.19**	**	0.04	47.16	0.26	-0.46	**
	2006	0.04	56.80	-0.19	**	0.04	54.39	-0.07	-0.11	**
	2016	0.05	62.00	-0.21**	**	0.05	53.12	0.11	-0.32	**
13-15	1986	0.05	64.51	-0.22**	**	0.05	48.59	0.25	-0.48	**
	1996	0.04	62.59	-0.19**	**	0.04	51.51	0.16	-0.35	**
	2006	0.03	58.22	-0.16**	**	0.03	46.25	0.29	-0.46	*
	2016	0.02	58.99	-0.15**	**	0.02	45.95	0.28	-0.42	**

†For the agility test, a lower time indicates better fitness.
*p<0.05, **p<0.01

Table 5. Results of the regressions by year of each test (dependent variable) on the BMI (independent variable) with two models: linear (fitness = a + b * BMI) and nonlinear quadratic (fitness = a + b * BMI + c * BMI^2), where a, b and c are constants: GIRLS

		Linear Model				Quadratic Model				
Age		R^2	a	b	F	R^2	a	b	c	F
Speed - 5 m dash (m/sec)										
7-9	1986	0.02	4.20	-0.15**	**	0.03	0.09	-0.25	-0.25	**
	1996	0.02	4.15	-0.13*	*	0.02	3.55	0.32	-0.46	
	2006	0.00	3.6	-0.70		0.06	1.38	2.36**	2.44**	**
	2016	0.01	3.66	-0.12	*	0.16	3.50	0.05	-0.18	*
10-12	1986	0.02	4.46	-0.13**	**	0.04	3.04	1.44**	-1.57	
	1996	0.06	4.54	-0.24**	**	0.06	3.83	0.50	-0.75	**
	2006	0.00	3.85	-0.01		0.00	3.42	0.47	-0.49	
	2016	0.04	4.15	-0.19**	**	0.04	3.89	0.11	-0.30	**
13-15	1986	0.02	4.72	-0.15**	**	0.06	3.18	1.45**	-1.62	**
	1996	0.04	4.62	-0.20**	**	0.04	4.12	0.28	-0.49	**
	2006	0.03	4.28	-0.16**	**	0.03	4.39	-0.29	0.14	*
	2016	0.05	4.49	-0.23**	**	0.06	3.74	0.51	-0.75	**
Agility - figure-of-eight run (sec)†										
7-9	1986	0.00	18.54	-0.02		0.00	19.09	-0.04	-0.069	
	1996	0.00	17.85	0.03		0.01	24.05	-0.93	0.96	
	2006	0.00	17.39	0.07		0.01	23.31	-0.90	0.97	
	2016	0.00	18.08	0.05		0.00	18.33	0.00	0.05	
10-12	1986	0.00	16.63	0.08		0.01	21.74	-0.83	0.88*	
	1996	0.02	15.42	0.14**	**	0.03	18.89	-0.66	0.81	**
	2006	0.00	16.97	-0.01		0.00	18.47	-0.31	0.31	
	2016	0.01	16.08	0.12*	*	0.01	16.58	0.02	0.10	
13-15	1986	0.01	15.77	0.11*	*	0.03	21.26	-1.03*	1.14**	**
	1996	0.01	15.41	0.10		0.20	18.99	-0.68	0.79	*
	2006	0.02	14.99	0.15*	*	0.02	16.14	-0.10	0.25	*
	2016	0.03	14.80	0.17**	**	0.06	22.84	-1.48**	1.67**	**
Explosive Power - vertical jump (cm)										
7-9	1986	-0.01	22.69	0.09		0.00	19.09	-0.04	-0.07	*
	1996	0.02	26.09	-0.14*	*	0.03	8.55	0.81	-0.96	*
	2006	0.00	21.20	0.01		0.00	21.39	0.00	0.01	
	2016	-0.02	23.93	-0.14**	**	0.02	23.28	-0.89	-0.05	*
10-12	1986	0.00	28.10	-0.07		0.03	0.55	1.44**	1.53**	**
	1996	0.04	34.03	-0.20**	**	0.05	16.03	0.80	-1.01*	
	2006	0.02	30.24	-0.14	**	0.02	33.84	-0.37	0.23	*
	2016	0.04	32.09	-0.19**	**	0.04	26.21	0.17	-0.37	**
13-15	1986	0.04	39.05	-0.19**	**	0.05	18.06	0.85*	-1.05*	**
	1996	0.02	36.41	-0.13**	*	0.05	5.82	1.38**	-1.52**	**
	2006	0.03	38.16	-0.17	**	0.04	23.89	0.56	-0.74	**
	2016	0.08	42.33	-0.28**	**	0.09	20.76	0.83	-1.11	**
Flexibility - forward bend (cm)										
7-9	1986	0.01	47.26	0.12*	*	0.02	37.92	0.54	-0.42*	
	1996	0.14	45.00	0.12		0.01	42.51	0.23	-0.11	
	2006	0.00	50.44	-0.06		0.01	66.21	-0.76	0.71	
	2016	0.00	48.95	0.03		0.00	43.36	0.34	-0.31	
10-12	1986	0.01	48.58	0.11**	**	0.01	40.50	0.49	-0.39	**
	1996	0.00	50.57	0.04		0.01	30.81	1.04*	-1.01*	**
	2006	0.00	49.96	0.01		0.00	50.09	0.00	0.01	
	2016	0.01	48.08	0.08		0.01	55.19	-0.28	0.39	
13-15	1986	0.02	50.19	0.15**	**	0.03	27.91	1.14**	-1.00*	**
	1996	0.06	44.63	0.25**	**	0.06	34.11	0.74	-0.50	**
	2006	0.03	47.69	0.17**	**	0.03	45.40	0.28	-0.12	*
	2016	0.01	50.58	0.09		0.10	43.27	0.38	-0.29	

CV Fitness (step test index)										
7-9	1986	0.00	50.23	-0.05		0.02	24.72	0.77*	-0.83**	*
	1996	0.01	52.18	-0.11		0.01	48.89	0.01	-0.12	
	2006	0.24	56.44	-0.16*	*	0.03	50.06	0.09	-0.26	
	2016	0.07	57.72	-0.27**	**	0.08	63.12	-0.06	0.28	**
10-12	1986	0.03	53.55	-0.17	**	0.03	39.87	0.36	-0.54	**
	1996	0.03	51.50	-0.16**	**	0.03	45.89	0.09	-0.25	**
	2006	0.00	46.56	0.00		0.00	37.77	0.39	-0.39	
	2016	0.01	49.36	-0.09		0.02	35.83	0.58	-0.37	*
13-15	1986	0.05	49.74	-0.23**	**	0.06	32.88	0.65	-0.89*	**
	1996	0.01	47.78	-0.09		0.01	36.29	0.42	-0.52	
	2006	0.00	45.70	-0.03		0.00	43.08	0.10	-0.14	
	2016	0.00	45.43	-0.05		0.00	39.58	0.22	-0.26	

†For the agility test, a lower time indicates better fitness.
*p<0.05, **p<0.001

In contrast, results for Polish youth in 2016 and Brazilian youth in 2013 (Lopes et al., 2019) were variable. Among Brazilian youth of both sexes, the relationship between the standing long jump and BMI was curvilinear among youth of both sexes 10-11 and 12-13, but was curvilinear among boys and linear among girls 14-15 years. Among Polish youth, the relationship between the vertical jump and BMI was linear at 10-12 years but curvilinear at 13-15 years in both sexes. For cardiovascular fitness, the relationship was linear between the BMI and multi-stage shuttle run in Brazilian girls 10-11, 12-13 and 14-15 years, but that between the BMI and step test in Polish was curvilinear among girls 10-12 years, but linear among girls 13-15 years.

The present study is not without limitations. An indicator of the biological maturity status of the youth was not available. Maturity status influences body size and also performances on tests of strength, speed and power. Individual differences in the timing of the growth spurts in height and weight are a potential confounder. The spurt occurs, on average, earlier in height than in weight in both sexes, and the respective spurts occur, on average, earlier in girls than in boys (Malina et al., 2004). The differential timing of the growth spurts can influence the BMI per se and also relationships between the BMI and tests of fitness during the transition into and through adolescence.

Conclusion

Relationships between the BMI and five tests of physical fitness were considered in rural Polish youth in four decennial surveys spanning 1986 through 2016. Performances on the tests differed significantly among weight status groups of boys and girls, with the exception of flexibility among boys 7-9 years and boys and girls 10-12 years. Although performances differed significantly among surveys except for cardiovascular fitness among boys 7-9 and 13-15 years and power among girls 13-15 years, the interactions between weight status and year of survey, however, did not consistently differ. Results of the sex-specific regressions of each fitness test on the BMI varied among age groups and across surveys due likely to the concentrations of youth within the normal weight range and proportionally fewer youth at both extremes of the BMI. The results, however, did suggest reasonably consistent curvilinear relationships between performances and the BMI in boys more so than in girls, but the explained variances were generally low. The hypothesis of a curvilinear association between the BMI and fitness test performances was thus partially supported.

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