THE EFFECT OF BODY BUILD AND BMI ON AEROBIC TEST PERFORMANCE IN SCHOOL CHILDREN (10-15 YEARS)

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ABSTRACT

Body Mass Index (BMI) has often questionably been used to define body build. In the present study body build was defined more specifically using fat free mass index (FFMI = fat free mass normalised to the stature) and fat mass index (FMI = fat mass normalised to stature). The body build of an individual is 'solid' in individuals with a high FFMI for their FMI and is 'slender' in individuals with a low FFMI relative to their FMI. The aim of the present study was to investigate the association between aerobic test performance and body build defined as solid, average or slender in 10 to 15 year old children. Five-hundred-and-two children (53% boys) aged 10 to 15 years of age were included in the study. Aerobic test performance was estimated with an incremental cycle ergometer protocol and a shuttle run test. BMI and percentage fat (by skin folds) were determined to calculate FMI and FFMI. After adjustment for differences in age, gender and body mass the solid group achieved a significantly higher maximal power output (W) and power output relative to body mass (W/kg) during the cycle test ($p<0.05$) and a higher shuttle-run score ($p<0.05$) compared to the slender group. The power output relative to FFM (W/kg FFM) was comparable ($p>0.05$) between different body build groups. This study showed that body build is an important determinant of the aerobic test performance. In contrast, there were no differences in aerobic test performance per kilogramme FFM over the body build groups. This suggests that the body build may be determined by genetic predisposition.

KEY WORDS: Shuttle run test, cycle test, BMI, percentage fat, solid body build, slender body build.

INTRODUCTION

Data from several recent studies indicate a progressive decrease in physical activity and a parallel decrease in aerobic performance in children and adolescents (Brownson et al., 2005; Hirasing et al., 2001; Irving et al., 2003; Rump et al., 2002). Besides, the body fat content and the prevalence of obesity in children has increased (Hirasing et al., 2001). For this reason, the interest in studies aimed at the association between aerobic capacity and body composition in children has increased (Eisenmann, 2004). Westerstahl (2003), for example, who stated that the aerobic fitness in adolescents was decreased in Sweden between 1974 and 1995 (Westerstahl et al., 2003), suggests that this change was partly due to the increased BMI. Goran (2000) specifies this statement by suggesting that the major influence of body mass on VO2max is explained by the fat free mass (FFM). Fatness and excess body mass do not necessarily imply a reduced ability to maximally consume oxygen (Goran et al., 2000). Hattori (1997) also states that the amount of body fat does not influence the aerobic capacity (Hattori, 1997). In

contrast, others suggest that body fat itself is associated with VO2max. (Eliakim et al., 1997; Mota et al., 2002; Watanabe et al., 1994). Overall, the results of these studies are inconsistent.

The methods which are generally accepted to express body composition in both adults and children in these studies are the body-mass-index (BMI) and the percentage fat. The BMI, however, is a crude measure (Cole et al., 2000). Although BMI is a general measure of body mass standardised for stature, it fails to account for differences in the two main components of body mass; fat mass (FM) and FFM. This implies that a high BMI can be caused either by a high FM or by a high FFM. Besides BMI, the percentage of fat is frequently used as an additional measure for body composition. Hence, percentage of fat itself ignores subject variation in FFM, thus individuals may differ in percentage fat either by an identical fat-free mass but different FM, or by an identical FM but different fat-free mass (Wells, 2001). Thus, both BMI as well as percentage fat may yield a distorted representation of body composition. To overcome this problem, the variables fat free mass index (FFMI) and the fat mass index (FMI) have been introduced (VanItallie et al., 1990; Wells and Cole, 2002; Freedman et al., 2005). The FFMI is the FFM normalised to stature, whereas the FMI is the FM normalised to stature (VanItallie et al., 1990). In order to combine both measures, Hattori et al (1997) combined FMI and FFMI in a statistical chart with the FFMI on the x-axis and the FMI on the y-axis (Hattori, 1997). In addition, previously we have transformed the chart in a regression model in which the FFMI could be predicted from the FMI (Van Etten et al., 1994). Based on the proportion of the FFMI and FMI, the body build of the individuals can be described as 'solid' in individuals with a high FFMI for their FMI and 'slender' in individuals with a low FFMI for their FMI (Van Etten et al., 1994). The description of body build based on the combination of FFMI and FMI is a more advanced and integrated way to describe the body build than by only BMI and/or percentage fat. Although, there are some more sophisticated measures to investigate body build, like Magnetic Resonance Imaging (MRI) or Dual Energy X-ray Absorptiometry (DEXA), it is not feasible to use these measures in large population based studies.

Because studies on body build are lacking and because some type of selection was introduced in most previous studies, in the present study the impact of body build on aerobic test performance was investigated in a representative cross sectional study population of school children. The aim of this study was to investigate the association between aerobic test performance measured by the maximal power output and the shuttle-run test and body build defined as solid, average or slender in 10 to 15 year old children. The absolute exercise capacity and the capacity normalized for body mass and FFM were evaluated.

METHODS

Subjects

Five-hundred-and-two school children (268 boys and 234 girls) aged between 10 and 15 years from primary and secondary schools in the province of Limburg, the Netherlands were included in the study. For the analyses the group was divided into six subgroups, based on age (10-11, 12-13, 14-15) and sex. Data have been collected between 2001 and 2005. Data used for this study were collected within the framework of the physical education classes. Within this framework selection bias is reduced, because all children in a class participate.

All children and their parents were fully informed about the nature and purpose of the study. They had the opportunity to inform the investigator of relevant health problems. Both had, according to the medical ethics committee legal procedures, the right to withdraw from the study at any time.

Anthropometry

To calculate the BMI, stature and body mass (BM) were determined bare footed in light clothes. Although there are more sophisticated measures of percentage fat, the percentage fat was estimated from the average sum of the four skin folds because this is valid in a large sample (Weststrate and Deurenberg, 1989; Vasudev et al., 2004). Biceps, triceps, sub scapular and iliac crest skin fold thickness were measured in triplicate. FM was calculated as percentage fat x BW. FFM was calculated as '(1-fraction of FM) x BW'. FM and FFM were normalised for stature by dividing them by squared stature, to get FMI and the FFMI (Wells, 2001). Plotting the FMI on the x-axis and the FFMI on the y-axis, subjects with different body compositions could be distinguished (Freedman et al., 2005; Wells, 2001; Wells and Cole, 2002). A FFMI-FMI-chart was plotted for the six different age and sex groups, and a regression line with one standard deviation was drawn (Figure 1), as has been shown previously by Van Etten et al (Van Etten et al., 1994). Subjects with a deviation of the regression line within one standard deviation were considered to have an average body build. The subjects beyond this prediction interval were assigned to either the slender group (actual FFMI < predicted FFMI) or the solid group (actual FFMI >
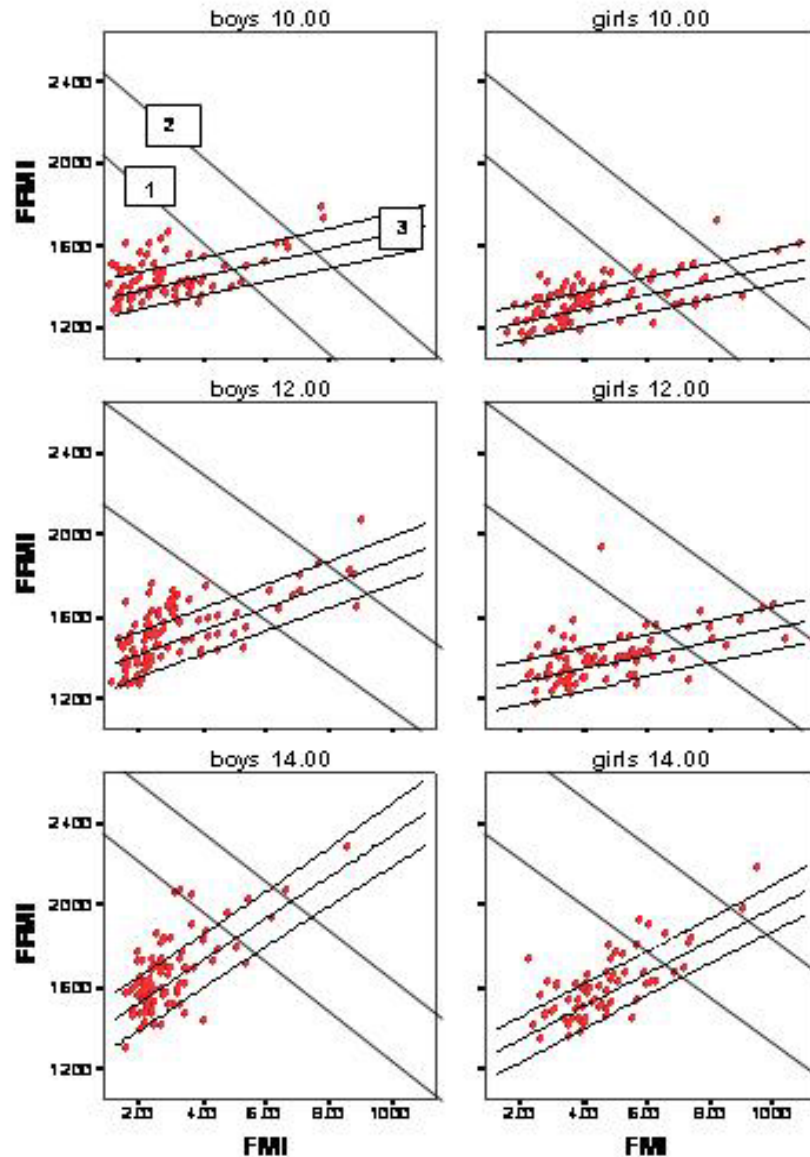
Figure 1. Allocation to body build groups. The figure shows the scatter plots with the FMI on the x-axis and the FFMI on the y-axis for the specific age en sex groups. Line 1 represents the BMI cut off point for overweight, line 2 represents the cut off point for obesity (Cole et al., 2000). Line 3 is the regression line for the FFMI predicted from the FMI, with one standard deviation above and beneath. The group 'boys 10' represents the group of boys in the age category 10-11, the group 'girls 12' represents the group of girls in the age category 12-13, etc.

predicted FFMI) (Van Etten et al., 1994). In brief, the subjects in the slender group had a relatively small amount of FFM, whereas the solid subjects had a large amount of FFM, compared to their FM and stature.

Aerobic test performance
The aerobic test performance was estimated with an incremental cycle protocol, in which the participants started with a 5 minute warm-up at 50 W for girls and 75 W for boys (Ergoline, Ergometrics 800, CE 0124). Heart rate was monitored by Polar heart rate monitors (Polar S610). In primary school children the work rate was increased by 25 W every 2.5 minute. When the heart rate reached 180 beats per minute, the work rate was increased by 10 W every 2.5 minute, to be able to reach the maximal test performance more precise. In secondary school children work rate was increased by 50 W every 2.5 minute and by 25 W when heart rate reached 180 beats per minute. The pedal rate was 60-80 rpm. The result of the cycle test is presented as the maximal achieved work load ('power output').

Additionally, the school children participated in a maximal multistage 20-m shuttle run test (Leger et al., 1988). Subjects were required to run back and

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Table 1. Anthropometric descriptives. Mean and standard deviation are shown for stature, body mass, body mass index (BMI), percentage fat, fat mass and fat free mass for different age groups and for boys and girls separately. Data are means (±SD).

	Age (yrs)	n	Height (m)	Body mass (kg)	BMI (kg·m^{-2})	Fat (%)	FM (kg)	FFM (kg)
♂	10-11	76	1.51 (.07)	39.6 (7.5)	17.27 (2.30)	17.18 (6.23)	7.1 (3.9)	32.5 (4.5)
	12-13	99	1.58 (.09)	46.0 (10.7)	18.20 (3.08)	17.33 (6.07)	8.5 (5.0)	37.6 (6.7)
	14-15	93	1.75 (.08)	60.0 (11.3)	19.47 (2.66)	15.59 (3.53)	9.6 (3.9)	50.4 (8.3)
♀	10-11	87	1.51 (.08)	40.5 (8.6)	17.68 (2.82)	24.93 (6.88)	10.6 (5.1)	30.0 (4.4)
	12-13	78	1.60 (.07)	47.7 (8.4)	18.63 (2.73)	25.58 (6.21)	12.65 (5.0)	35.1 (4.5)
	14-15	69	1.67 (.06)	56.9 (9.1)	20.51 (2.83)	22.93 (4.04)	13.3 (4.3)	43.6 (5.3)

forth on a 20-m course and touch the 20-m line with their foot at the same time a beep was emitted from a tape recorder. The Queen's University of Belfast protocol was used in which the frequency of the sound signals increases in such a way that running speed started at 8.0 km·h^{-1} and increased by 0.5 km·h^{-1} every minute (Tomkinson et al., 2003). The result of the test was expressed in number of stages, which reflected the number of minutes the participants preceded the test.

In both the cycle as the shuttle run test the heart rate measurements were used to evaluate whether the subjects performed maximally. A peak heart rate of > 185 beats/minute considered as maximal aerobic performance. Only the data of the subjects who performed maximally were included in the study. During both test verbal encouragements were used to stimulate the participants in performing maximally. Both tests were separately completed, with at least one day in between.

Data analysis
The results are shown as means and standard deviations. To test differences between subjects with an average, solid or slender body build, the total group was divided into six groups based on sex and age categories (10-11, 12-13, 14-15 years of age). Subjects were assigned to one of the defined groups for body build by comparison with their own age and sex group. To test the differences in anthropometric measures between children with a solid, average or slender body build two-way analysis of variance (ANOVA) was used. Post hoc analyses were executed with the Bonferoni test. To test the differences in aerobic test performance analysis of covariance (ANCOVA) was used, with body mass, age and gender as covariates. For statistical analysis SPSS 11.0 was used. A p-value < 0.05 was considered statistically significant.

RESULTS

In total 502 school children participated in the study. The cycle ergometer test was performed by 462 subjects whereas the shuttle-run test was performed by 479 subjects. Non-participation in the exercise tests was due to injuries or absence on the day of the test. Stature, body mass and percentage fat were determined in all subjects.

Table 1 shows the anthropometric data for different age groups, for boys and girls separately. An increase in BMI (from 17.27 to 19.47 kg/m^2 in boys and from 17.68 to 20.51 kg·m^{-2} in girls) and a decrease in percentage fat (from 17.18 to 15.59 % in boys and from 24.93 to 22.93 % in girls) has been shown with an increase in age from 11 till 15 years of age.

Table 2 shows the results of the cycle ergometer test and the shuttle run test for the different age and sex categories.

Table 2. Descriptives of aerobic test performance Mean (±standard deviation) are shown for maximal achieved power output in the incremental cycle test, maximal achieved power output relative to body mass (PO/BM) and fat free mass (PO/FFM) and shuttle run test for different ages for boys and girls separately. N depicts the number of subjects in the groups.

	Age (yrs)	Power output (W)	PO/BM (W/kg)	PO/FFM (W/kg FFM)	Shuttle run (step)
♂	10-11	135.89 (21.5)	3.50 (.63)	4.24 (.63)	6.10 (1.89)
	12-13	159.15 (30.25)	3.53 (.59)	4.26 (.52)	6.74 (2.36)
	14-15	252.61 (49.61)	4.28 (.75)	5.08 (.82)	10.49 (2.36)
♀	10-11	120.63 (18.80)	3.05 (.52)	4.05 (.55)	4.71 (1.86)
	12-13	138.91 (23.12)	2.96 (.49)	3.98 (.53)	5.30 (1.99)
	14-15	201.29 (42.81)	3.66 (.70)	4.70 (.79)	7.60 (2.12)

Table 3. Differences in anthropometry in body build groups. Means (±standard deviations) are shown in measures for body composition for groups based on body build defined by FFMI and FMI. The differences between the values are evaluated with the depicted P-value from the ANOVA analysis.

	Slender-1 (n = 78)	Average-2 (n = 348)	Solid-3 (n = 76)	P value
Body mass (kg)	43.77 (10.59)[2,3]	48.16 (12.01)[1,3]	54.50 (11.95)[1,2]	.000
Stature (m)	1.58 (.11)[3]	1.60 (.12)	1.63 (.11)[1]	.015
BMI (kg/m^2)	17.41 (2.70)[2,3]	18.47 (2.84)[1,3]	20.34 (2.90)[1,2]	.000
Fat percentage (%)	22.78 (7.77)[2,3]	20.24 (6.75)[1]	18.40 (6.14)[1]	.000
Fat mass (kg)	10.38 (5.18)	10.05 (5.03)	10.23 (4.72)	.857
Fat free mass (kg)	33.39 (7.11)[2,3]	38.11 (8.86)[1,3]	44.27 (9.44)[1,2]	.000

Superscripts represents a significant differences among the columns (1 = slender, 2 = average, 3 = solid) by a Bonferroni test.

The FFMI-FMI scatter plots for the six different age/sex groups are shown in figure 1. This figure also presents regression lines for the FFMI predicted from the FMI and the BMI cut-off points for overweight and obesity. Based on the deviation from the regression line the body build of the subjects was classified as solid (n = 76), average (n = 348) or slender (n = 78).

To evaluate the differences between the body build groups, well known measures for body composition are depicted in Table 3 for the three groups of body build. Table 4 shows the differences in aerobic test performance in the incremental cycle ergometer test and the shuttle run test for the different groups of body build adjusted for age, gender and body mass.

As a result of the methods, the solid group had a higher FFM (p < 0.05). ANCOVA controlling for age, gender and body mass also revealed group differences (p < 0.05) in power output, power output relative to body mass and shuttle run in favor of the solid group. There were no significant differences between the groups regarding the power output relative to FFM (p > 0.05).

DISCUSSION

The aim of the present study was to investigate the association between aerobic test performance and body build measured by FFMI and FMI in 11 to 15 year old school children. An important finding of this study was that children with a solid body build, thus a high FFMI compared to their FMI, scored significantly higher on the exercise tests, even after controlling for age, gender and body mass. On the contrary, the power output relative to FFM was comparable over the groups.

Because complete school classes were examined in this study selection bias was minimized and a valid representative cross-sectional sample might be expected. When the BMI values found in this study were compared to previous found Dutch data in a similar population an increase was found (Hirasing et al., 2001). This is, however, in line with previously posted assumptions that the BMI in children is increasing (Gerver, 2001; Hirasing et al., 2001).

In this study it was shown that the subjects with a solid body build, who have a higher amount of FFM, achieved a higher aerobic test performance as measured by a cycle ergometer test and the shuttle-run test. The results suggest that in the solid group the FM appears to be compensated by the amount of FFM. Although the total body mass was also higher in the solid group compared to the slender group, the differences in aerobic test performance can not be explained by the differences

Table 4. Differences in aerobic test performance in body build groups. Body mass, age and gender adjusted means (±standard deviations) are shown for aerobic test performance for groups based on body build defined by FFMI and FMI. The differences between the values are evaluated with the depicted P-value from the ANCOVA analysis.

	Slender-1 (n = 78)	Average-2 (n = 348)	Solid-3 (n = 76)	P value
Watt load (Watt)	156.21 (4.01)[3]	164.93 (1.82)[3]	178.64 (4.13)[1,2]	.001
PO/BM (W/kg)	3.30 (.08)[3]	3.48 (.04)[3]	3.70 (.08)[1,2]	.002
POt/FFM (W/kg)	4.37 (.08)	4.36 (.04)	4.37 (.09)	.962
Shuttle run (step)	6.20 (.29)[3]	6.85 (.13)	7.50 (.29)[1]	.008

Superscripts represents a significant differences among the columns (1 = slender, 2 = average, 3 = solid) by a Bonferroni test. PO = power output, BM = body mass index.

in body mass because the analysis was corrected for body mass. Therefore, the body build itself seem to be a predictor for the aerobic capacity in adolescents independent of age, gender and body mass.

In addition, the maximal achieved power output relative to FFM was evaluated and there were no significant differences between the groups based on body build. The total FFM can be considered as the main functional mass which plays a key role during physical activity (Goran et al., 2000). The maximal power output relative to FFM is associated with the physical exercise level. This is confirmed by a study of Nikolic et. al. (1992) with 15-year-old boys, where it was shown that the maximal aerobic power expressed per kilogramme lean body mass was 20.6% higher in the trained than in the untrained group (Nikolic and Ilic, 1992). From the similar functional capacity of the FFM for subjects with a solid, average or slender body build in our study, suggests a similar physical exercise level in the groups. Previously, we have found estimates for the level of sports participation for the different groups of body build (unpublished data). The hypothesis of similar physical exercise level is strengthened by the finding that the sport participation of the solid, average and slender parts of the previous study was comparable between the three groups. This may indicate that the body build is independent of the physical exercise level in this age category (11-15 years of age). When the body build is not influenced by physical exercise, it might be determined by genetic factors.

In this study, the generally recognized BMI cut-off points were compared to the FFMI-FMI-charts with regression lines which distinguish between solid, average or slender body build. Children who are overweight based on their BMI can be classified in the solid, slender or average group. The overweight group consisted of 56 children, in which 13 have a slender, 38 an average and 5 a solid body build. All these children have a high BMI for their age and sex, while the solid children have a relatively high FFM compared to their FM and stature, whereas the slender children have a relatively low FFM (Van Etten et al., 1994). It is hypothesized that the slender overweight children are more disadvantaged by their body mass in daily life compared to the solid overweight children who have more FFM.

Unfortunately, the group of overweight adolescents was too small to evaluate the impact of body build on aerobic test performance in obesity children. It would be interesting to test this hypothesis in a larger population of overweight children. Besides, an interesting research question could also be whether health status in children with a solid body build might even be better than the health status in slender children.

There are some limitations in this study to be acknowledged. The used measures have certain limitations. The percentage fat for example could have been measured with a more laboratory based measurement like hydro densitometry weighing, and the aerobic test performance with direct oxygen measurements. However, considering the aim of the study the prime aspect of the study design was to recruit a large random sample of the population. This requires that complete classes of the cooperating schools should be able to participate in the study. Therefore, laboratory measurement of all interesting physiological variables was not feasible. Another limitation is that no information was collected about the maturation status of the participants. Differences in the maturation status may partly explain the differences in exercise performance between the body build groups (Armstrong et al., 1998).

In conclusion, in this study it was shown that in the studied age group the aerobic test performance is better in children with a solid body build compared to children with a slender body build. The power output relative to FFM is comparable over the three groups. Because the capacity per FFM is associated with exercise training, the results suggest that body build status is determined by genetics, rather than by physical exercise at this age. In future research it is relevant to investigate possible differences in aerobic test performance between overweight children with a solid, average or slender body build, and health differences between different body build groups.

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KEY POINTS

- Children with a solid body build perform better in aerobic exercise tests than slender children.
- The power output relative to fat free mass was comparable in the solid, slender and average group.
- Besides body composition, body build should be considered related to other performance measurements.

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