Original Paper

DE GRUYTER OPEN

Biomedical Human Kinetics, 7, 9–16, 2015

DOI: 10.1515/bhk-2015-0002

The changes in running economy during puberty in overweight and normal weight boys

Marcin Maciejczyk[1], Joanna Gradek[2], Jadwiga Szymura[3], Jerzy Cempla[1], Magdalena Więcek[1], Łukasz Tota[1]

[1] Department of Physiology and Biochemistry, Faculty of Physical Education and Sports, University of Physical Education, Kraków, Poland; [2] Institute of Sport, University of Physical Education, Kraków, Poland; [3] The Department of Clinical Rehabilitation, University of Physical Education, Kraków, Poland

Summary

Study aim: running economy (RE) is important indicator of endurance performance. During puberty dynamic changes in body composition and function are observed, as such RE is also expected to change. The aim of the study was to compare the running economy (RE) in overweight and normoweight boys during a running exercise performed with constant velocity, and the assessment of changes in RE during puberty.

Material and methods: the RE of the subjects was evaluated twice: at the age of 11–12 and two years later. 18 overweight and 17 normal weight boys performed a graded test and a week later a submaximal run on a mechanical treadmill. During the exercise, physiological variables (oxygen uptake, heart rate, pulmonary ventilation, tidal volume and breathing frequency) were measured.

Results: the intensity of work in both tests (%VO_2max, %HRmax) was significantly higher in the overweight boys and decreased with age (non significantly) in both groups. The physiological response during the run in the overweight boys was significantly higher compared to normal weight. When the oxygen uptake was expressed as $VO_2 \cdot BM^{-0.75}$, the RE was similar in normal weight and overweight boys. During puberty, the inter-group differences in the metabolic cost of work stay at a relatively stable level.

Conclusions: the lowered endurance performance in the overweight boys during puberty remains unchanged. The changes in physiological variables during puberty in both groups occurred in a similar way – the body composition did not influence the course of these changes in puberty.

Key words: Body composition – Oxygen uptake – Running – Obesity – Boys – Puberty

Introduction

The maximal oxygen uptake (VO_2max) and the lactic threshold level, determines the endurance performance. In overweight people, including overweight children, the relative body mass VO_2max value and the level of lactic threshold are much lower than in persons with normal body composition [18, 19, 31]. The lower values of these indicators show decreased aerobic performance in obese persons. Running economy (RE) may be a more important indicator of endurance performance than the lactate threshold or the VO_2max level [9]. Running economy is typically determined by measuring the steady-state consumption of oxygen (VO_2) for a given velocity of submaximal running. As such, the reason for inferior aerobic performance by overweight subjects may be different: the high metabolic cost of work caused by carrying the additional, excessive body weight in the form of fatty tissue. An interesting issue is the course of developmental changes in running economy in obese boys during puberty. During puberty the body height, mass and composition rapidly changes: body height and mass (in boys mostly due to changes in the fat-free mass) increase within a short period of time. During this period of dynamic change in body composition and functioning, running economy in overweight boys is also expected to change, due to changes in co-ordination during movement.

The aim of the study was to compare running economy in overweight and normal weight boys during running

Author's address Dr Marcin Maciejczyk, Institute of Biomedical Sciences, University of Physical Education, Al. Jana Pawła II 78, 31-571 Kraków, Poland marcin.maciejczyk@awf.krakow.pl

performed with constant velocity, and the assessment of changes in running economy in overweight and normal weight boys during the period of puberty.

Material and methods

The project obtained approval of the Bioethics Committee of the Regional Medical Chamber, and the Education Welfare Service. All participants and their parents/guardians gave informed consent for their children to participate in the study.

Procedures

Thirty five healthy boys, divided into two groups (Group O-overweight, N = 18; Group N – normal weight, N = 17), significantly different in terms of body mass and composition, were studied in this investigation. The examined boys participated in endurance tests twice. The first study was conducted at the age of approximately 11–12 years, the second one–two years later. There were no other interventions between study: the boys were not encouraged to be on a diet and a physical activity program was not advised. Three boys resigned from participating in the second series of tests (2 from group O; 1 from group N). The endurance tests were preceded by anthropometric measurements and consisted of two tests (incremental test and running performed with constant velocity) carried out over a few days.

Somatic measurements, criteria for inclusion to group of overweight and normal weight boys, assignment of age peak height velocity

The following somatic parameters were measured: body height (BH), body mass (BM), body fat (%F), fat-free mass (FFM), body mass index (BMI). Body height, body mass, and BMI were also expressed as a standard deviation score (SDS) relative to growth standards [1, 2, 7] using the LMS method [3].

The body mass and body composition were assessed using tetrapolar bioelectrical impedance analysis and the Tanita TBF-300 scale (measurement frequency 50 kHz, measurement current 500 μA, measurement range 150–900 Ω), and measurements of BH were conducted with up to 0.01 cm accuracy, using an anthropometer. Measuring the BM and body composition was always conducted during the morning hours and in similar conditions (hydration; skimming, clean feet).

In order to stratify into the overweight and normal weight group, initial somatic parameter measurements were undertaken. These covered 649 boys in the age of approximately 9 years. The boys whose results exceeded the sum of the mean value ($\bar{x}$) and standard deviation (SD) for the level of body fat in the studied population formed the group composed of overweight boys. The normal weight group consisted of boys with average body mass and body fat.

The overweight and normal weight boys participated in regularly repeated (every 4 months) somatic measurements up to the age of 14 (beginning from age 9, at least until the moment of the pubescent spurt in body height, also in some cases after that moment). The body height measurement made it possible to determine every participant's age at the onset of puberty (A-"take off") and the age at peak height velocity of body height (A-PHV) [8]. The age at which the greatest height gain (cm/year) was observed was taken as the A-PHV.

Participants

The examined boys from the characterized groups differed significantly in body mass and body composition. When beginning both series of endurance tests the overweight boys, had – in comparison to the normal weight boys – significantly greater body mass, higher percentage of body fat, and a higher BMI. No significant differences, however, were detected between groups as far as body height and the average calendar age were concerned (Table 1).

The first endurance tests were conducted at the age of 11.65 years, i.e. before the onset of the pubescent spurt in body height (12.8 years in Group O and 13.4 years in Group N), while the second study was conducted at age approximately 13.5 years i.e. at the time of the pubescent spurt of body height or just after its occurrence (Table 2).

Exercise tests

Initially, a graded exercise (until exhaustion) was conducted on a cycle ergometer (Monark 818E, Sweden). During the test the maximal oxygen uptake and maximal heart rate (HRmax) were measured. The test started with a 4-minute exercise performed with a fixed workload amounting to about 1.0 $W \cdot kgFFM^{-1}$. Following this the workload was increased every 2 minutes by about 0.5 $W\ kgFFM^{-1}$. The rhythm of pedaling was constant at 60 revolutions per minute.

The principal endurance test, in which the metabolic cost was assessed based on the levels of the analyzed physiological parameters noted in the steady state, consisted of a six minute run on a mechanical treadmill (Cardionics 2113, Sweden) with a speed of 7.5 $km \cdot h^{-1}$ (constant speed in both studies). In this test, the natural form of movement should have been run, not walk or jogging and work intensity should have been submaximal.

During both tests measurements of breathing parameters [breathing frequency (FR), tidal volume (TV), pulmonary ventilation (VE), and oxygen uptake (VO_2)] were conducted using the Medikro 919 Ergospirometer

Table 1. The level of somatic parameters in the examined boys when commencing the successive series of endurance tests (BH – body height, BM – body mass, FFM – fat free mass, F – body fat, BMI – body mass index, SDS – standard deviation score, *p < 0.05, O – overweight boys, N – normal weight boys, d – difference)

Parameter	Group	Study I	Study II	dI-II
N	O	18	16	
	N	17	16	
Age (years)	O	11.76 ± 0.87	13.61 ± 0.84	1.85
	N	11.6 ± 0.78	13.54 ± 0.79	1.94
	d	0.16	0.07	
BH (cm) [SDS]	O	157.2 ± 7.32 [1.37 ± 0.74]	168.88 ± 6.26 [1.2 ± 0.65]	11.68*
	N	153.7 ± 4.79 [1.05 ± 0.84]	167.57 ± 6.7 [1.10 ± 0.95]	13.87*
	d	3.5	1.31	
BM (kg) [SDS]	O	61.39 ± 8.89 [2.22 ± 0.52]	76.25 ± 11.73 [2.33 ± 0.63]	14.86*
	N	40.85 ± 5.08 [0.49 ± 0.76]	50.25 ± 8.0 [0.34 ± 0.87]	9.4*
	d	20.54*	16*	
FFM (kg)	O	44.79 ± 7.71	57.05 ± 9.58	12.26*
	N	36.08 ± 3.72	46.12 ± 6.53	10.04*
	d	8.71*	10.925*	
F (%)	O	26.97 ± 6.39	24.98 ± 6.04	–1.99
	N	11.59 ± 3.93	8 ± 3.4	–3.59
	d	15.38*	16.98*	
BMI [SDS]	O	24.75 ± 2.41 [2.23 ± 0.58]	26.67 ± 3.30 [2.24 ± 0.67]	1.92
	N	17.27 ± 1.88 [–0.12 ± 1.04]	17.80 ± 1.99 [–0.43 ± 1.05]	0.53
	d	7.48*	8.87*	

Table 2. The age (A) and body height (BH) at the moment of "take off" and at the moment of peak height velocity (PHV) in the compared groups of boys (HGmax – the maximal height gain, d – difference, *p < 0.05, NS – non-significant, $\bar{x}$ – mean value, SD – standard deviation)

Parameter	Group O	Group N	d
	$\bar{x}$ ± SD	$\bar{x}$ ± SD	
A-take off (years)	10.43 ± 0.79	10.93 ± 1.08	–0.5
BH-take off (cm)	147.52 ± 5.65	148.92 ± 4.21	–1.4
A-PHV (years)	12.8 ± 0.86	13.4 ± 0.65	–0.6*
BH-PHV (cm)	165.35 ± 5.61	165.6 ± 5.48	–0.25
HG_{max} (cm/year)	10.57 ± 2.06	10.85 ± 1.85	–0.28

(Finland). The heart rate (HR) was registered with the use of a Polar (Finland) cardiac monitor.

Oxygen uptake was expressed in absolute terms ($L \cdot min^{-1}$), relative to body mass ($VO_2 \cdot BM^{-1}$), relative to free-fat mass ($VO_2 \cdot FFM^{-1}$) and in terms of $mL \cdot kg^{-0.75}$ ($VO_2 \cdot BM^{-0.75}$) [20, 28].

Statistical analysis

The significance of changes with age (difference between studies in each group) of the analyzed parameters was conducted using the non-parametric Wilcoxon Test and significance of intergroup differences (in each study) was conducted using the non-parametric the Mann-Whitney U Test.

Results

Aerobic capacity in overweight and normal weight boys

In both studies, there was a significant difference in VO_2max (expressed as VO_2max·BM^{-1} and VO_2max·$BM^{-0.75}$) between overweight and normal weight boys. The inter-group differences in absolute and relative to FFM values of VO_2max were non significant. During puberty, the VO_2max changed significantly in both groups: absolute VO_2max increased and relative (VO_2max·BM^{-1} and VO_2max·FFM^{-1}) decreased. There were no changes in VO_2max·$BM^{-0.75}$ during puberty in both groups. No changes between groups and during puberty were noted in the maximal heart rate (Table 3).

Differences between overweight and normal weight boys in physiological response during running in particular studies

There were significant differences between overweight and normal weight boys in most of the physiological variables in both studies. The absolute and relative to FFM values of VO_2, TV and V_E – noted at the end of the running effort – were in both studies significantly higher in the overweight boys in comparison to normal weight boys. Yet, when VO_2 was expressed relative to BM, the significantly lower values of VO_2 were noted in both studies in the overweight boys when compared to those seen in the normal weight boys. When VO_2 was expressed in mL·$kg^{-0.75}$ there were no differences between groups in both studies.

Breathing frequency and heart rate noted in the steady state of effort did not significantly differentiate both comparative groups. The intensity of work noted in principal endurance test and expressed as %VO_2max, was in both studies significantly higher (by about 12%) in the overweight boys than in the control group. A similar outcome was detected as far as the intensity of work expressed as %HRmax was concerned – the overweight boys performed the work with an intensity of about 90%HRmax, while the normal weight boys with an intensity of about 84%HRmax, and the inter-group difference was statistically significant (Table 4).

Changes of running economy during puberty in overweight and normal weight boys

The running economy was significantly improved during puberty in both groups. In both comparative groups, the decrease with age of the relative values of the oxygen uptake (VO_2·BM^{-1}, VO_2·FFM^{-1} and VO_2·$BM^{-0.75}$) registered in the steady state of running was noted. At the same time the absolute oxygen uptake significantly increased during puberty in both groups.

The running intensity in principal endurance test (%VO_2max, %HRmax) remained unchanged during puberty in both groups, but a slight decreasing tendency was

Table 3. Maximal oxygen uptake (VO_2max) and maximal heart rate (HRmax) in overweight (O) and normal weight (N) boys (BM – body mass, FFM – fat free mass, d – difference, *p < 0.05)

Variable	Group	Study I	Study II	dII-I
VO_2max (L·min^{-1})	O	2.44 ± 0.51	2.74 ± 0.45	0.3*
	N	2.13 ± 0.32	2.41 ± 0.51	0.28*
	d	0.31	0.33	
VO_2max·BM^{-1} (mL·kg^1)	O	39.90 ± 6.43	36.27 ± 5.76	–3.63*
	N	52.13 ± 5.58	47.68 ± 5.0	–4.56*
	d	–12.23*	–11.41*	
VO_2max·FFM^{-1} (mL·kg^{-1})	O	54.69 ± 6.76	48.35 ± 6.0	–6.34*
	N	58.89 ± 5.98	51.93 ± 5.69	–6.96*
	d	–4.2	–3.58	
VO_2max·$BM^{-0.75}$ (mL·$kg^{-0.75}$)	O	111.63 ± 18.18	106.77 ± 15.99	–4.86
	N	131.61 ± 14.22	126.99 ± 15.46	–4.62
	d	–19.98*	–20.22*	
HRmax (b·min^{-1})	O	194 ± 8.6	193 ± 10.3	–1
	N	197 ± 7.9	197 ± 7.4	0
	d	–3	–4	

Table 4. The level of the physiological parameters noted in overweight (O) and normal weight (N) boys at steady state in the principle endurance test (running at 7.5 km·h^{-1}) and in relation to the maximal values (BM – body mass, FFM – fat free mass, VO_2 – oxygen uptake, HR – heart rate, FR – breathing frequency, TV – tidal volume, V_E – pulmonary ventilation, *p < 0.05, d – difference)

Variables	Group	Study I	Study II	$d_{II–I}$
VO_2 (L·min^{-1})	O	2.13 ± 0.31	2.31 ± 0.39	0.18*
	N	1.60 ± 0.22	1.70 ± 0.23	0.1*
	d	0.53*	0.61*	
%VO_2max	O	88.33 ± 14.05	84.1 ± 15.47	–4.2
	N	75.45 ± 8.31	72.17 ± 10.14	–3.28
	d	12.88*	11.93*	
VO_2·BM^{-1} (mL·kg^{-1})	O	34.79 ± 3.11	30.26 ± 2.58	–4.53*
	N	39.1 ± 3.99	34.03 ± 2.86	–5.07*
	d	–4.31*	–3.77*	
VO_2·FFM^{-1} (mL·kg^{-1})	O	48.04 ± 5.18	40.66 ± 4.48	–7.38*
	C	44.26 ± 4.02	36.98 ± 2.83	–7.28*
	d	3.78*	3.68*	
VO_2·BM$^{-0.75}$ (mL·kg$^{-0.75}$)	O	97.33 ± 8.45	89.34 ± 7.91	–7.99*
	N	98.91 ± 9.58	90.28 ± 6.39	–8.63*
	d	–1.58	–0.94	
HR (b·min^{-1})	O	175 ± 11.47	171 ± 14.68	–4
	N	168 ± 10.95	164 ± 9.45	-4
	d	–7	–7	
%HRmax	O	90.23±5.48	88.29 ± 6.60	–1.94
	N	84.89 ± 4.61	83.32 ± 5.0	–1.57
	d	5.34*	4.97*	
V_E (L·min^{-1})	O	61.59 ± 8.9	67.06 ± 12.66	5.47*
	N	43.53 ± 5.81	47.50 ± 5.11	3.97*
	d	18.06*	19.56*	
FR (1·min^{-1})	O	52 ± 8.62	44 ± 9.37	–8*
	N	46 ± 7.03	40 ± 7.11	–6*
	d	–6	–4	
TV (L)	O	1.21 ± 0.18	1.56 ± 0.30	0.35*
	N	0.96 ± 0.17	1.24 ± 0.33	0.28*
	d	0.25*	0.32*	
V_E/VO_2	O	29.02 ± 2.89	29.16 ± 3.26	0.14
	N	27.39 ± 2.44	28.1 ± 2.04	0.71
	d	1.63	1.06	

observed. A similar tendency of HR decrease with age was also noted. With age, the V_E values had significantly increased in both normal weight boys and overweight boys. A significant increase in TV was observed with age, as well as a significant decrease of the FR recorded in both groups (Table 4).

Discussion

Our study indicated that the overweight or obese pubertal children who run at the same velocity as normal-weight individuals were working at a higher relative load. Running economy, defined as oxygen uptake at a given submaximal speed, was significantly higher in the overweight boys in comparison to the normal weight group. The boys with high body fat performed (in both trials) the running exercise (principal endurance test) with a significantly higher work intensity (%VO_2max, %HRmax) than their slimmer peers, which may explain their worse endurance performance, thus the earlier completion of exercise at the submaximal level due to more rapidly accumulating fatigue. When performing work during exercise at the same velocity, the normal weight and overweight subjects in this study demonstrated absolute VO_2 values that were significantly different. This indicates that the two groups had varying energy efficiency during exercise. These observations were reported in previous studies [14, 15, 27]. In the studies conducted by Maffeis et al. [14], the obese children walking with a speed of 5 km·h^{-1} consumed about 50% more energy than slim children. The results were similar in tests done at different speeds (2–11 km·h^{-1}) and the increase of locomotion speed led to the deepening of the inter-group differences in the cost of work. Souza et al. [27], found that overweight children while performing the shorter test effort on a mechanical treadmill had to expend totally as much energy as normal weight children who were performing the effort for a much longer time. Marinov et al. [15], concluded that the absolute metabolic cost of exercise on the treadmill was higher in the obese group compared with the control subjects.

Usually the high metabolic cost of exercise performed on the treadmill in obese/overweight persons is explained by the greater body fat content and also higher fat-free mass. Volpe Ayub and Bar-Or [30] examining boys with a similar gross body mass but differing in the level of body fat showed that the cause of such a high cost of the walk could rather be attributed to the gross body mass than to the excessive amount of body fat – the cost of work was, particularly at lower speeds, similar in both groups but the heart rate was – in all exercises – significantly higher in the obese boys. The reason for the differences in the total energy expenditure of work may also result from a higher resting metabolic rate noted in the obese children resulting from the higher fat-free mass [13, 16].

A comparison of submaximal heart rate responses to exercise between obese and normal weight children has produced conflicting results. In Reybrouck's et al. [19] study the heart rate during treadmill exercise was lower in obese children, but in another study [14] was not significantly different when boys and girls were combined but was higher in obese boys and obese girls when analyzed separately. The results of this study indicted lower (but not significantly) submaximal heart rate during running in normal weight boys compared to the overweight group.

The differences between obese and non-obese children in the level of physiological reaction can be different depending on the exercise protocol used (weight-bearing and non-weight-bearing tests), work intensity, and level of obesity. When the aspect of carrying excessive body mass during exercise is eliminated by using a cycle ergometer in the test, absolute oxygen uptake values can differ for exercise on a treadmill and a cycle ergometer. For exercise on a treadmill, absolute VO_2 values for obese children are higher than for normal weight children [12, 17] – similar results were noted in this study. In the exercises on a cycle ergometer, though, absolute oxygen uptake values in obese and normal weight children are usually at the same level [12]. The relative to body mass VO_2 values are seen to be to be significantly lower in obese children in exercises done both on a treadmill and a cycle ergometer [12, 17]. Scaling VO_2 to fat-free mass may or may not eliminate the significant differences between obese and non-obese children [17]. Our study confirmed that significantly higher absolute and relative to fat-free mass and significantly lower relative to body mass oxygen uptake during treadmill exercise is noted in overweight boys compared to normal weight boys.

The novelty of this study is data interpretation, when the oxygen uptake was scaled to the exponent of body mass to the 0.75 power. A scaling factor of body mass to the 0.75 power provides a more appropriate method of comparison than a simple ratio standard of body weight [20]. When the oxygen uptake was expressed as $VO_2 \cdot BM^{-0.75}$, the running economy was similar in normal weight and overweight boys.

Karp [9] reports that during efforts of moderate intensity (70% VO_2max) the breathing muscles use from 3 to 6% of the oxygen uptake, and during maximal efforts between 10 and 15% of VO_2max. The higher cost of physical work in obese children in comparison to normal weight children may be a result of the high cost of breathing. The unfavorable pattern of breathing observed in obese children –higher breathing frequency and lowered tidal volume – stimulates breathing muscles to work more intensely, and this also increases oxygen uptake [25, 26]. Our results did not support these findings.

Drinkard and colleagues [6] claim that the increased metabolic cost of work in obese children results from the worse biomechanics of locomotion. This is confirmed by Katch et al.[10], who observed that obese people, in order to maintain proper balance while moving with an increased speed, bend the upper parts of their bodies, thus distorting

the biomechanics of a walk or run. In our study, the exercise intensity near 90% VO_2max (noted in overweight boys) was rather high. At such intensities coordination of movements is poor, thus it seems that running economy was not optimal.

The metabolic cost of work (running economy) diminishes with age in the course of a human development – children perform efforts less economically than adults – and the metabolic cost of work decreases with biological maturity [4, 21]. The course of the developmental changes of the observed physiological parameters in both characterized groups was typical for that development period [22]. Rowland et al. [24], showed on a cycle-ergometer the lack of changes in the economy of work between children and adults, so the cause of the differences in the economy of work during such activities like a march or run, which require carrying of the body mass, probably results from the body volume. Undoubtedly, the higher cost of work in children is caused by biomechanical factors such as step-length and step frequency, as well as higher vertical oscillations of the bodies centre of gravity [23, 29]. It is also suggested that the reasons for the higher metabolic cost of work in children in comparison to adults are attributed to such factors as higher resting metabolic rate, greater ventilatory equivalents for oxygen (VE/VO_2) or the differences in energy substrates used for physical work (low RER) [11].

During puberty significant changes in body height and body composition (fat-free mass increases) are observed. In consequence changes in coordination patterns can be observed, and those changes can influence running economy. The improvement in the metabolic cost is referred to the improvement with age of the coordination patterns during a march or run [5], but during puberty the body height increases quickly and thus coordination may be impaired. In our study, the second exercise test was performed at the age close to the age of peak height velocity, but the observed changes in body height and body composition during puberty did not impair the running economy. Moreover in both comparative groups, similar pubertal changes of the analyzed physiological parameters were observed – the physiological cost of work was seen to diminish at a similar rate in both groups – therefore it may be concluded that in the analyzed period of life, the differences in the cost of physical work between the overweight and normal weight boys remain at a similar level, despite the fact that these boys entered the pubertal height spurt significantly earlier.

Conclusions

In both studies the physiological response during a run was significantly higher in the overweight boys compared to the normal weight, which proves the existence of permanently worse endurance performance in overweight boys in the analyzed period of life. There were no significant differences between overweight and normal weight boys in oxygen uptake only when this was expressed as $VO_2 \cdot BM^{-0.75}$. The changes in running economy during puberty were similar in both groups. As such the body composition did not influence the course of these changes in the pubertal period. In puberty, the inter-group differences in the metabolic cost of physical work remained at a relatively stable level.

References

1. Cole T.J., Freeman J.V., Preece M.A. (1995) Body Mass Index reference curves for the UK, 1990. *Arch. Dis. Child.,* 73: 17-24. DOI: 10.1136/adc.73.1.25.
2. Cole T.J., Freeman J.V., Preece M.A. (1998) British 1990 growth reference centiles for weight, height, body mass index and head circumference fitted by maximum penalized likelihood. *Statist. Med*., 17: 407-29. DOI: 10.1002/(SICI)10970258(19980228)17:4<407::AID-SIM742>3.0.CO;2-L.
3. Cole T.J., Green P.J. (1992) Smoothing reference centile curves: The LMS method and penalized likelihood. *Statist. Med.,* 11: 1305-19. DOI: 10.1002/sim.4780111005.
4. DeJaeger D., Willems P.A., Heglund N.C. (2001) The energy cost of walking in children. *Eur. J. Physiol*., 441: 538-43. DOI: 10.1007/s004240000443.
5. Donkervliet E., Smits T., Ziemba A.W., Kemper H.C.G., Wagenaar R.C. (2000) Can sex and puberty-related differences and running economy be explained by the differences in co-ordination patterns? *Biol. Sport*, 17: 243-54.
6. Drinkard B., McDuffie J., McCann S., Uwaifo G.I., Nicholson J., Yanovski J.A. (2001) Relationship between walk/run performance and cardiorespiratory fitness in adolescents who are overweight. *Phys. Ther.,* 81: 1889-96.
7. Freeman J.V., Cole T.J., Chinn S., Jones P.R., White E.M., Preece M.A. (1995) Cross sectional stature and weight reference curves for the UK, 1990. *Arch. Dis. Child.,* 73: 17-24. DOI: 10.1136/adc.73.1.17.
8. Karlberg J. (2002) Secular trends in pubertal development. *Horm. Res.,* 57 (suppl 2): 19-30. DOI: 10.1159/000058096.
9. Karp J.R. (2008) An in-depth look at running economy. *Track coach*, 182: 5801-5806.
10. Katch V., Becque M.D., Marks C., Moorehead C., Rocchini A. (1988) Oxygen uptake and energy output during walking of obese male and female adolescents. *Am. J. Clin. Nutr*., 47: 26-32.
11. Krahenbuhl G.S., Wiliams T.J. (1992) Running economy: changes with age during childhood and adolescence. *Med. Sci. Sports Exerc*., 24: 462-6.
12. Maffeis C., Schena F., Zaffanello M., Zoccante L., Schutz Y., Pinelli L. (1994) Maximal aerobic power

during running and cycling in obese and non-obese children. *Acta Paediatr.,* 83: 113-6. DOI: 10.1111/j.1651-2227.1994.tb12965.x.
13. Maffeis C., Schutz Y., Pinelli L. (1992) Effect of weight loss on resting energy expenditure in obese prepubertal children. *Int. J. Obes. Relat. Metab. Disord.,* 16: 41-7.
14. Maffeis C., Schutz Y., Schena F., Zaffanello M., Pinelli L. (1993) Energy expenditure during walking and running in obese and nonobese prepubertal children. *J. Pediatr*., 123: 93-9. DOI: 10.1016/S0022-3476(05)81688-9.
15. Marinov B., Kostianev S., Turnovska T. (2002) Ventilatory efficiency and rate of perceived exertion in obese and non-obese children performing standardized exercise. *Clin. Physiol. Funct. Imaging*, 22: 254-60. DOI: 10.1046/j.1475-097X.2002.00427.x.
16. Molnar D., Schutz Y. (1997) The effect of obesity, age, puberty and gender on resting metabolic rate in children and adolescents. *Eur. J. Pediatr.,* 156: 376-81. DOI: 10.1007/s004310050618
17. Owens S., Gutin B. (1999) Exercise testing of the child with obesity. *Pediatr. Cardiol.,* 20: 79-83. DOI: 10.1007/s002469900405.
18. Reybrouck T., Mertens L., Schepers D., Vinckx J., Gewillig M. (1997) Assessment of cardiorespiratory exercise function in obese children and adolescents by body mass-independent parameters. *Eur. J. Appl. Physiol. Occup. Physiol.,* 75: 478-83. DOI: 10.1007/s004210050192.
19. Reybrouck T., Weymans M., Vinckx J., Stijns H., Vanderschueren-Lodeweyckx M. (1987) Cardiorespiratory function during exercise in obese children. *Acta. Paediatr. Scand.,* 76: 342-8. DOI: 10.1111/j.1651-2227.1987.tb10472.x.
20. Rogers D.M., Olson B.L., Wilmore J.H. (1995) Scaling for the VO_2-to-body size relationship among children and adults. *J. Appl. Physiol.,* 79: 958-67.
21. Rowland T.W. (1992) On body size and running economy. *Pediatr. Exerc. Sci*., 4: 1-4.
22. Rowland T.W., Cunningham L.N. (1997) Development of ventilatory responses to exercise in normal white children. A longitudinal study. *Chest*, 111: 327-32. DOI: 10.1378/chest.111.2.327.
23. Rowland T.W., Green G.M. (1987) Physiological responses to treadmill running in adult and prepubertal males. *Int. J. Sports Med.,* 8: 292-7. DOI: 10.1055/s-2008-1025672.
24. Rowland T.W., Staab J.S., Unnithan J.M., Rambusch JM, Siconolfi S. (1990) Mechanical efficiency during cycling in prepubertal and adult males. *Int .J. Sports Med*., 11: 452-5. DOI: 10.1055/s-2007-1024836.
25. Sakamoto S., Ishikawa K., Senda S., Nakajima S., Matsuo H. (1993) The effects of obesity on ventilatory response and anaerobic threshold during exercise. *J. Med. Syst.,* 17: 227-31. DOI: 10.1007/BF00996950.
26. Salvadori A., Fanari P., Mazza P., Fontana M., Clivati A., Longhin, E. (1993) Breathing pattern during and after maximal exercise testing on young untrained subjects and in obese patients. *Respiration,* 60: 162-9. DOI:10.1159/000196193.
27. Souza M.S., Cardoso A.L., Yasbek P. Jr, Faintuch J. (2004) Aerobic endurance, energy expenditure and serum leptin response in obese, sedentary, prepubertal children and adolescents participating in a short-term treadmill protocol. *Nutrition*, 20: 900-4. DOI: 10.1016/j.nut.2004.07.001.
28. Svedenhag J. (1995) Maximal and submaximal oxygen uptake during running: how should body mass be accounted for? *Scand. J. Med. Sci. Sports*, 5: 175-80. DOI: 10.1111/j.1600-0838.1995.tb00033.x.
29. Unnithan V.B., Eston R.G. (1990) Stride frequency and submaximal treadmill running economy in adults and children. *Pediatr. Exerc. Sci.*, 2: 149-55.
30. Volpe Ayub B., Bar-Or O. (2003) Energy cost of walking in boys who differ in adiposity but are matched for body mass. *Med. Sci. Sports Exerc*., 35:669-74. DOI: 10.1249/01.MSS.0000058355.45172.DE.
31. Zanconato S., Baraldi E., Santuz P., Rigon F., Vido L., Da Dalt L., Zacchello F. (1989) Gas exchange during exercise in obese children. *Eur. J. Pediatr*., 143: 614-7. DOI: 10.1007/BF00441512.

Received 22.01.2015
Accepted 10.02.2015

© University of Physical Education, Warsaw, Poland