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Cardiorespiratory Responses to Submaximal Exercise in 16-18-Year-Old Trained and Untrained Boys

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Key words: *circumpubertal age, physical training, submaximal exercise, oxygen pulse, oxygen deficit.*

Abstract

Background: *The aim of this study was to compare chosen parameters and coefficients characterizing the action of the cardiovascular system and the respiratory system at a low level of a cycloergometric exercise in young boys practicing handball and their untrained peers. In the present study we searched for an answer to questions concerning the influence of physical training on children's organism in progressive youth development.*

Material/Methods: *The technique of parallel groups was used: the experimental one (boys training handball, n=12) and the control one (not trained boys, n=58). The developmental age of the subjects was evaluated by percentile charts. A five-minute work on a bicycle ergometer was used to observe reaction of the organism to submaximal exercise below AT. During the test the parameters characterizing the respiratory and cardiovascular systems were measured by means of a gas analyzer Oxycon Pro Jaeger (Viasys) and Breath by Breath program.*

Results: *We noted adapting changes in the circulatory system in young handball players. The group practicing handball showed a higher value of $O_2 \cdot HR^{-1}$ ($p \leq 0.05$) in comparison with the untrained boys. Oxygen deficit was higher in the trained group, but there were no statistically significant differences between the trained and untrained boys.*

Conclusions: *Training during the biological progressive development causes adaptive changes in the cardiovascular system in the light of an increase in pulse oxygen ($O_2 \cdot HR^{-1}$) in submaximal work. Handball training during the biological progressive development causes an increase in oxygen deficit (Def. O_2).*

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Introduction

Understanding the reaction of a child's respiratory system, cardiovascular system, musculoskeletal system, metabolic changes to the physical activity of varying intensity should be the starting point for planning and programming of training loads and can protect against their negative effects. Kozłowski et al. [1] think that cardiorespiratory responses to submaximal and maximal exercise are different and should always be clearly distinguished. Susceptibility of the organism to physical training, and ultimately adaptive changes resulting in an increase in aerobic capacity are determined largely genetically. Continuous observation of the reaction of a child's organism and the impact of training on aerobic capacity provides valuable information about the body's metabolic reserve and the purposefulness of forming aerobic capacity. Bar-Or and Zwiren [3] proved that there is no significant improvement in the level of aerobic capacity in children trained before the puberty age. Rowland [4] states that before the puberty age the level of testosterone is too low to stimulate the development of aerobic capacity. There is high physical activity during this period, which is a strong stimulus, so the use of specific training is not effective. In this paper the aerobic exercise possibilities were determined using selected parameters characterizing the function of the respiratory and cardiovascular systems – responsible for transporting oxygen to tissues and the parameters characterizing oxygen uptake in terms of submaximal work below the anaerobic threshold (AT) and the constant load. This paper attempts to answer what impact specialized handball training has on the organism of children during the progressive development exposed to submaximal exercise below AT.

Material and methods

The technique of parallel groups was used: the experimental one (handball training [TR], n=12) and the control one (not trained [NT], n=58). Boys from both groups were on average about 16 years old when the study began, and the period of the experiment took two years. The research has been carried out on teenagers (born in 1986) who have been selected from the most talented boys from Poland and who are the students of the Polish Handball Federation Sports Masters' Secondary School in Gdansk (TR, n=12). The control group (NT), which was tested on the same parameters as the handball players group, were secondary school pupils from Tricity (Poland), and were only subjected to typical obligatory P.E. activities at their respective schools. In choosing this control population, the only condition of significance was their height, with the criterion of being at least 170 cm. The set of tests has been carried out three times at the stage of direct start preparation (BPS) for the first round of league games, in which the training boys were characterized by the highest level of performance. The results obtained in the continuous tests allowed us to gather some comparative material, which was essential to determine the influence of a handball player training on the ability of adolescents at circumpubertal age to perform submaximal work. Developmental age of the subjects was evaluated by percentile grids [5]. A five-minute work on a bicycle ergometer (*Jaeger ER900*) was used to observe the reaction of the organism to submaximal exercise below AT. The load of 2.0 W per kilogram of body weight and frequency of 50 pedal revolutions per minute ensured a comparable performance of work by all subjects.

The parameters characterizing the respiratory and cardiovascular systems were continuously monitored and recorded every 15 seconds using a gas analyzer *Oxycon Pro Jaeger* (Viasys) and *Breath by Breath* program during the test. Oxygen deficit (Def.O_2) was determined as the difference between the demand for oxygen (steady-state) during the work and its consumption. Ventilation equivalent of oxygen consumption ($\mathring{V}E \cdot \mathring{V}O_2^{-1}$), ventilation equivalent of carbon dioxide production ($\mathring{V}E \cdot \mathring{V}CO_2^{-1}$) and pulse oxygen ($O_2 \cdot HR^{-1}$) were calculated.

The data were statistically analyzed using a computer program STATISTICA PL 9th StatSoft. We used the multiple comparison test (post-hoc) to determine the statistical differences between the groups' means. The constant number of the subjects in the examined TR group allowed the usage of Tukey's test of the reasonable essential difference (RIR) for the even size of the two samples. In the case of the control group (NT) we chose the second variant of the test – for an uneven size of the samples. For variables which did not fulfil the assumptions of normal distribution or homogeneity variance we used the Kruskal-Wallis test. In this case we verified the difference between groups' means using multiple averages comparison for all samples test. For all conducted analyses statistical significance was determined at the level of $p \leq 0.05$ [6].

Results

There were significant statistic differences ($p \leq 0.05$) between the groups in somatic parameters. The body height was higher in the TR group in all periods of the study. The body mass and fat free mass (FFM) were higher in the 16- and 17-year-old TR group. Percentile values for weight and body height in the TR group were between 85 and 90. In the NT group we observed percentile level of body weight in 60–78 and body height in 70–62 (Tab.1).

Tab. 1. The values of selected anthropometric parameters characterizing the boys of the group training handball (TR) and the control group (NT) in subsequent periods of research

Group	Age [years]	Body height [cm]	Percentile of body height	Body mass [kg]	Percentile of body mass	FFM [kg]
TR16 (n=12)	**16.3 ± 0.07**	**185.9 ± 4.80**	**90.3 ± 7.81**	**78.8 ± 9.43**	**85.8 ± 14.5**	**71.4 ± 7.63**
NT16 (n=20)	**16.1 ± 0,28**	**179.3 ± 4.44**	**68.6 ± 21.7**	**63.5 ± 7.34**	**58.6 ± 24.6**	**57.3 ± 5.32**
p	*(=0.391)*	*(=0.012) is*	*(=0.053)*	*(<0.001) is*	*(=0.008) is*	*(<0.001) is*
TR17 (n=12)	**17.1 ± 0.20**	**186.7 ± 4.65**	**89.2 ± 9.10**	**79.8 ± 8.09**	**87.9 ± 9.97**	**69.6 ± 6.79**
NT17 (n=20)	**17.2 ± 0.23**	**179.6 ± 5.18**	**62.3 ± 23.7**	**67.5 ± 7.93**	**59.1 ± 25.2**	**60.3 ± 5.41**
p	*(=0.601)*	*(<0.001) is*	*(=0.007) is*	*(<0.001) is*	*(=0.004) is*	*(<0.001) is*
TR18 (n=12)	**18.3 ± 0.13**	**187.6 ± 4.67**	**89.2 ± 9.10**	**82.1 ± 5.02**	**90.4 ± 7.93**	**70.4 ± 4.38**
NT18 (n=20)	**18.1 ± 0.28**	**180.2 ± 4.54**	**62.3 ± 21.3**	**75.7 ± 7.85**	**78.2 ± 15.7**	**65.3 ± 5.11**
p	*(=0.422)*	*(<0.001) is*	*(=0.007) is*	*(=0.332)*	*(=0.613)*	*(=0.263)*

The results introduced as average (X); - standard deviation (SD); FFM – fat free mass; TR16 – TR18 – training group in age 16,17,18; NT16-NT18 – not trained group in age 16,17,18; n – number; is – average significant differences statistics; p – level of significance.

Comparing the values of chosen parameters characterizing the reaction of an organism to submaximal intensity effort in both tested groups (Tab.2), we found no important statistical differences between the 16-year-old boys from the control group and their peers who have been training handball for many years. The only important statistical difference was seen in the value of an oxygen pulse ($O_2 \cdot HR^{-1}$). The indicator among the training boys was on average 2.85 mL higher (Fig. 1A) than in the NT group. The volume of lung minute ventilation ($\mathring{V}E$) was higher (2.50 $L \cdot min^{-1}$), the time of achieving functional stabilization ($TA_{st.st.}$) was shorter by 33 seconds, and the heart rate (HR) was lower by 15 $1 \cdot min^{-1}$ in TR16 group. The level of oxygen deficit ($Def.O_2$) in subsequent periods of research was higher in the TR group on average by 0.26 L (Fig. 1B). It was observed that the difference in the value of $O_2 \cdot HR^{-1}$ between the TR group and the NT group increased in the two consecutive years. This value was higher in the TR group by 3.10 mL and 4.20 mL in the first and second year of observation. This was the only statistically significant difference in subsequent periods of observation. In the following two years of the difference in values of the $\mathring{V}E$ and $\mathring{V}T$ between the TR group and the NT group increased respectively by 5.10 $L \cdot min^{-1}$ and 5.00 $L \cdot min^{-1}$ and 0.16 L and 0.18 L. The $TA_{st.st.}$ was shorter in the TR group by 36.6 s and 41.4 s respectively in the first and the second year of observation. The values of the ventilation equivalent of oxygen consumption ($\mathring{V}E \cdot \mathring{V}O_2^{-1}$) and the production of carbon dioxide equivalent ($\mathring{V}E \cdot \mathring{V}CO_2^{-1}$) were higher in the NT, in each of the subsequent research.

Tab. 2. Selected parameters characterizing the reactions of boys' organisms to submaximal work in the group training handball (TR) and the control group (NT) in subsequent periods of research

Group	P [W·FFM⁻¹]	Def.O_2 [L]	$TA_{st.st.}$ [min]	HR [1·min⁻¹]	$\mathring{V}E$ [L·min⁻¹]	$\mathring{V}T$ [L]	BF [1·min⁻¹]	RQ	$\mathring{V}E\cdot\mathring{V}O_2^{-1}$	$\mathring{V}E\cdot\mathring{V}CO_2^{-}$	$O_2\cdot HR^{-1}$ [mL]
TR16											
(n=12)	**2.21±0.14**	**1.58±0.36**	**2.10±0.64**	**127±10**	**45.1±11.5**	**1.94±0.43**	**24±4**	**0.87±0.08**	**26.7±2.76**	**23.3±3.58**	**15.2±2.67**
NT16	**2.24±0.09**	**1.36±0.19**	**2.65±0.51**	**142±15**	**42.6±7.18**	**1.81±0.48**	**25±7**	**0.90±0.05**	**27.4±2.09**	**24.6±2.17**	**12.4±1.92**
(n=20)	*(=0.993)*	*(=0.341)*	*(=0.211)*	*(=0.072)*	*(=0.981)*	*(=0.971)*	*(=0.993)*	*(=0.964)*	*(=0.971)*	*(=0.916)*	*(=0.022)is*
p											
TR16											
(n=12)	**2.35±0.16**	**1.57±0.28**	**1.97±0.56**	**129±10**	**45.5±9.73**	**1.99±0.47**	**24±7**	**0.87±0.08**	**25.8±1.70**	**22.5±3.21**	**15.6±1.94**
NT16	**2.25±0.09**	**1.31±0.20**	**2.53±0.63**	**134±12**	**40.4±6.56**	**1.83±0.42**	**23±6**	**0.92±0.05**	**26.4±2.12**	**24.2±2.42**	**12.5±1.45**
(n=20)	*(=0.600)*	*(=0.161)*	*(=0.192)*	*(=0.944)*	*(=0.722)*	*(=0.945)*	*(=0.991)*	*(=0.665)*	*(=0.978)*	*(=0.782)*	*(<0.001)is*
p											
TR16											
(n=12)	**2.30±0.09**	**1.70±0.29**	**1.61±0.42**	**123±7**	**45.2±11.1**	**2.02±0.25**	**23±7**	**0.83±0.11**	**25.6±1.96**	**21.4±3.89**	**17.1±2.62**
NT16	**2.28±0.27**	**1.39±0.33**	**2.30±0.69**	**137±16**	**40.2±8.65**	**1.84±0.45**	**23±5**	**0.87±0.08**	**26.4±3.34**	**23.1±3.85**	**12.9±2.47**
(n=20)	*(<0.992)*	*(<0.072)*	*(=0.061)*	*(=0.071)*	*(=0.733)*	*(=0.912)*	*(=0.992)*	*(=0.774)*	*(=0.961)*	*(=0.776)*	*(<0.001)is*
p											

The results introduced as average (X); ± – standard deviation (SD); P – power; Def.O_2 – oxygen deficit; $TA_{st.st.}$ – time of achieving functional; HR – heart rate; $\mathring{V}E$ – volume of lung minute ventilation; $\mathring{V}T$ – respiratory volume; BF – respiratory frequency; RQ – respiratory quotient; $\mathring{V}E\cdot\mathring{V}O_2^{-1}$ – ventilator equivalent for oxygen; $\mathring{V}E\cdot\mathring{V}CO_2^{-1}$– ventilator equivalent for carbon dioxide; $O_2\cdot HR^{-1}$ – oxygen pulse; TR16–TR18 – training group in age 16,17,18; NT16-NT18 – not trained group in age 16,17,18; n – number; is – average significant differences statistics; p – level of significance.

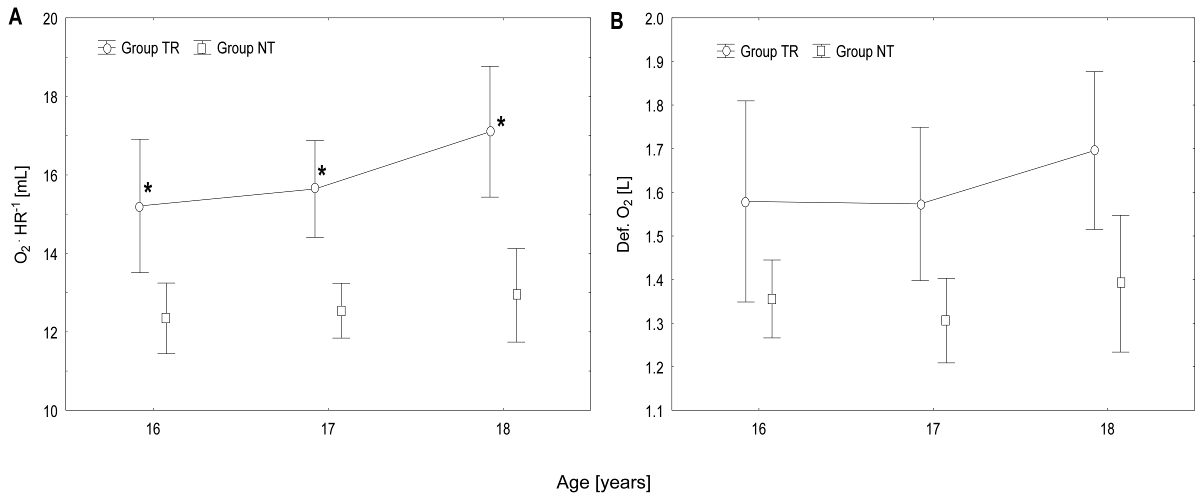

Fig. 1. Mean values of oxygen pulse ($O_2\cdot HR^{-1}$) [A] and the oxygen deficit (Def.O_2) [B] in submaximal exercise in the training (TR) and control (NT) groups in the subsequent periods of research (vertical bars indicate the confidence interval 0.95, * average significant differences statistics between TR and NT at $p \le 0.05$)

Discussion

The first handball players' (TR16) tests brought to comparative analysis with the results of the control group (NT16) suggest a possibility of the conclusion about the influence of 4-6 years' handball training on the development of children at the circumpubertal age. Location of the body weight and height above 50 percentile in the first study suggests that acceleration of the biological development of the boys in the TR group may be a result of the previous training load (between the age of 10–16). Their biological development can be defined as harmonious with little differentiation in somatic terms as shown by the percentile value for weight and body height located between 85 and 90 percentile growth. All anthropometric parameters and coefficients were characterized by smaller dispersion in the TR group than in the NT group. The obtained results suggest that handball training stabilizes the changes at the morphological and functional level, which leads to a more harmonious development and increasing the physical efficiency. The results in the TR group are consistent with the observations by Jensen et al. [7] and differ from the results of Wilmore and Costill [8]. Comparing the values of chosen parameters characterizing the reaction of an organism to submaximal intensity effort in both tested groups, we stated important statistical differences between the 16-year-old boys from the control group and their peers who have been training handball for many years. The only important statistical difference was seen in the value of an oxygen pulse ($O_2 \cdot HR^{-1}$). The indicator of the training boys was on average 2.85 ml higher. Comparing the values $O_2 \cdot HR^{-1}$ to the norm (13–15) indicated by Gondorowicz et al. [9], we find that in the case of the NT group the result was below (the first study) and in the lower range of the norm (the second and the third test). The $O_2 \cdot HR^{-1}$ of the TR group was in the upper range of the norm (the first test) and above (the second and third test). This situation confirms adaptive changes in the cardiovascular system as a result of training. It is known that $O_2 \cdot HR^{-1}$ depends on the cardiac stroke volume (SV) and arteriovenous difference (AVd). Both indicators are higher during physical submaximal exercise after training than before its beginning [1,10]. Lower values of $O_2 \cdot HR^{-1}$ and higher values of $\dot{V}E \cdot \dot{V}CO_2^{-1}$ in the NT group may indicate a greater oxygen cost of physiological processes in the boys' bodies. According to Szczęsna-Kaczmarek et al. [11] high $\dot{V}E \cdot \dot{V}CO_2^{-1}$ value is associated with less effective alveolar diffusion, whereas low $O_2 \cdot HR^{-1}$ value suggests low oxygen content (in the volume of blood) offered by the blood volume equal to the cardiac stroke volume. Moreover, the authors suggest that children's 'immaturity' of the mechanisms described above is compensated by a high AVd value. That means that a large amount of oxygen diffuses from the arterial blood to tissues. We observed that carbohydrate oxidation was the primary source of energy during work below AT in both groups, as evidenced by the respiratory quotient (RQ). There were interesting results of Def.O_2 which show higher values in TR group than in NT group in subsequent periods of observation. The higher values of Def.O_2 in TR group may indicate more advanced processes of anaerobic energy production for muscular work, as a result of loads used in handball training. Similar differences in values of Def.O_2 were observed by Szczęsna-Kaczmarek at al. in untrained children and long-distance runners [12]. Handball training not only caused an increase in Def.O_2 but also shortening $TA_{st.st.}$ and reduction in HR. Rannou suggests that handball training generates adaptive changes in anaerobic metabolism as well as sprinter training [13].

Conclusion

1. Handball training during the biological progressive development causes adaptive changes in the cardiovascular system in the light of an increase in pulse oxygen ($O_2 \cdot HR^{-1}$) in submaximal work.
2. Handball training during the biological progressive development causes an increase in oxygen deficit (Def.O_2) in submaximal work.
3. Several years of handball training at the prepubertal age of boys may accelerate biological development.

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