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Features of the Reaction of the Cardiorespiratory System of Schoolchildren with Physical Loads on the Tradmile

Tatiana Krutsevich[1], Natalia Pangelova[2], Sergei Trachuk[3] and Maryna Diedukh[4]

1,3, 4 National University of Physical Education and Sport of Ukraine, Kiev, Ukraine
2 Pereiaslav-Khmelnitsky Hryhorii Scovoroda State Pedagogical University, Pereiaslav-Khmelnitsky, Ukraine.

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ABSTRACT

Purpose. The aim of our work is to evaluate the reaction of the cardiorespiratory functional system of boys 7-9 years old when performing physical exercises in a wide range.
Material. The study was conducted on the basis of the laboratory of the theory and methodology of sports training and reserve capabilities of athletes of the Research Institute of the National University of Physical Education and Sports of Ukraine, 75 boys of 7-9 years took part.
Results. The article provides an assessment of the functional characteristics of boys 7–9 years of age, which are reflected in the reactions of adaptation to physical exertion, which is manifested in the adaptation of the cardiovascular and respiratory systems and the balance of muscular bioenergetics.
Conclusions. The study of the features of functional changes in the body of children aged 7–9 years when performing dosed muscular work on a tradmile is of great importance for the scientific substantiation of motor activity rationing.

1. Introduction

In the practice of physical education indicators of the functional capabilities of the child's body serve as the main criterion during the selection of physical exertion, the structure of motor actions, methods of influence on the body [9, 10, 21, 26, 31].

At present, the results of the study of physical performance are used not only to fully understand the functional reserves of the cardiorespiratory system, which limits this performance, but also for the adequacy of dosing physical activity [4, 7, 8, 24]. The study of the work of a different nature in children of primary school age contributes to the determination of physiological changes to optimize the level of motor activity [5, 17, 18].

The most common types of muscular work used in the exercise of motor activity are walking and jogging, as the simplest natural types of activity and at the same time effective means of enhancing the functional capabilities of the cardiovascular system.

According to the recommendations of the International Committee for Standardization, nonspecific tests for determining physical performance along with pedaling on a bicycle ergometer and a step test also include running on a treadmill [9, 10, 11, 13, 30].

Since children have relatively undeveloped knee extensors, testing on a treadmill is preferable to bicycle ergometry in small children [2].

Methods

The aim of our work was to evaluate the reaction of the cardiorespiratory functional system of boys 7-9 years old when performing physical activities in a wide range.

The study was conducted on the basis of the laboratory of the theory and methodology of sports training and reserve capabilities of athletes of the Research Institute of the National University of Physical Education and Sports of Ukraine.

This laboratory study was carried out using high-informative equipment (LE-200 CE treadmill, Jaeger high-speed automatic gas analyzer, Germany, Sport Tester Polar telemetry sensor, Finland). Data processing was carried out using non-parametric mathematical statistics and the package Statistica 6.

Computer processing of data in real time with an interval of 10 s made it possible to obtain and use in further analysis the values [16] of the following physiological parameters: pulmonary ventilation (VE, ml · min), respiratory rate (fT, min), respiratory volume (VT, l), oxygen consumption (VO_2, ml · min^{-1}), CO_2 level CO_2 (VCO_2, ml · min^{-1}), gas exchange ratio (VCO_2 / VO_2), ventilation equivalents for O_2 (EQO_2 = VE / VO_2) and for CO_2 ($EQCO_2$ = VE / VCO_2), oxygen pulse (VO_2 / HR, ml·beats^{-1}).

Statistical Results

Experimental loads were selected taking into account the recommendations set forth in the special literature, as well as in accordance with the requirements of reliability and informativeness [2, 14, 23, 25].

The selection of a complex of test loads was carried out taking into account the type of physical activity, the level of fitness and age. The functional readiness of children to perform muscular work was assessed by changes in individual parameters of the cardiovascular and respiratory systems and the number of work performed [2, 8, 15].

The test loads were carried out on the LE-200 CE tradmile, the intensity of the loads is easily controlled and does not require additional correction during its execution.

Energy costs and the response of the respiratory system to physical loads were evaluated using a high-speed gas analyzer of the Oxycon Pro type. Continuous registration and processing of computer data in real time allowed us to obtain data and use them in the future to analyze the values of physiological parameters with an interval of 5 seconds. (Table 1).

Table 1. *Functional indicators of the cardiovascular and respiratory systems of boys 7-9 years old at rest (n=75), Me (25%; 75%)*

Functional indicators	Age					
	7 years old (n=25)		8 years old (n=25)		9 years old (n=25)	
	Me	LQ; UQ	Me	LQ; UQ	Me	LQ; UQ
$\dot{V}_E$, l·min^{-1}	5,94	5,58; 8,03	7,67*	6,24; 10,56	8,22	5,69; 9,50
V_T, l	0,33	0,32; 0,37	0,42**	0,40; 0,43	0,39	0,30; 0,49
$\dot{V}O_2$, ml·min^{-1}	172,46	160,15; 229,67	196,21	174,79; 199,42	187,08	153,95; 257,1
$\dot{V}O_2$/kg, ml·min^{-1}·kg^{-1}	5,38	4,55; 6,56	4,91	4,39; 6,18	5,86	4,70; 6,43
$\dot{V}CO_2$, ml·min^{-1}	144,92	131,53; 196,61	172,31	151,79; 204,14	161,57	132,96; 208,6
RER	0,85	0,82; 0,88	0,84	0,80; 1,08	0,93	0,81; 1,03
HR , beat·min^{-1}	95,68	89,78; 97,03	100,97*	97,39; 102,70	101,01	91,29; 108,9
ΣHR , beat	283	271; 289	284	276; 303	296	241; 320

Note: Significant differences in the parameters according to the Mann-Whitney test ($p < 0.05$ *, $p < 0.01$ **)

compared with the previous age

At rest, there are significant differences in boys 7 and 8 years of respiratory volume (V_T, l) ($p < 0{,}01$), pulmonary ventilation E) ($p < 0{,}05$). The increase in tidal volume is associated with a decrease in respiratory rate, and an increase in tidal volume is proportional to an increase in muscle mass.

In 7-year-old boys, the RER – 0,85 (0,82; 0,88) indicates that 50% of the energy comes from carbohydrates and 50 % from fats. This energy is also observed in 8 year olds RER-0.84 (0,81; 1,03). An RER of 0,93 (0,80; 1,08) in 9-year-old boys indicates that a greater percentage of energy comes from carbohydrates.

During the transition in walking from 3 min at a speed of 3 km·h^{-1} to 5 min at a speed of 5 km·h^{-1}, significant differences in boys of 7 years are observed in terms of VE, - from 13,76 l · min^{-1} (8. 73; 16,48) to 19,76 l · min^{-1} (17,08; 21,73) ($p < 0{,}01$).

The increase in pulmonary ventilation is due to changes in respiratory rate and respiratory volume VT, from 0,38 (0,21; 0,47) to 0,46 l (0,41; 0,53) ($p < 0{,}01$). In other indicators of the respiratory system VCO_2 (ml min^{-1}), VO_2 (ml min), VO_2 / kg, (ml min^{-1} kg^{-1}) significant differences are observed at $p < 0.01$ (Table.2).

Table 2. *Indicators of the cardiovascular and respiratory systems of boys 7 years old during the test loads performed on a running ergometer (n=25), Me (25%; 75%)*

Indicators statistics	Functional indicators							
	$\dot{V}_E$, l min^{-1}	V_T, l	$\dot{V}O_2$, ml min^{-1}	$\dot{V}O_2$/кг, ml min^{-1}·k^{-1}	$\dot{V}CO_2$, ml min $^{-1}$	RER	HR, Beat min $^{-1}$	Σ HR , beat
walking 3 min 3 km·h $^{-1}$								
Me	13,67	0,38	453,22	14,45	353,49	0,78	119,35	349
LQ	8,73	0,21	255,51	10,22	210,30	0,64	110	329
UQ	16,48	0,47	546,31	17,48	435,19	0,85	145,22	358
walking 5 min 5 km·h^{-1}								
Me	19,76**	0,46**	634,19**	20,73**	536,38**	0,84**	129,01**	643**
LQ	17,08	0,41	542,9	18,20	448,28	0,83	126,3	636
UQ	21,73	0,53	742,62	21,77	613,63	0,86	131,6	654
walking 3 min 3 km·h^{-1}								
Me	15,99**	0,41**	456,45**	14,88**	403,11**	0,87**	119,02**	602*
LQ	13,41	0,37	416,72	13	354,19	0,85	116,02	596
UQ	16,66	0,47	519,83	15,88	452,82	0,90	124,62	609
walking 5 min 7 km·h^{-1}								
Me	28,96**	0,59**	871,74**	27,38**	780,85**	0,94*	162,74*	818*
LQ	23,82	0,54	677,92	23,99	637,10	0,87	156,41	732
UQ	34,18	0,70	1011,13	29,06	955,95	0,95	169,27	866
walking 5 min 3 km·h^{-1}								
Me	16,34**	0,40**	403,09**	12,98**	387,27**	0,94	127,44**	646*
LQ	15,53	0,33	302,15	11,48	305,87	0,88	111,92	621
UQ	19,20	0,49	442,73	14,18	414,41	0,99	133,54	683

Note: according to the Wilcoxon test, $p < 0{,}05$ * $p < 0{,}01$ ** compared with the previous load.

The 7-year-old boys' cardiovascular system also responds accordingly to physical exertion, which is observed in HR-119 heart rate (119 beats · $^{-1}$ (110; 145), ΣHR - 349 beats (329; 358) when walking 3 min 3 km · hour^{-1} and go to walk 5 min 5 km · h^{-1}, where HR - 129 beats · min^{-1}(126; 131) and the pulse cost of ΣHR robots was 643 beats (636; 654) ($p < 0{,}01$). A similar picture is observed in boys of 7 years old in terms of respiratory and cardiovascular systems when walking 3 min 3 km·min^{-1}, 5 min 7 km·h^{-1}, 5 min 3 km · h^{-1}. ($p < 0{,}01$; $p < 0{,}05$). So the respiratory coefficient RER

(VCO_2 / VO_2) varies from 0.78 (0,64; 0,85) to 0,84 (0,83; 0,86), (p <0,01).

This indicator is an important parameter that allows to determine the type of substance that serves as a source of energy and is used during muscular activity. As work capacity increases, the proportion of carbohydrates for energy production increases and the proportion of fats decreases.

Less oxygen consumption at rest is observed in schoolchildren at the age of 8 years, and during physical exertion in schoolchildren at the age of 9 years, which may indicate more economical work performance (p<0,05). Table 3 presents the dynamics of changes in boys of 8 years in terms of the cardiorespiratory system when walking 5 min 5 km · h^{-1}, 3 min 3 km · h^{-1}, 5 min 7 km · h^{-1}, 5 min 3 km · h^{-1}. (P <0,01, p <0,05).

Table 3. *Indicators of the cardiovascular and respiratory systems of schoolchildren 8 years old when performing test loads on a running ergometer (n=25), Me (25%;75%)*

Indicators statistics	Functional indicators							
	$\dot{V}_E$, L min^{-1}	V_T, l	$\dot{V}O_2$, Ml min^{-1}	$\dot{V}O_2$/кг, Ml $min^{-1}\cdot kg^{-1}$	$\dot{V}CO_2$, ml min^{-1}	RER	HR, Beat min^{-1}	ΣHR, beat
	walking 3 min 3 km h^{-1}							
Me	12,85	0,46	473,2	13,35	344,65	0,73	115,76	349
LQ	8,59	0,32	306,51	11,40	212,7	0,64	111,81	344
UQ	16,59	0,61	626,84	17,48	465,43	0,83	120,36	358
	walking 5 min 5 km h^{-1}							
Me	18,22*	0,51	597,10**	16,85**	500,75**	0,84*	127,57**	639**
LQ	17,34	0,43	563,37	16,03	459,11	0,81	126,37	629
UQ	22,02	0,55	787,88	20,47	648,47	0,85	131,81	655
	walking 3 min 3 km h^{-1}							
Me	14,38*	0,44	440,11**	11,90**	384,05**	0,87*	124,21*	627**
LQ	13,43	0,37	407,51	11,53	352,29	0,84	118,90	606
UQ	17,17	0,47	553	14,86	475,53	0,91	124,47	637
	walking 5 min 7 km h^{-1}							
Me	33,17*	0,58	960,57**	24,71**	913,82**	0,94*	165,92**	847**
LQ	27,07	0,52	883,43	24,01	769,19	0,87	162,13	824
UQ	35,41	0,71	994,02	29,96	950,80	0,96	170,26	870
	walking 5 min 3 km h^{-1}							
Me	16,49*	0,47	468,08**	13,24**	426,81**	0,92	136,92*	680**
LQ	15,68	0,39	434,55	12,02	408,61	0,90	131,36	671
UQ	17,64	0,54	548,54	14,83	501,33	0,97	137,42	688

Note: according to the Wilcoxon criterion p <0.05 * p <0.01 ** compared with the previous loads.

When walking 5 min 7 km·min^{-1}, the highest VO2 values are 960,57 ml · min^{-1} (883,43; 994,02), VO_2 / kg - 24.71 ml·min^{-1}·kg-¹ (24,01; 29,96), HR −165,92 beats·min^{-1} (162,13; 170,27), Σ HR - 847 beats (824; 870) are observed in relation to other load ranges.

Table 4 presents functional indicators of the cardiorespiratory system in boys 9 years old, where there are significant differences in a wide range of physical activity: when walking 3 min 3 km·hr^{-1}, 5 min 7 km·hr^{-1}, 5 min 3 km·hr^{-1} (p<0,01, p <0,05).

Table 4. *Indicators of the cardiovascular and respiratory systems of 9-year-old schoolchildren when performing test loads on a running ergometer (n = 25)*

Indicators statistics	Functional indicators							
	$\dot{V}_E$, l min^{-1}	V_T,l	$\dot{V}O_2$, Ml min^{-1}	$\dot{V}O_2$/кг, Ml min^{-1}·kg^{-1}	$\dot{V}CO_2$, ml min	RER	HR, Beat min	ΣHR, beat
walking 3 min 3 km·h^{-1}								
Me	12,16	0,46	427,65	11,78	334,17	0,78	110,32	340
LQ	8,41	0,32	306,51	9,63	212,70	0,69	103,84	321
UQ	17,28	0,56	572,14	14,30	461,94	0,85	117,31	353
walking 5 min 5 km·h^{-1}								
Me	15,83*	0,59	536,86**	15,81**	460,17**	0,85**	123,08*	619**
LQ	13,09	0,43	506,57	14,17	412,40	0,78	112,47	573
UQ	20,07	0,63	733,82	18,34	590,95	0,86	129,31	636
walking 3 min 3 km·h^{-1}								
Me	13,38*	0,50*	368,61**	11,66**	361,34**	0,87**	115,43	582**
LQ	10,73	0,36	359,11	10,17	309,57	0,83	110,70	541
UQ	18,93	0,54	574,69	14,37	499,18	0,92	119,48	607
walking 5 min 7 km·h								
Me	29,79**	0,67*	898,19**	27,10**	845,22**	0,91**	154,43	789*
LQ	24,30	0,58	827,53	23,74	739,74	0,85	148,18	762
UQ	36,66	0,78	1211,5	30,29	1056,56	0,93	165,66	835
walking 5 min 3 km·h^{-1}								
Me	17,11**	0,54*	440,95**	13,74**	460,87**	0,90	130,04**	633**
LQ	13,71	0,43	428,91	11,30	397,82	0,88	116,97	589
UQ	20,37	0,62	632,02	15,80	561,08	1,01	133,41	653

Note: according to the Wilcoxon test, $p < 0{,}05$ * $p < 0{,}01$ ** compared with the previous load.

In absolute terms, pulmonary ventilation increases with age, this indicator is informative, as it clearly reflects age-related features [18, 19, 22]. In our studies, when performing physical loads of various sizes, boys of 7–9 years old have such a tendency, however, there are no significant differences, no significant changes are observed at rest.

Heart rate (beats·min^{-1}), oxygen consumption values (ml·min^{-1}), pulmonary ventilation (l·min^{-1}), respiratory rate (RER), which characterize the state of the cardiorespiratory system of schoolchildren, had significant differences in boys 7 and 9 years old at different levels of load (according to the criterion of Mann-Whitney $p<0{,}05$).

Discussion

The high ability of the muscles of children of primary school age to consume oxygen is observed in a number of functional features that manifest themselves in muscular work.

According to the scientific literature [3, 21], after puberty, glucose begins to prevail in the mitochondrial oxidation substrate in motor activity, which comes to the muscles mainly due to the utilization of its own glycogen resources.

The increase in power leads to an increase in oxygen consumption, which is explained by the more limited possibilities for mobilizing the oxygen-transport system of the body.

So according to Astranda [1], children do not have very large amounts of oxygen debt, which is observed in adults during muscular work.

Less oxygen indebtedness is associated with higher recovery rates after exercise, as has been repeatedly noted in the scientific literature. Less oxygen debt in children indicates, on the one hand, less anaerobic capacity, and on the other, that oxidative mechanisms cope with the proposed load, and therefore anaerobic sources are activated to a small extent [12, 20].

In children, as in adults, cardiac output increases at the beginning of physical exertion or during a transition to a higher level of exercise. A new steady level of cardiac output is established within a few minutes. A higher heart rate in children of primary school age is biologically favorable, since it compensates for a lower systolic volume. It remains fairly stable in childhood and begins to decline closer to 20 years. This reduction does not depend on age, gender, fitness level, climate and other factors and is 0,7–0,8 beats min-per year [2, 3, 25].

At rest and during physical exertion, VO_2 consumption depends on the intensity of metabolic processes, as well as on the power and duration of work. When calculating for 1 kg of body weight with age, oxygen consumption decreases, and in general it increases (from 80 ml min^{-1} to 250–350 ml min^{-1}) [2].

In the scientific literature [1, 5, 21] we find some data on the age-related changes of the substrate for energy metabolism, reflecting the ratio of energy supply mechanisms for children 7-9 years.

Respiratory coefficient (RER) - the ratio of the amount of VO_2 that is inhaled with the amount of VCO_2, and exhaled for a certain period of time reflects the ratio of fats and carbohydrates, which are oxidized to form energy [7, 10].

In early school age, the most important substrate of oxidation at rest, as in physical work, are fatty acids, due to the mobility and practical inexhaustibility of fat depot.

The respiratory function of the blood also does not restrict the ability of children to actively use aerobic mechanisms for energy supply of physical activity. Thus, the oxygen capacity of blood in children 6–9 years old does not differ from the values typical for adults.

Since respiratory rate and tidal volume affect pulmonary ventilation, it is important to note what changes occur in both variables in the child's developmental process. Age differences indicate less effective ventilation for younger students than older children. The main indicator of less effective ventilation in children is the higher oxygen cost of breathing.

In addition to transporting VO_2 and VCO_2 during motor activity, the respiratory system affects the acid-base balance, controlling the VCO_2 reserves in the body. The increased exchange of VO_2 and VCO_2 contributes to increased ventilation, which also leads to an increase in alveolar ventilation.

In addition, a proportional increase in blood flow through the pulmonary capillaries occurs, and the intensity of pulmonary oxygen diffusion increases. Increased ventilation is achieved by increasing the frequency of respiration and tidal volume.

According to the dependence of the heart rate and oxygen consumption on the power of the work performed, from which it can be seen that in children of primary school age there is a linear relationship between the above indicators [28].

The fact that children, unlike adults, are less prone to the transfer of anaerobic loads, indicates the specificity of oxygen consumption in the "transition period". In any person during the transition from a state of rest to performing physical loads or from one level of load to another, higher, the intensity of metabolism increases. First, aerobic support lags behind energy requirements, which leads to the creation of an oxygen deficiency. The balance of chemical energy production at these initial stages facilitates anaerobic energy supply [2, 25, 29].

It is necessary to dwell on the recovery processes after prolonged physical exertion. Data on the recovery period allows us to estimate the cost of the work performed and the adaptation of functional systems to it. When studying recovery processes after performing physical loads, attention was paid to the degree of deviation of the studied functions from the level of rest. The main factor characterizing the recovery period after muscular work is enhanced oxygen consumption (VO_2), carbon dioxide emission (VCO_2), a significant increase in the pulse amount of recovery [2, 6, 8].

In a number of studies [1, 13, 17, 21] it was shown that physiological functions and motor activity in children are restored faster than in adults after submaximal and maximum loads. Although it is not completely clear why this happens, since the mechanism of this phenomenon may be different for different physiological functions.

It can be assumed that the rapid recovery of heart rate in children is due to a higher parasympathetic tone. Faster recovery of mechanical power is the result of less use of anaerobic energy sources during exercise, many researchers have suggested [2, 19].

In general, our data confirm the data of scientific literature [17, 22, 27] about the age-related development of muscular energy, which comes down to the fact that children and adolescents have a lower level of glycolytic power than adults, but are endowed with great aerobic power, which allows them to quickly resynthesis adhesin triphosphate and creatine phosphate during the recovery period.

Conclusion

Determination of the functional state of the cardiovascular and respiratory systems of younger schoolchildren in the laboratory facilitated understanding of the functioning patterns of the body's regulatory systems, and made it possible to determine HR or ΣHR as one of the indicators that can be used for the operational control of energy expenditure in the process of physical activity of schoolchildren.

Conflict of Interest. The authors declare that there is no conflict of interest.

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