The influence of short-term interval exercise on respiratory and circulatory dynamics in pre and post puberty boys

by
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The main aim of the study was to designate the differences in dynamics of physiological reactions in respiratory and circulatory systems, in boys at the age of pre and post puberty, in response to short supramaximal interval exercises. The research was conducted on 20 boys, divided into two groups of ten in each. The primary research group consisted of individuals, about 12 years old (pre puberty boys), whereas in the secondary group - around the age of 16 (post puberty boys). The main part of the research included an interval test, performed on a bicycle ergometer, which consisted of 10 repetitions, lasting 10 s, interrupted with 30 s rest periods ("10 x 10 s effort + 30 s rest"). Exercise power output was Pmax + 40% MAP, at the pedaling rate of 80· rev/min^{-1}*. Dynamics in changes of minute ventilation, tidal volume, respiratory frequency and heart rate from every 5 s were analyzed.*
The dynamics of the respiratory and circulatory variables, during short-term repeated physical exercises, didn't indicate differences between pre and post pubertal boys. The range of changes in measured variables decreased with each consecutive repetitions of exercise at identical intensity. The research demonstrated similar dynamics in changes of the minute ventilation and the respiratory frequency - its value was characterized by a very rapid reaction, indicating the greatest changes in the initial 5 seconds of exercise and post exercise recovery.

Keywords: *interval exercise, supramaximal efforts, respiratory variables, heart rate, puberty*

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Introduction

Changes, which take place during puberty, have an influence on the capability to perform physical efforts at different intensity. Researches of developmental physiology are predominantly concerned with the analysis of reactions to physical efforts in children and teenagers, based mostly on aerobic metabolism. Research regarding dynamics in physiological variables in repetitive short-term physical exercise is scarce, although the influence of this type of exercise in improving physical working capacity is emphasized (Adeniran and Toriola 1988; Gullstrand and Lawrence 1987; Lesmes et al. 1984; Oliver et al. 1989; Richardson et al. 1991).

Some research studies regarding kinetics of oxygen uptake, as well as variables of the respiratory and circulatory system, relate to short efforts at constant submaximal intensity (Armon et al. 1991; Casaburi et al. 1989; Cooper et al. 1985; Macek et al. 1971; Whipp 1987). The lack of scientific data, regarding dynamics of the respiratory and circulatory system during short-term intermittent exercises, allows undertaking the following research.

Energy for short-term interval exercise is derived mainly from anaerobic sources. Literature indicates that children exhibit lesser abilities to perform this type of effort (Bar-Or 1983; Eriksson 1980; Paterson et al. 1986). The organisms of young boys are not sufficiently prepared to expand maximal power. The reason for this one can find in many factors related to biochemical changes in working muscles. It has been established that this is related to less efficient exercise metabolism, especially anaerobic ATP resynthesis in children (Bar-Or 1983; Eriksson 1980). Other studies demonstrated the existence of lower supply of high-energy compounds in younger individuals (Eriksson et al. 1980; Lundberg et al. 1979) or slower pace in use of muscle glycogen (Saltin et al. 1971). These factors should theoretically differentiate pre and post puberty boys, in relation to physiological reactions to supramaximal intensity.

This type of exercises, frequently repeated, alters the character course of changes in physiological variables. Also, one should mention the "stack up" effects that take place during subsequent exercise. Lack of research results regarding repetitive physical exercises at supramaximal intensity, in reference to developmental changes, which occur during maturation, has become an inspiration for this research. The main aim of this research were then to reveal the differences in dynamics of changes in physiological reactions, in respiratory and circulatory systems, in boys at the age of pre and post puberty, in response to short supramaximal interval exercises. The attempt to designate the influence of "stack up" successive effects of short-term exercise on proportions of changes in chosen parameters in the respiratory and circulatory systems was also undertaken.

Material and methods

The research was conducted on 20 boys, divided into two age groups of ten in each (12 and 16 year olds). It was assumed, that 12 year olds didn't reach the puberty stage, and that in 16 year olds the maturity period already has ended. The above assumption was confirmed by established moment of age of peak height velocity (A-PHV) in the 16-year-old boys, which occurred at the age of somewhat less then fourteen. In the 12-year-old group, not one person reached the age of peak height velocity during the following year after the study. An increase of changes of body height was not noticed as well, which gives evidence that all of them were still in the pre puberty stage.

In the 12 year old group there were individuals of medium body height at 147.2 cm and body mass of 37.8 kg, in the 16 year old group ? boys 174.5 cm tall with body mass 61.2 kg (tab. 1). Significant differences were also noted in cases of fat-free mass. The 16-year-old boys characterized the greater volume of this parameter up to 20.9 kg. The differences in percentage of fatty tissue, in relation to total body mass, were not noted as well. The post pubertal boys displayed 15.8 %, whereas the pre pubertal ones ? 18.1 %.

Table 1 Morphological and physiological characteristics of tested subjects. Values marked with asterisks (*) show significant differences at the 0.05 level

Variable	Pre pubertal boys (mean ± SD)	Post pubertal boys (mean ± SD)	Diff.
Age [years]	11.6 ± 0.21	15.6 ± 0.26	4.0*
A-PHV [years]	——————	13.8 ± 0.83	———
BH [cm]	147.2 ± 7.32	174.5 ± 7.55	27.3*
BM [kg]	37.8 ± 5.72	61.2 ± 7.27	23.4*
LBM [kg]	30.8 ± 3.97	51.7 ± 5.92	20.9*
% F	18.1 ± 4.2	15.8 ± 4.16	-2.3
Pmax [$W \cdot kg^{-1}$]	2.88 ± 0.18	3.18 ± 0.39	0.3*
VO_2max [$ml \cdot kg^{-1}$]	46.89 ± 4.18	46.67 ± 5.33	-0.2
HRmax [$1 \cdot min^{-1}$]	193.9 ± 9.43	198,2 ± 6.64	4.3
MAP [$W \cdot kg^{-1}$]	7.57 ± 0.56	9.9 ± 0.76	2.3*

The study was divided into a ”general” and a ”specific” part. The first one included:

1. Measurement of somatic variables: body height, body mass, and skin-fat tissue folds. This allowed determining body composition and the relation between fat free mass and fat mass.
2. Progressive bicycle ergometry exercise test protocol, which allowed evaluating power output (Pmax). The initial workload was calculated relatively to lean body mass (1 W·kg LBM^{-1}). Every 2 min the intensity was increased by half of the initial workload value. The exercise was continued until exhaustion.
3. Measurement of maximal anaerobic power (MAP) with the use of 30 s Wingate Test (Bar-Or 1981).

Conventional statistical procedures were applied to aerobic and anaerobic power data analysis. Non-parametric Mann-Whitney Test verified the significance of between-group differences. The level of significance was set at $p<0.05$.

Maximal power output (Pmax), as well as maximal anaerobic power (MAP), allowed to calculate the power output for the bicycle interval exercise: „10 x 10 s effort + 30 s rest" (“10 x 10 + 30”). This test relied on performing ten repeated efforts, lasting 10 s, interrupted with 30 s rest periods. Exercise power output was Pmax + 40% MAP, at a pedaling rate of 80 rev/ min^{-1}.

Change in dynamics of the respiratory and circulatory system, were analyzed by minute ventilation ? VE, tidal volume ? VT, respiratory rate ? FR and heart rate -HR from every 5 s.

The registration of the respiratory system was done by computerized ergospirometer ,,Medikro 202" (Finland). Heart rate was recorded by means of Sport-Tester PE-4000, recording at 5 s intervals.

Dynamics of selected physiological variables during interval exercise was illustrated on evenly scaled line graphs, separately for pre puberty boys (fig. A) and post puberty ones (fig. B). Analysis of dynamics of physiological variables subjected the first, third, sixth, and ninth effort, which were marked with, appropriate numbers (1,3,6,9). The tenth repetition was omitted because of psychological factors involved in the last effort during the test that could disturb tested reactions.

Results

Measurement of selected physiological variables, which allowed to determine aerobic efficiency during maximal effort, demonstrates, that 16 years old boys reached higher values of maximal oxygen consumption by 1.1 l·min^{-1}. The level of VO_2max in both groups became almost identical when related to body mass (0.2 ml·kg^{-1}·min^{-1}). However post pubertal boys, performed the exercise at a significantly higher intensity (about 85.7 WPmax·kg^{-1}). These values were significantly higher in 16-year-old boys (by 0.3 W·kg^{-1}).

Maximal anaerobic power demonstrated large differences between subjects of pre and post puberty age. The 16 year old boys achieved 611.9 W, whereas the 12 year olds ? 286.7 W. After calculating relative values, the difference was somewhat smaller. The results of 9.9 W · kg^{-1} in post-pubertal boys, in comparison to 7.57 W · kg^{-1} in pre pubertal ones, gives evidence that the older group has significantly greater ability to perform short duration exercises at maximal intensity.

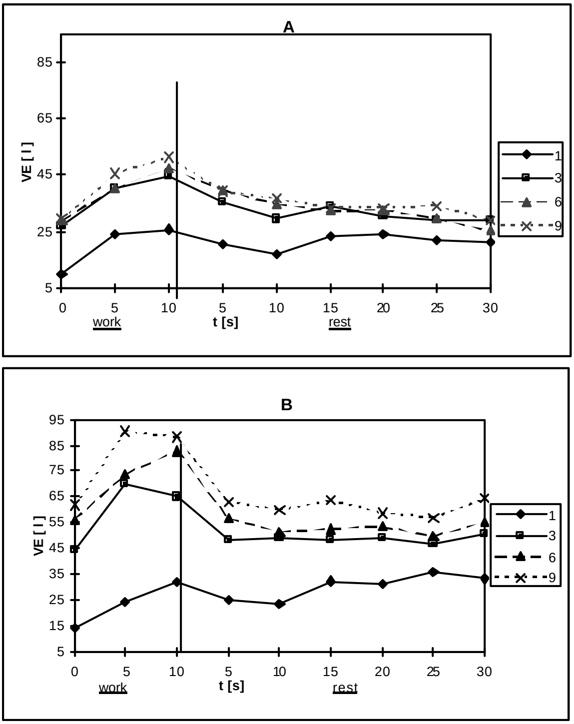

Fig. 1 Dynamics of changes in minute ventilation during “10 x 10+30” interval test in pre (A) and post (B) puberty boys (1, 3, 6, 9 ? first, third, sixth, and ninth effort of the interval test)

The comparative analysis of minute ventilation, between pre and post pubertal boys (fig. 1 A-B), showed almost a twice as much increase in the 16-

year-old boys. The maximal value of VE reached 90 l · min-1, in post pubertal boys, whereas nearly 50 l · min-1 in pre pubertal ones. The greatest changes of minute ventilation were noticed at the beginning of the test. The successive repetitions, however, didn't cause such pronounced increases of VE in 12-year-old boys. In the older group, the dynamics of minute ventilation were minimal. The greatest increases were noticed during the first 5 seconds of exercise and during resting periods.

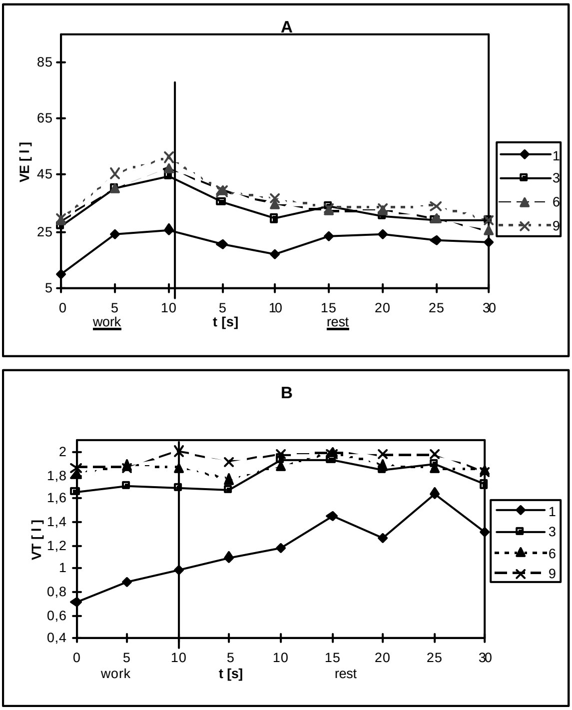

Fig. 2 Dynamics of changes in tidal volume during "10 x 10+30" interval test in pre (A) and post (B) puberty boys (1, 3, 6, 9 ? first, third, sixth, and ninth effort of the interval test)

In post pubertal boys a double fold increases in tidal volume occurred, then those in the 12-year-old group (fig. 2 A-B). The 12-year-old boys reached tidal volume of 1 liter, the 16-year-old ones, however, acquired values up to 2 liters, at the very similar dynamics. Opposed to the initial exercise, which was performed at much lower level of tidal volume, the following repetitions were performed at almost the same level. Furthermore, during initial exercise, the constant increases in VT included not only the period of work, but the entire section of rest periods as well. Consecutive repetitions, however, didn't bring any changes in tidal volume.

Pre pubertal boys registered a slightly higher respiratory rate than post pubertal ones (fig. 3 A-B). The maximal level of FR acquired by them, was 60 respirations, however, in the post pubertal group it was 50 respirations per minute. The highest increases were noted after the initial 5 seconds of each exercise. Similarly, as it was in the exercise period, maximal changes in respiratory rate were demonstrated in the initial 10 seconds of the rest periods.

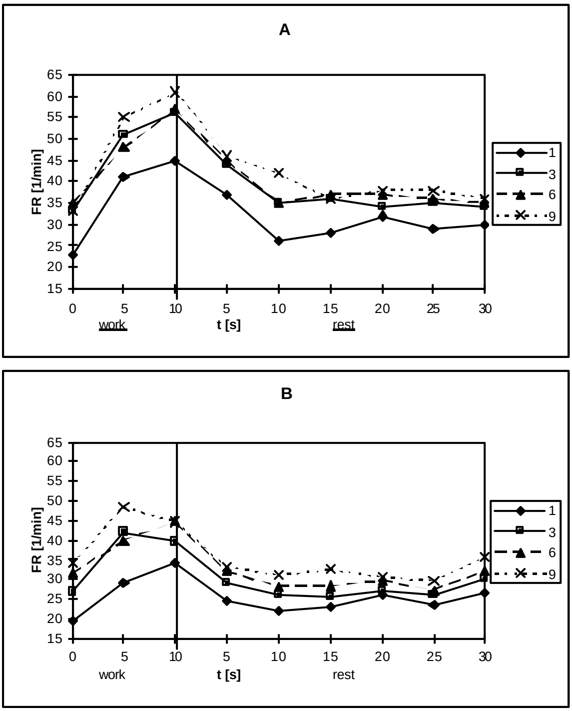

Fig. 3 Dynamics of changes in respiratory frequency during “10 x 10+30” interval test in pre (A) and post (B) puberty boys (1, 3, 6, 9 ? first, third, sixth, and ninth effort of the interval test)

Dynamics of changes in heart rate did not show any differences between the pre and post pubertal boys (fig. 4 A-B). The 16 year olds reached a higher maximal HR (around 10 beats per minute) than 12-year-old boys. The increase in heart rate took place during the periods of work and also during the first 10 seconds of recovery periods. Later the HR slowly declined. The highest increase in heart rate took place during the initial exercise of the experiment. The following ones didn't bring any significant changes.

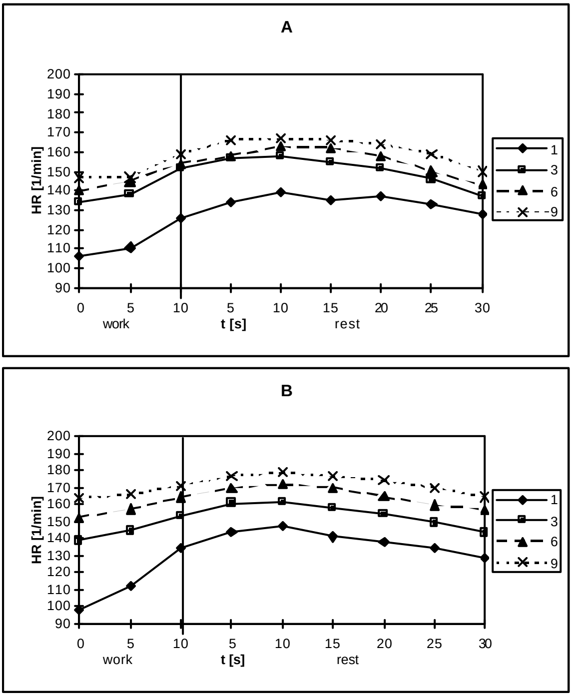

Fig. 4 Dynamics of changes in heart rate during "10 x 10+30" interval test in pre (A) and post (B) puberty boys (1, 3, 6, 9 ? first, third, sixth, and ninth effort of the interval test)

Discussion

Taking under consideration the effects of short-term physical exercises on respiratory system variables, one should remember their ,,delay" in relation to muscular metabolic changes (Whipp 1987). The reason for this is, in one sense, the time of CO_2 transport from muscles, where the changes take place, to the lungs; and the other ? the ability to take advantage of tissue reserve of oxygen connected with myoglobin. Due to this, the analysis of expired air composition should be treated as a delayed effect in metabolic changes, which occurs in working muscles.

Cooper et al. (1985) have discovered that values of minute oxygen uptake and heart rate during steady-state, do not show any differences in age groups between 10 and 18. The present research confirms this data. Heart rate in both research groups was similar. Cooper et al. (1985) noted, that the dynamics of these variables were also similar. Dependence of kinetic minute oxygen uptake and heart rate, in relation to age and body size, was not established. This study fully confirmed this in relation to HR; dynamics of oxygen uptake were not subjected to detailed analysis. De Vries et al. (1982) accomplished the comparison in VO_2 and HR in age groups of 2l-29 and 60-69 yr. old. In this case, the dynamics of mentioned variables, didn't show any significant differences as well.

Research results of Cooper et al. (1985) and De Vries et al. (1982) are somewhat different from the observations of Macek and Vavra (1980), who have noted that in 10-year-old boys there was a faster increase in minute oxygen consumption than in 20-year-old males. The dynamics of heart rate were also significantly higher in younger individuals. Similar results were obtained by Armon et al. (1991). They noted greater changes in $VO_2 \cdot kg^{-1} \cdot min^{-1}$, and faster achievement of “steady-state”, in children at the age of 6-12, during efforts of submaximal intensity, than in adults at age of 27-40.

Own research demonstrated faster stabilization of other variables: minute ventilation, tidal volume and respiratory frequency in pre pubertal boys. The level of VE and VT was definitely lower than in post pubertal boys. The respiration rate, however, was somewhat higher in the 12 yr. olds. Minute ventilation and minute carbon dioxide output, according to Cooper et al. (1987), showed greater dynamics in children than in adults, although this author confirms, that mentioned differences are not so great as the differences in body size and age.

Casaburi et al. (1989), also tested the dynamics in changes of minute oxygen uptake, minute ventilation and carbon dioxide output, during submaximal intensity. They showed that VE and VO_2 dynamics, at the greater intensity of exercise, are lower than during the less intensive exercises. Dynamics of changes are minute carbon dioxide output is different. During greater exercise intensity, however, there is no decrease in VCO_2. This is probably due to non-metabolic CO_2, which is the product of buffering of hydrogen ions. The presented above results were confirmed by other authors (Linnarsson 1974; Pearce and Milhorn 1977; Whipp and Wasserman 1972). Casaburi et al. (1989) noted, that at constant intensity of exercise, initially there is stabilization of minute oxygen consumption, later carbon dioxide output, and at the end ? minute ventilation. At a higher intensity of workload, VO_2 and VCO_2 are stabilized almost simultaneously.

Similar to those in this research study, 10 s exercise tests, were conducted by Macek et al. (1971). These tests referred to designation of dimorphistic differences in minute oxygen uptake and heart rate. The first variable showed higher values in boys, the second one, however, did not differentiate the tested groups.

Significant increase in minute ventilation and minute oxygen uptake was noted after exercise lasting several seconds, as the result of increased impulsation from proprioceptors and motor cells of anterior spinal column (Dejours 1963). Exercises lasting 10 s used in presented research, due to short time of duration, undergo the same regulation mechanisms. This refers especially to the initial exercise of each test. Changes of minute ventilation in consecutive repetitions are the effect of nerve regulation and humoral influence.

Hebestreit et al. (1991) noted, that after the exercise test at supramaximal intensity, lasting 30 s, the effective rest period was shorter in boys in relation to adults. The teenager group was characterized by shorter recovery time of muscle capability to achieve maximal anaerobic power. This problem was not analy zed in this research, due to very short duration of resting periods.

Earlier research of other authors proved, that dynamic of changes of minute oxygen uptake and minute ventilation (Hughson and Morrisey 1982), as well, as the heart rate (Lamarra 1982), is greater right after the beginning of exercise, than as a result of repeated interval exercises. This was confirmed by own research. Due to high initial levels of studied variables, the repeated exercises showed lower increases. This was the effect of earlier performed exercises. This related to all other variables, especially the tidal volume, that indicated an increase only in the initial exercises. The following repetitions didn't bring any change in values of VT.

In this study, unlike other studies, selection of workload in both age groups was based on aerobic power output and maximal anaerobic power of particular individuals. The most popular way to compute work intensity, in relation to body mass of subjects, is not always proportional to effort capabilities, because of different pubertal changes in anaerobic and aerobic power. Relation between those two magnitudes indicate different tendency to change in different individuals. This would indicate, that their individual workload should be taken into consideration. Principles of selecting intensity of exercise, presented in this study, turned out to be valid. This is confirmed by similar reaction of heart rate in both age groups.

Conclusions

1. The dynamics in basic variables of the respiratory and the circulatory system, during short-term repeated physical exercises, didn't indicate differences between pre and post puberty boys.
2. During performance of interval exercise at supramaximal intensity, post pubertal boys were characterized by twice as high levels of minute ventilation and tidal volume, compared to pre pubertal boys. The respiration rate was somewhat lower.
3. The study didn't reveal any differences in the range of heart rate at given level of exercise. This indicates that there is no actual impact of the developmental phase on magnitude in HR changes.
4. The range of increases in variables of the respiratory and the circulatory systems became smaller with each consecutive repetition of exercise at the identical intensity.
5. The research demonstrated similar dynamics in minute ventilation and respiration rate. Its value was characterized by a very rapid reaction, indicating the greatest changes in the initial 5 seconds of successive exercises and post exercise recovery. Similar dynamic changes were observed in tidal volume and the heart rate

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