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Supramaximal intermittent exercise – A comparison of effects on anaerobic and aerobic capacity in trained prepubertal boys and trained adults

Authors' Contribution:
A Study Design
B Data Collection
C Statistical Analysis
D Data Interpretation
E Manuscript Preparation
F Literature Search
G Funds Collection

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abstract

Background: The aim of this study was to investigate possible variations in trained children and adults in physiological, metabolic and performance factors in response to supramaximal intermittent exercise.

Material and methods: Fourteen adult trained men (eight long-distance runners and six sprinters) and seven 12-year-old trained boys performed two exercise tests on separate days: incremental cycloergometric test to determine VO_2 max, AT and a supramaximal intermittent exercise (SMIE) test to determine peak power, anaerobic and aerobic capacity and also blood acidification.

Results: The results have shown similar relative values of VO2 max and total work performed in WAnT between boys and adult ($p > 0.05$) and significant differences in power peak between boys and sprinters. Total work in SMIE was performed at the energy cost from aerobic and anaerobic metabolism in boys and sprinters respectively: aerobic – 49% and 10%, glycolytic – 31% and 70%, phosphagenic – 20% and 20%. There were significant differences between groups in [La-], with no changes in parameters of acidification.

Conclusions: Differences between boys and adults shown under SMIE conditions are important in the practical conduct of the training appropriate to the metabolic and physical capacity of peri-pubertal boys.

Key words: repeated 30-s WAnT, ATP-PCr and glycolytic processes, blood lactate, acid-base balance.

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INTRODUCTION

Physical effort of certain intensity in different sports can be continued if the supply of ATP and its consumption in recruited to work myocytes are balanced. This condition can be met if the processes of ATP resynthesis and utilization are balanced.

The most important aspect of metabolic demands is the proper contribution of the energy systems (aerobic, anaerobic, alactic-phosphagenic and anaerobic lactic-glycolytic), in the adequate proportion in the total energy required by organism for activity in football (sprint-endurance repetition exercise). It is known that also children take part in physical training of football consisting of elements of repeated endurance and sprint.

The specific metabolic requirements in the body of boys training football in pre-pubertal/pubertal period are also interesting because of differences resulting from the child's developmental age. It is well recognised that functional changes occur throughout children's growth, particularly in skeletal muscles. Scientific studies have identified a number of important functional changes in muscles, especially significant for strength development; however, fatigue factors resulting from metabolic processes are not recognised well [1, 2].

Similarly, metabolic changes studied during repeated high-intensity exercise in the child's body give a different functional effect in comparison to adults [3, 4, 5]. Exercise capabilities differ in children and adults. These differences are connected with morphological, metabolic and regulative differences in tissues and organs, including the circulatory, respiratory and locomotion system. In children's skeletal muscle slow-twitch fibres ST dominate, and low glycolytic enzymes activity is present. This seems to predispose children to aerobic exercises [6, 7]. Such conditions in adults provide a basis for continuing of endurance training.

Taking into consideration important conditions given above, consisting of endurance and strength as well as functional and metabolic differences between children and adults, we used a model of physical exercise in that study. It consisted of three times repeated cycloergometric 30-s Wingate Test with seven min of recovery between each bouts. Such a protocol was used earlier in our studies [8, 9]. The 30-s Wingate Test allows evaluating relative anaerobic and aerobic contributions to the total energy release [10, 11] and allows estimating the possibilities to maximal acidification in the examined athletes [13, 14].

The aim of this study was to determine the differences between children and adults in selected physiological, metabolic and functional factors, which may be caused by the basis of comparative studies of answers to the SMIE test of the body of children training football and adult athletes training long-distance and sprint running.

MATERIAL AND METHODS

PARTICIPANTS

Fourteen young trained men (eight 24.7 ±4.5 years long-distance runners and six 20.4 ±2.1 years old sprinters) and seven 12 ±0.8 years old football player voluntarily participated in the study. This study was approved by the local Research Ethic Committee and was conducted in accordance with the Declaration of Helsinki. All participants performed two-exercise tests. Exercise tests were performed on separate days: an incremental cycloergometric test to determine VO_2 max, anaerobic threshold (AT) [10] and after 48h rest – supra-maximal intermittent exercise test – 30 s Wingate Test (WAnT) [9] three times repeated with seven min of recovery between each bout to determine peak anaerobic power, anaerobic, aerobic capacity and blood acid base balance.

Experimental protocol

Aerobic power measurement

All subjects performed a graded cycloergometric test on an electromagnetically braked cycloergometer ER 900 Jaeger, Germany. Participants started the test with a warm-up that consisted of a five-min cycloergometric work at an intensity of 1.5 W/kg with a pedalling cadence of 60 rpm. Immediately after the warm-up, they began VO_2 max testing by cycling at increasing workloads in which resistance was increased by 25 W/min until the participant reached the point of volitional exhaustion. The recovery was passive with the participant in a seated position. Breath-by-breath pulmonary gas exchange was measured (Oxycon-Pro, Jaeger-Viasys Health, Germany) VE, VO_2 and carbon dioxide output (VCO_2) were continuously measured breath by breath the nonlinear increase in ventilation (ventilation threshold) was used to determine AT. The AT indicates the point during exercise at which lactate and ($H^{+)}$ protons concentration begins to increase in the blood [11]. Protons are buffered by the bicarbonate, and CO_2 is liberated. CO_2 is released in this reaction. Its increase results in a disproportionately high expansion in VE and VCO_2 compared to VO_2.

Anaerobic power measurement

The subjects performed a five-min warm-up at 1.0 W/kg b.m. and the appropriate exercise test on the mechanically braked cycle ergometer (884E Sprint Bike, Monark, Sweden) according to the previously described procedures [10].

After five min of rest, the subjects performed three consecutive 30s Wingate Tests (WAnT) separated by seven-minute recovery intervals against a friction load. A flywheel resistance equalling 0.075 kg/kg b.m. (corresponding to 7.5% of each individual's body mass) was applied at the onset of the WAnT. After test termination, the participants were supervised during a fifteen-minute recovery in a seated or supine position. The participants were actively encouraged throughout the test. During the test, the computer software automatically calculated the following indices describing the WAnT performance for each five-second segment of the WAnT: mechanical power, Peak Power (PP), defined as the highest mechanical power achieved at any stage of the test; Mean Power (MP), the average power sustained throughout the 30-second period; the Fatigue Index (FI); Total Work (Wtot), expressed in Joules (J) or J/kg b.m.

Blood sampling

Each participant in the study was had his blood sample taken twice:

- 1st blood collection: capillary arterialized blood was collected under anaerobic conditions to determine the acid-base balance parameters.

- 2nd blood collection: blood samples were taken from antecubital vein to determine lactate and $[H^+]$ – at rest and five minutes after each episode of the 30s Wingate Test in the SMIE test and after fifteen minutes of rest after the entire SMIE test.

Blood acid-base equilibrium parameters measurement – Using a blood-gas analyser (model 238, Ciba-Corning), the following parameters were measured immediately after blood collection: blood pH, pCO_2, pO_2, $[HCO_3^-]$, tCO_2, BE (base excess), $\%SatO_2$.

Lactate, H^+ concentration measurement – Immediately after collection, the blood was deproteinised by the addition of ice perchloric acid. The samples were centrifuged and plasma was used to determine lactate concentration. Lactate concentration was determined enzymatically according to the spectrophotometric method, using the Randox kit based on the L-lactate O_2 oxide reductase, which catalyses oxidation of L-lactate to pyruvate and hydrogen peroxide. The [La] value corresponds with each $[H^+]$.

Statistical analysis

The results were reported as mean ±SD. All statistical analyses were conducted using Statistica 8.0 software. Statistical differences in time within groups were evaluated by paired Sample t-test. Because of the small group size, the non-parametric Kruskal-Wallis test was used for evaluating statistical differences between the groups. Relationships between variables were analysed by Pearson’s correlation coefficient. The level of significance was set at $p \leq 0.05$.

Results

Physical characteristics and VO_2 max of the subjects are described in Table 1. Absolute values of VO_2 max (L/min) are the highest in the adult endurance athletes and the lowest in the trained boys group. The differences are statistically significant ($p < 0.01$). Absolute VO^2 max values, as expected, are the lowest in boys training football and the highest in adult long-distance athletes (Fig. 1). However, after converting these values into kg body mass, we obtained relative values VO^2 max in boys equal to these in long-distance runners and slightly higher than in sprinters (Fig. 2).

AT values measured in % of VO2 max were in the groups of trained boys, long-distance runners and sprinters, respectively: 69.0 ±8.9, 76.2 ±7.5, 54.2 ±6.9 (differences are statistically significant $p \leq 0.05$) (Table 1).

Table 1. Participants’ anthropometric characteristic and aerobic and anaerobic parameters

Variables	Long-distance runners	Sprinters	Boys training football
Age (years)	24.7 ± 4.5	20.4 ± 2.1	12.7 ± 0.8
Body mass (kg)	69.0 ± 5.4	78.2 ± 3.2	42.3 ± 6.3
Height (cm)	176 ± 5.8	177 ±6.3	160 ± 6.4
VO2 max (l/min/kg)	62.8 ± 3.3	54.8 ± 4.2	60.1 ± 2.4
Peak power (Watt)	373.1 ± 35.6	344.3 ± 27.1	202.4 ± 26.9
AT in % VO2 max	79.3 ± 5.8	57.6 ± 8.7	69.0 ± 6.3

VO_2 max = maximal oxygen uptake; AT = anaerobic threshold. Values are mean ±SD

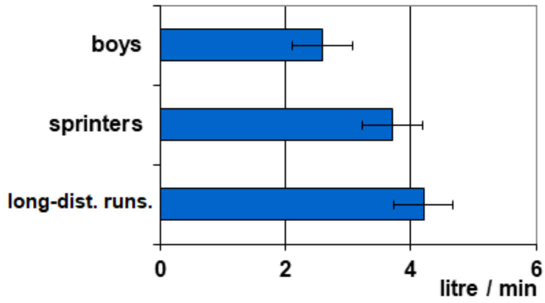

Fig. 1. Absolute values of VO_2 max in footballers – boys, adult sprinters, and adult long-distance runners

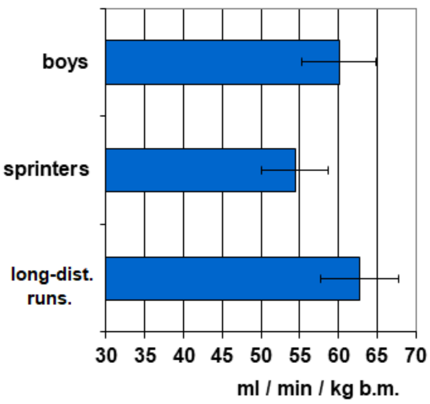

Fig. 2. Relative values of maximum O_2 uptake (VO_2 max) in footballers – boys, adult sprinters, and adult long-distance runners

Anaerobic work capacity, power peak

The relative values of total anaerobic capacity during SMIE were the highest in every 30-s Wingate Test in sprinters and the lowest in the group of boys (Fig. 3). In consecutive repetitions of 30-s Wingate Test, we controlled the participation of phosphagenic and glycolytic components of total work done in boys and sprinters (Fig. 4 and Fig. 5). Differences in the obtained energy between the studied groups are clear. In boys almost 50% of energy uptake comes from aerobic processes and in sprinters about 70% from glycolysis. In both groups the contribution from PCr breakdown to energy demand was about 20%.

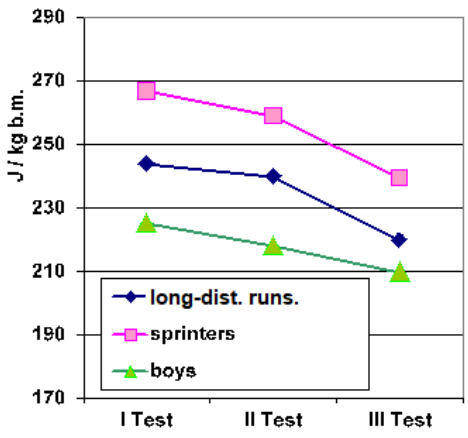

Fig. 3. Relative values of total work performed in subsequent repetition of 30-s WAnT by footballers-boys, long-distance runners, and sprinters

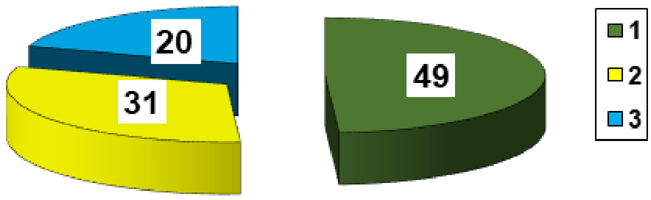

Fig.4. Percentage share of anaerobic [phosphagenic (3) and glycolytic (2)] and aerobic (1) processes in covering the energy demand for the total anaerobic work (30-s WAnT – 3-times repetition) in trained boys

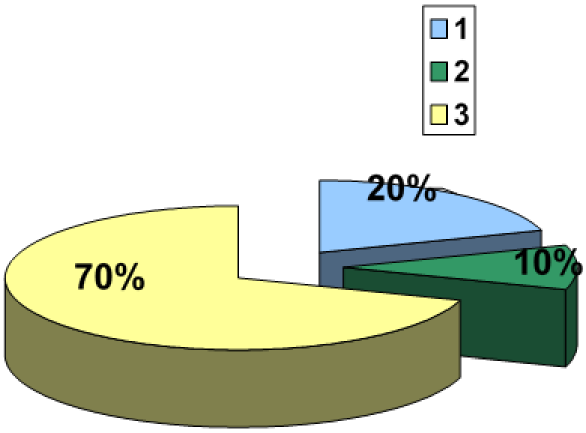

Fig. 5. Percentage share of anaerobic [phosphagenic (1) and glycolytic (3)] and aerobic (2) processes in covering the energy demand for the total anaerobic work in adult sprinters

Absolute and relative values of peak power output during exercise bouts 1, 2 and 3 were greater in the group of sprinters than in boys and the endurance group, and the differences were significant ($p \leq 0.05$) (Fig. 6).

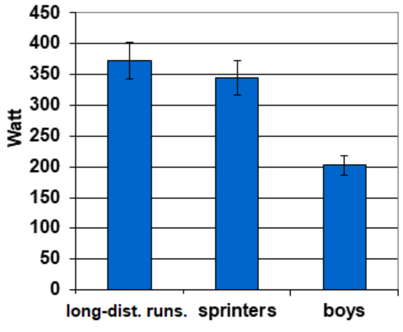

Fig. 6. Absolute values of maximal anaerobic power obtained in the first WAnT by footballers-boys, adult sprinters and long-distance runners during the SMIE test

Blood lactate concentration and acid–base balance parameters

After the each performance of three repetitions of WAnT, La- /H+ concentration was the greatest in the both groups of adult athletes and the smallest in boys (Fig. 7). Differences are statistically significant ($p<0.05$). Changes in blood [La-] were as follows: after the first bout 4.5 mmol/l, 9.94 mmol/l, 17.52 mmol/l in boys, long-distance runners and sprinters, respectively. After the complete SMIE test, the values of blood [La-] increased up to 5.16 mmol/l, 14.5 mmol/l, 20.65 mmol/l in boys, long-distance runners and sprinters, respectively (Fig. 7). It is interesting that despite 2–3 times lower blood [La-] in boys than in adult athletes, the difference in acid-base balance parameters between the investigated groups were not statistically significant ($p > 0.05$) (Fig. 8, 9, 10).

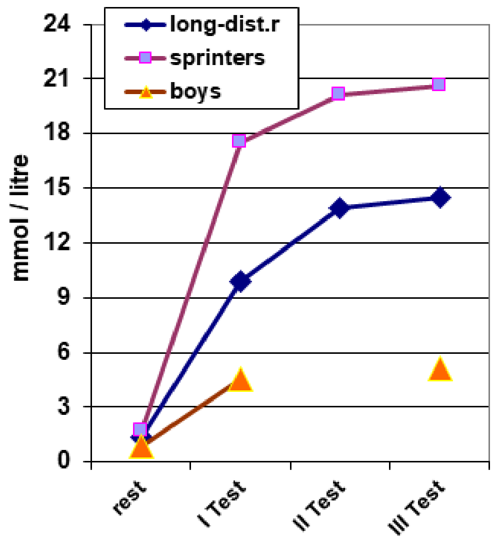

Fig.7. Concentration blood La- / H+ changes during subsequent repetitions of 30-s WAnT in boys and adults: sprinters and long-distance runners.

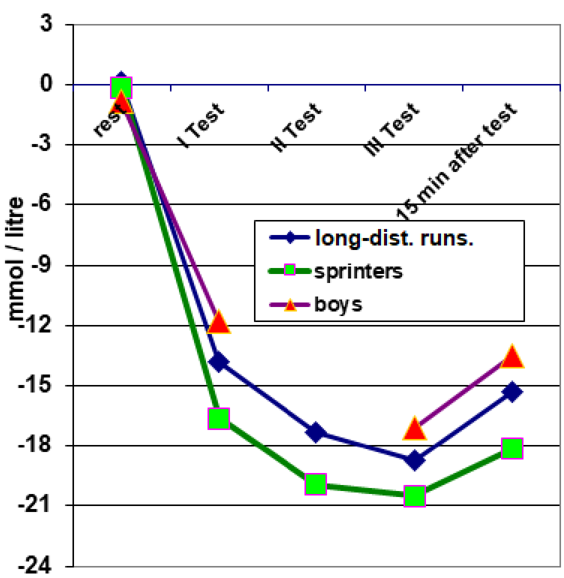

Fig. 8. Changes in values of blood base buffering deficiency (BE) after successive repetitions of WAnT in boys, long-distance runners, and sprinters

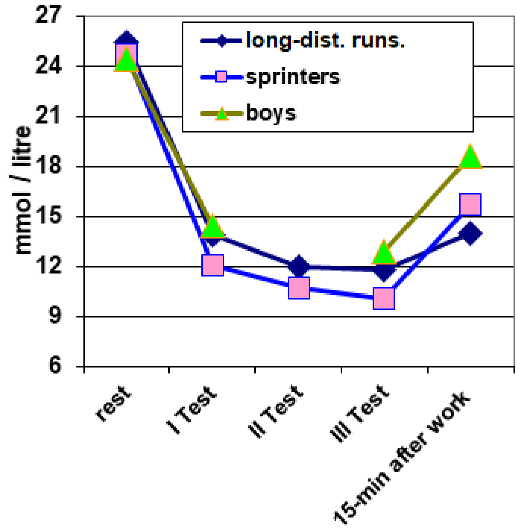

Fig. 9. Changes of blood bicarbonate values after successive repetitions of 30-s WAnT in boys, long--distance runners, and sprinters

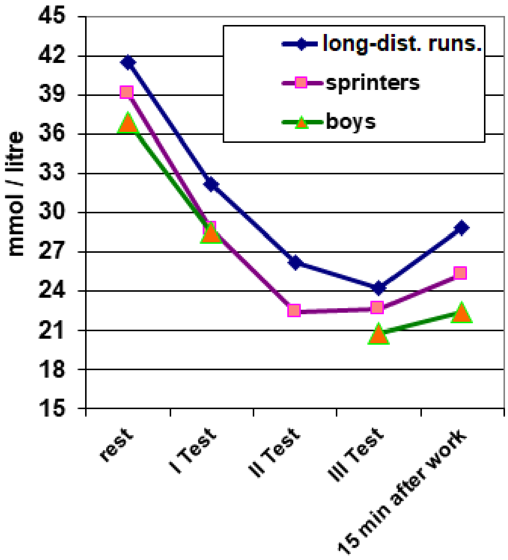

Fig. 10. Changes of blood partial CO_2 pressure (pCO_2) after successive repetitions of 30-s WAnT in boys, long-distance runners, and sprinters

DISCUSSION

The ability to perform in a football match consists of the ability to perform important components of activity, such as speed, repeated sprint and endurance running acceleration, maximum running speed and repeated sprint ability [14–16]. It is known that the above-mentioned capabilities are considered in terms of specific physiological and metabolic factors and different training techniques. In boys training football, the ability to perform such specific physical effort is poorly recognised. In addition, in boys the capability to alternate sprint and endurance runs changes with the processes of growth and maturation [15–17].

The main aim of the present study was to determine possible variations in trained children and adults in specific physiological, metabolic and performance factors in response to supramaximal intermittent exercise. The analysis of the maximum oxygen uptake (VO_2 max in ml/min/kg b.m.) by the examined athletes did not show significant differences between boys training football and adult sprinters and values were close to these in adult long-distance runners. Our results were similar to those of other researchers [18–20]. Similarly, we found no significant differences in the anaerobic threshold (AT) between the studied groups. Differences were visible in the results of other researchers concerning the kinetics of exercise oxygen uptake in children and adults. They showed a higher oxygen uptake by children in II-kinetic phase, which can be explained by the higher amount of type I fibres in their skeletal muscles [21–23]. This study shows that high aerobic performance measures of boys training football are comparable to those measured in adult long-distance athletes. The obtained results indicate that the examined boys have a great ability to make endurance efforts in a football match. Taking into consideration the importance of the ability of football players to perform speed efforts, including the possibility of its repetition, the anaerobic power parameters of boys and adult athletes were measured based on the SMIE test. The experimental procedure was based on supramaximal intermittent exercise consisting of three bouts of 30-s Wingate Test separated by seven minute rest (SMIE), because this model of exercise more accurately reflected the activities in some acyclic sports. During conditions of supramaximal intermittent exercise, we investigated changes in parameters defined the anaerobic power, total work done and its phosphagenic and glycolytic components and also fatigue factors assessed on the basis of changes in blood amount of La^- and parameters of acid-base balance. The SMIE exercise test due to appropriately selected length of rest breaks between successive full transport of La^- / H^+ [8, 25–27] to blood and effective functioning of phosphocreatine shuttle regulates the oxidative function by effects of mitochondrial oxidative phosphorylation [28, 29].

The obtained results have shown the relative maximum power (P max in W/kg b.m.) in 12-year-old boys training football close to adult long-distance runners and only 20 % lower than in sprinters. The values of the total absolute and relative work done in the SMIE test was the highest in sprinters and the lowest in boys group .These differences may result from the percentage of skeletal muscle fibres types I, II and mixed in athletes and from adaptive changes caused by different types of training in adults participants. In children of pre-pubertal and pubertal age, the composition of muscle fibres does not change [30, 31]. But the revealed decline of total work done during consecutive WAnT bouts in all groups could indicate the growing share of aerobic processes and an increase in the glycolytic activity in adults, mainly in adult sprinters [31–33].

In the SMIE test conditions used in one study, we determined the percentage share of phosphagenic, glycolytic and aerobic processes in the energy supply to perform the total work done in 30 s WAnT in boys and adults sprinters. A similar share of phosphagenic energy supply, as obtained by the author, has been described by other researchers [31, 33, 34]. The SMIE test applied in this study allowed us to differentiate well the participants' ability to maximal acidification. The obtained results showed 2–3 times lower blood [La^-] in boys, while the changes in acid-base balance parameters were similar to these in adults. The explanation of such differences requires further research taking into account the complexity of physiological processes in the period of intensive growth and maturation.

CONCLUSIONS

These data demonstrate that the model of SIME exercise consisted of three repetitions of 30-s WAnT with seven minutes' rest periods between following bouts, applied in this research, allowed us to determine the physical parameters characterising aerobic and anaerobic effort and to determine the share of phosphagenic, glycolytic and aerobic processes in covering the energy demand for the total work to be done.

A properly selected relationship between physical effort and rest time after following exercise repetitions [35, 36] gives an opportunity to assess the ability of the body of children and adults to adapt to maximal acidification and to compare the body's response to physical activity characteristic of many acyclic sports disciplines. A comparison of differences in the boys and adult athletes' reaction to the applied exercise load of the SMIE test allows specifying the basic practical suggestions for specific training of boys in the pre-pubertal, pubertal, and post-pubertal periods.

In practice:

- pre-pubertal children's skill training improves running economy, technique and basic training – VO_2 max,
- pubertal and post-pubertal children's training focus improves anaerobic energy processes, speed and strength.

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