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Improving Aerobic Power in Primary School Boys: A Comparison of Continuous and Interval Training

Abstract

The purpose of this study was to assess whether the magnitude of change in aerobic power was different in boys (mean age 10.25 ± 0.50 y) who followed a high-intensity interval training protocol, compared to those who followed a moderate-intensity continuous training protocol. Boys were assigned to either a control group ($n = 15$), a continuous training group ($n = 10$), or an interval training group ($n = 10$). They completed peak oxygen uptake tests at baseline and following an 8-week training period. The control group continued with normal activity habits, whilst the continuous training group followed a 20-minute steady-state cycle protocol at 80 – 85% of the maximal heart rate, and the interval training group completed 30-s sprints on a cycle ergometer, interspersed with active rest periods. The two training protocols were designed to incur similar cardiovascular work over the 20 minutes of each training session. Significant increases ($p < 0.05$) in peak oxygen uptake were noted for both the interval and continuous training groups. The interval training group showed marked pre- to post-increases in both peak oxygen pulse, oxygen pulse at the ventilatory threshold, and ventilatory threshold that were not apparent in the continuous group boys. It would appear that a high-intensity interval protocol confers a different training effect in comparison to continuous steady-state training in boys. Possible mechanisms that underpin these adaptations may include increased blood volume and a concomitant adjustment in stroke volume.

Key words
Cardiorespiratory fitness · training · children

Introduction

High-intensity interval training in adults has been shown to result in marked increases in oxidative metabolism [5,6,14,31], and attenuation of glycogenolysis and glycolysis [10]. The degree of change in aerobic power and related variables not only depends upon the intensity of the given intervals, but also the length and nature of the recovery. The combination of short, intense intervals with longer recovery periods appears to tax the anaerobic system less and the aerobic system more, since more time is available for phosphagen re-synthesis [5]. When active as opposed to passive recovery periods are used, this has been found to additionally facilitate lactate removal, allowing the high-intensity intervals to be tolerated for longer [6].

Recent reviews [2,15] provide evidence that increases in aerobic power in children are also gained at a higher training intensity (at least 75% of heart rate maximum), with training at “all-out” intensities eliciting the greatest response. Our understanding of the effectiveness of interval training in children is, however, limited. A review of the available interval training studies reveals wide differences in the training protocols utilized, from long intervals (3 minutes) with short pause durations [28], to short intervals with short pause durations [1], to fixed distance runs [3]. Establishing whether the magnitude of change in aerobic power

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would be different in children who follow a high-intensity interval training protocol, compared to those who follow a more traditional continuous training protocol, also requires other aspects of the training to be held constant (such as training duration, frequency, and total work). None of the available studies in children that have compared continuous and interval training protocols [20,32] have attempted to equalise total work. Therefore this study investigated the effect of moderate-intensity continuous training and high-intensity interval training (short intervals, long recovery bouts) on aerobic power and related variables, whilst keeping total cardiovascular work constant. We choose to use total cardiovascular work as our total work equalization model because of the established link between alterations in cardiac parameters and improvements in aerobic power in childhood [21–23].

Material and Methods

Subjects

Chinese boys in primary grades four and five volunteered to participate in this study. We chose this nine- to eleven-year-old age group because the published growth and development data for Hong Kong [16] indicate that most Chinese boys are prepubertal at this chronological age. The study protocol was approved by the Institutional Ethics Committee and written parental and child consent were obtained. All the testing and training took place at school in a laboratory temporarily established in an air-conditioned room. Subjects who successfully attained a peak value in the pre-training peak$\cdot\dot{V}O_2$ test were selected on a random basis to be a part of a control group (CG), a continuous training group (CTG), or an interval training group (ITG). From the remaining 45 boys, 15 were assigned to each group. Group sizes in the final analyses were reduced to 15 boys for CG and 10 boys for CTG and ITG due to non-compliance, which was defined as completion of less than 22 of the 24 training sessions.

Testing procedures and measurements

The children completed pre- and post-training peak$\cdot\dot{V}O_2$ tests. They were asked not to eat two hours before each exercise test. When they arrived they were familiarised with the equipment and procedures, and were asked to fill in a short questionnaire. The questionnaire asked about their recent health and whether they were involved in any competitive sport training. None of the boys trained regularly. Stature was measured, to the nearest 0.1 cm, using a wall mounted stadiometer and mass was measured, to the nearest 0.1 kg, using electronic scales.

A continuous, incremental exercise test to volitional exhaustion was conducted on a mechanically braked upright cycle ergometer (LODE NV, Holland). Following a five-minute warm-up, the children were asked to pedal continuously at 70 rpm throughout the test. The test began with an initial two minutes of unloaded pedalling. Following 4 minutes at 50 W, the intensity was increased every minute in 10-W increments until exhaustion.

Throughout each test, standard respiratory gas samples were analysed breath by breath using a Jaegar Oxycon Pro metabolic cart (Jaegar Toennies, Germany). These data were averaged using 20-s intervals. The Oxycon Pro has previously been validated and shows very good reliability [8,26]. The system was calibrated before each test with gases of known concentrations of oxygen and carbon dioxide. Calibration of the digital turbine volume sensor was performed using a 3-l syringe (Hans Rudolf, USA). Heart rate (HR) was recorded using a Polar heart rate monitor (Polar Electro Oy, Finland). Heart rate data were expressed every 20 s from 8-beat averages. To estimate the oxygen delivery to the exercising muscle during each cardiac cycle, we calculated the oxygen pulse ($mlO_2 \cdot beat^{-1}$) by dividing $\dot{V}O_2$ ($ml \cdot min^{-1}$) by heart rate ($beats \cdot min^{-1}$).

The highest $\dot{V}O_2$ was accepted as the peak$\cdot\dot{V}O_2$ when at least two of the following criteria were attained:

1. intense signs of effort (sweating, hyperpnoea, facial flushing, grimacing);
2. reaching a heart rate within five percent of the age-predicted maximum;
3. a levelling of heart rate over the final stages;
4. a respiratory exchange ratio of at least unity [27].

To assess submaximal responses, we reported HR, $\dot{V}O_2$ ($l \cdot min^{-1}$), $\dot{V}O_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$), percent peak$\cdot\dot{V}O_2$, and oxygen pulse recorded at the ventilatory threshold (VT). VT was determined by a single investigator who was blinded to the identity of the subject and test. VT was determined using the following criterion [11]: an increase in ventilatory equivalent for oxygen ($V_E/\dot{V}O_2$), without an increase in the ventilatory equivalent for carbon dioxide ($V_E/\dot{V}CO_2$).

Design of the training protocols

A pilot study was conducted to develop two training protocols that delivered comparable cardiovascular work. Subjects from the training groups were asked to complete a two-phase protocol. The first phase took place over two separate days and involved the children in three 10-minute steady-state bouts on a cycle ergometer, with a 40-minute rest period between each bout. Each bout consisted of 2 minutes unloaded cycling, immediately followed by a 4-minute loaded cycling phase and 4 minutes of recovery. On the first day, the boys completed the three 10-minute bouts at 70% of individual peak$\cdot\dot{V}O_2$, whilst on the following day, the load was set at 85% of individual peak$\cdot\dot{V}O_2$. Throughout this protocol, heart rate and oxygen uptake responses were assessed.

The children completed the second phase a day later, which consisted of a warm-up, immediately followed by a 30-s maximal speed sprint on a cycle ergometer and a 4-minute recovery. The sprint intensity was set at the peak power elicited during their peak$\cdot\dot{V}O_2$ test. The HR graph against time was plotted for the steady-state bouts at 70 and 85% peak$\cdot\dot{V}O_2$ loading, and for the sprint bout. The area under the curve was integrated and equalized in all cases to determine the mean intensity and the recovery time for the interval training, allowing an equalization of the total cardiovascular work done.

Training protocols

The CTG and ITG trained on cycle ergometers for 20 minutes, three times per week for 8 weeks. The CG were asked to maintain their normal physical activity habits.

During the eight weeks, the CTG programme consisted of 20-minute sessions of continuous cycling period at a heart rate between 160 to 170 beats per minute. This equated to a mean intensity of 75 – 85% peak$\cdot\dot{V}O_2$, or 85% heart rate maximum (HR_{max}), established in the pre-training peak$\cdot\dot{V}O_2$ test. Intensity was monitored by HR monitors during each training session and supplemented by reporting the travelled distance for each session. Intensity was maintained via a resistance of around 1 kg in the initial sessions with the children choosing their preferred rate, which was between 75 – 85 rpm. The intensity was adjusted whenever necessary to maintain the targeted heart rate.

In contrast, the ITG completed 30-s interval sprints each time they heard a whistle during the 20-minute sessions. The pilot tests resulted in a protocol of seven maximal speed sprints of 30 s being completed during a 20-minute session, with a load set at the power elicited at peak$\cdot\dot{V}O_2$. Between each sprint, an active unloaded rest bout of 2 minutes 45 s cycling was allowed. The boys also recorded the total distance travelled in each session. Verbal encouragement was given throughout each session to ensure that the boys gave an all-out effort during sprinting.

Statistical analyses

The pre- and post-test data are expressed as mean and standard deviation (mean ± SD). A two-way analysis of variance (group by time) was used to compare pre- vs. post-training anthropometric values. A one-way analysis of variance (ANOVA) was used to compare the groups at baseline. Since baseline differences were apparent in a number of metabolic variables, the effect of training on both maximal responses and responses at VT were analyzed for statistical significance by using an analysis of covariance, with the pre-test value as the covariate. The adjusted post-test data are expressed as means and standard error (mean ± SE). Where necessary, a Tukey post-hoc test was used to confirm where the differences occurred. Data were analysed with SPSS 11.0 software. The threshold for statistical significance was set at $p < 0.05$.

Results

The baseline anthropometric data are presented in Table **1**. There were no statistical differences between the groups.

Table **1** Anthropometric characteristics at baseline

	Continuous (CTG) n = 10	*Interval (ITG) n = 10*	*Control (CG) n = 15*
Age (months)	125.0 ± 5.6	124.2 ± 3.8	126.1 ± 4.6
Height (m)	1.40 ± 0.04	1.45 ± 0.04	1.40 ± 0.04
Mass (kg)	35.9 ± 7.3	38.9 ± 5.6	36.3 ± 7.2

Maximal values

Mean maximal values by group and time as well as adjusted post-test means are presented in Table **2**. ANCOVA analyses indicated a group effect ($p < 0.005$) for both absolute peak$\cdot\dot{V}O_2$ and mass-related peak$\cdot\dot{V}O_2$. The post-hoc analyses confirmed that following training, absolute peak$\cdot\dot{V}O_2$ was greater in the ITG compared to either the CT or the CTG. No significant difference was apparent between the CTG and CT. When expressed relative to body mass however, post-training peak$\cdot\dot{V}O_2$ was greater in both the ITG and CTG in comparison to the CG ($p < 0.05$), with the difference between the ITC and CTG no longer apparent ($p > 0.05$).

Watts at maximum (W_{max}) was significantly greater in the ITG than the other two groups, even when pre-test W_{max} had been accounted for. Post-training oxygen pulse was also greater in the ITG compared to both the CG and CTG, once adjusted for pre-training values ($p < 0.05$), whilst no significant difference was apparent between the CTG and CG ($p > 0.05$). Mean values for RER, V_E, and HR_{max} showed no significant difference over time for all three groups.

Submaximal values

The mean results for the responses at VT by group and time, and the adjusted means, are shown in Table **3**. Heart rate and percent peak$\cdot\dot{V}O_2$ remained constant over the 8 weeks in all three groups ($p > 0.05$). In contrast, absolute and mass-related $\dot{V}O_2$ showed a significant group effect ($p < 0.05$). Subsequent post-hoc analyses indicated that it was the ITG which had significantly higher absolute and relative adjusted $\dot{V}O_2$ values compared to both the CTG and CG. Likewise, the group effect for oxygen pulse at VT was accounted for by the ITG having significantly higher values following training compared to either the CG or CTG, once pre-test scores had been accounted for.

Discussion

In adults high-intensity interval training protocols can elicit very rapid increases in maximal aerobic power [12]. High-intensity interval training has also been found to simultaneously improve both oxidative and glycolytic energy systems, whereas moderate intensity, continuous training primarily influences aerobic power [17,29]. We know much less about the responses of peak$\cdot\dot{V}O_2$ to high-intensity interval exercise in children or the underlying mechanisms that account for such responses. Our study has shown that the training effects were different following high-intensity interval training compared to moderate-intensity continuous training, when total cardiovascular work was held constant. The cardiovascular equalisation model we employed resulted in no significant differences ($p > 0.05$) in the mean weekly distance covered during training for any week. The ITG and CTG cycled 7.2 and 8.0 km, respectively in week 1, and by week 8 the ITG and CTG cycled 9.7 k and 8.7 km, respectively.

Both the CTG and ITG showed improvement in relative peak$\cdot\dot{V}O_2$. The mean difference in adjusted mass-related peak$\cdot\dot{V}O_2$ between the ITG and CG was $4.7\,ml\cdot kg^{-1}\cdot min^{-1}$, and $3.4\,ml\cdot kg^{-1}\cdot min^{-1}$ between the CTG and CG. These findings are similar to the work of Tabata et al. [29], who concluded that both continuous and high-intensity training elicited a significant improvement in aerobic power.

Table **2** Cardiorespiratory responses at maximal exercise pre- and post-training

	Continuous (CTG) n = 10			***Interval (ITG) n = 10***			***Control (CG) n = 15***		
	Pre-training mean ± SD	***Post-training mean ± SD***	***Adjusted mean ± SE***	***Pre-training mean ± SD***	***Post-training mean ± SD***	***Adjusted mean ± SE***	***Pre-training mean ± SD***	***Post-training mean ± SD***	***Adjusted mean ± SE***
Peak $\dot{V}O_2$ (ml · min^{-1})	1652 ± 164	1723 ± 174	1747 ± 36.2	1758 ± 195	1959 ± 220	1913 ± 39.6*†	1585 ± 204	1570 ± 236	1660 ± 30.8
Peak $\dot{V}O_2$ (ml · kg · min^{-1})	47.0 ± 6.5	50.7 ± 6.9	49.7 ± 1.17*	45.5 ± 3.4	50.7 ± 3.7	51.0 ± 1.17*	44.7 ± 6.5	45.4 ± 6.4	46.3 ± 0.96
Maximal work rate (W)	73 ± 7	85 ± 9	89 ± 4	76 ± 12	99 ± 15	101 ± 3*†	81 ± 16	80 ± 16	80 ± 3
Oxygen pulse (mlO$_2$ · beat^{-1})	8.4 ± 0.88	8.7 ± 0.92	8.9 ± 0.20	8.9 ± 1.01	10.2 ± 1.2	10.0 ± 0.22*†	8.2 ± 1.2	8.1 ± 1.3	8.5 ± 0.17
Ventilation (l · min^{-1})	58.4 ± 7.2	59.3 ± 6.8	–	56.7 ± 6.00	63.6 ± 9.7	–	55.6 ± 11.1	53.3 ± 7.1	–
Heart rate (bpm)	198 ± 6	198 ± 5	–	197 ± 8	193 ± 6	–	195 ± 9	195 ± 7	–
RER	1.02 ± 0.05	1.04 ± 0.07	–	0.99 ± 0.03	1.02 ± 0.05	–	1.00 ± 0.06	1.00 ± 0.03	–

* Significantly different from the CG, $p < 0.05$; † significantly different from the CTG, $p < 0.05$

Table **3** Cardiorespiratory responses at the ventilatory threshold pre- and post-training

	Continuous (CTG) n = 8			***Interval (ITG) n = 9***			***Control (CG) n = 11***		
	Pre-training mean ± SD	***Post-training mean ± SD***	***Adjusted mean ± SE***	***Pre-training mean ± SD***	***Post-training mean ± SD***	***Adjusted mean ± SE***	***Pre-training mean ± SD***	***Post-training mean ± SD***	***Adjusted mean ± SE***
$\dot{V}O_2$ (ml · min^{-1})	1307 ± 103	1305 ± 221	1339 ± 56.6	1378 ± 170	1629 ± 211	1599 ± 53.3*†	1345 ± 162	1322 ± 190	1322 ± 47.8
$\dot{V}O_2$ (ml · kg · min^{-1})	36.1 ± 602	36.7 ± 5.2	37.3 ± 1.37	35.2 ± 6.0	41.6 ± 7.2	42.9 ± 1.30*†	39.3 ± 7.6	39.7 ± 5.1	38.2 ± 1.19
Percent peak $\dot{V}O_2$ (%)	79 ± 6	74 ± 6	75 ± 3	76 ± 10	80 ± 9	82 ± 3	85 ± 7	85 ± 8	84 ± 2
HR (bpm)	170 ± 14	165 ± 12	165 ± 3	170 ± 10	164 ± 8	164 ± 3	170 ± 10	170 ± 7	169 ± 3
Oxygen pulse (mlO$_2$ · beat^{-1})	7.7 ± 0.9	7.9 ± 1.1	8.1 ± 0.30	8.1 ± 1.1	9.9 ± 1.1	9.8 ± 0.28*†	7.9 ± 0.98	7.9 ± 1.3	7.9 ± 0.25

* Significantly different from the CG, $p < 0.05$; † significantly different from the CTG, $p < 0.05$

In both adults and children [18,24] VT has been reported to increase following training, both in ml · kg^{-1} · min^{-1} and as a percentage of peak · $\dot{V}O_2$. We found an increase in the ITG, however, only when expressed as ml · kg^{-1} · min^{-1}. It should be noted that VT could not be detected in all our subjects, reducing the sample size.

The most striking feature of our data was the change in oxygen pulse in the ITG. Obert et al. [22] attributed increases in peak · $\dot{V}O_2$ following training to an increased stroke volume, after assessing stroke volume by echocardiography. These authors attributed the alterations in stroke volume to increases in pre-load, decreases in after-load and cardiac enlargement. Similar findings were reported with highly trained male child cyclists [21]. We can probably assume, based on these previous findings, that the higher oxygen pulse recorded in our ITG boys is credited to an increased stroke volume, as opposed to AVO-D. Recent data in adults showed that cycle ergometer training elicited changes in blood volume, in contrast to treadmill training [7]. Temporary increases in blood volume are also more apparent following a short burst of pedalling at a higher rather than lower exercise intensity [30]. Since a high blood volume enhances venous return and diastolic function, the ITG boys may have been experiencing qualitatively superior cardiovascular stimulus during their training, even though we had attempted to hold total cardiovascular work constant across the two groups. An example of the heart rate response over time in half a training session is given for both groups in Fig. **1**.

Our understanding of the peripheral mechanisms underlying the child's lower reliance on glycolytic pathways during high-intensity exercise remains poor [25]. Prolonged intervals of more than 15 s require considerable aerobic energy production [5], a contribution which is substantially greater in children than in adults. This, and the evidence that intracellular phosphate levels are lower in children [33], supports the contention that it is the oxidative and not glycolytic pathway that is more likely to be stimulated during this type of interval training in children. Interval sprint training has also been shown to increase the percentage of type IIa fibres in adolescents [13]. High-intensity exercise can elevate the aerobic potential of these fast-twitch motor units, which are substantially recruited after 90% maximum $\dot{V}O_2$ in adults [9]. Again, this may contribute to high-intensity interval protocols having the greatest impact upon peak · $\dot{V}O_2$ in children.

Understanding the mechanisms which contribute to improvements in peak · $\dot{V}O_2$ following high-intensity interval training in children is not easy. This is in part due to the inability previously to non-invasively study the adaptive mechanisms of training during childhood, such as myocardial contractility, plasma volume, peripheral oxygen extraction, and concentrations of oxidative or glycolytic enzymes. However, the utilization of recently available non-invasive methods in the exercising child, such as exercise echocardiography, near infra-red spectroscopy, and magnetic resonance spectroscopy, will help to elucidate these mechanisms.

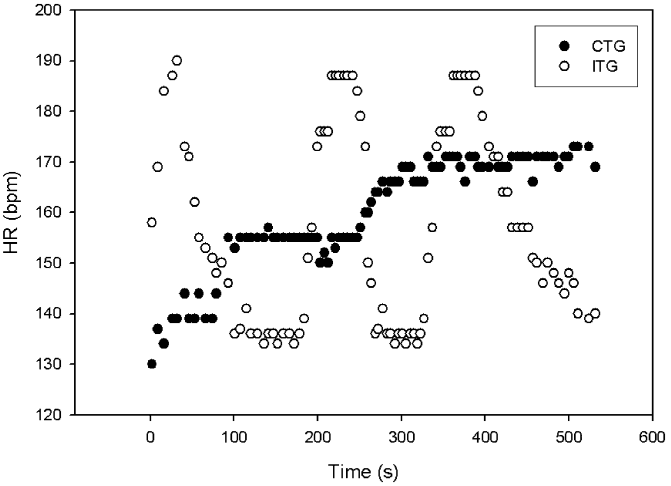

Fig. **1** An example of the heart rate response during the first 10 minutes of a training session in the CTG and in the ITG.

Conclusion

In conclusion, the results of this study demonstrate a modest increase in mass-related aerobic power following both high-intensity interval training and moderate-intensity continuous training. It would appear, however, that the two training protocols result in different responses in VT and oxygen pulse, with the high-intensity interval training resulting in greater changes. High-intensity interval training is well tolerated in children as they recover rapidly and appear to be much more fatigue-resistant than adults [25]. Importantly, it is more akin to their habitual movement patterns [4] and may be a valuable tool in school surroundings.

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