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Effects of High Intensity Intermittent Training on Peak $\dot{V}O_2$ in Prepubertal Children

Abstract

This study was designed to examine peak $\dot{V}O_2$ responses of prepubescent children following a 7-week aerobic training. Twenty-three boys and thirty girls (9.7 ± 0.8 years) were divided into a high intensity experimental group (HIEG: 20 girls and 13 boys) and a control group (CG: 10 girls and 10 boys). A graded 20-m shuttle run with measurement of gas exchange values was performed prior to and after the 7-week training program. The test consisted of a 3-min run at $7\ km \times h^{-1}$ to determine energy cost of running, immediately followed by a 20-meter shuttle run test. HIEG had two 30 min-sessions of short intermittent aerobic training per week at velocities ranging from 100 up to 130 % of the maximal aerobic speed. For HIEG, absolute peak $\dot{V}O_2$ (9.1 %) and relative to body mass peak $\dot{V}O_2$ (8.2 %) increased significantly ($p < 0.001$); it was unchanged in the CG. Similarly, maximal shuttle run improved significantly in HIEG (5.1 %, $p < 0.001$). In contrast, there was no significant change for CG. For both groups energy cost of running remained unchanged. These findings show that prepubescent children could significantly increase their peak $\dot{V}O_2$ and maximal shuttle velocity with high intensity short intermittent aerobic exercises.

Key words
Aerobic · field tests · fitness · gender · interval training · school

Introduction

Several studies have focused on the effects of aerobic training in children, but with many discrepancies between the authors' findings. In a review of the literature, Pate and Ward [23] noticed that some of them had suggested that endurance training failed to increase peak oxygen uptake (peak $\dot{V}O_2$), while others reported positive effects. It was hypothesized that maximal aerobic power could be increased, but also that prepubescent children might be less adaptive to endurance exercise training than older youths [9]. Nevertheless, Vaccaro and Mahon [33] have shown that children were trainable, with aerobic training using guidelines for adults. Kemper and Van de Kop [16] also concluded that, in prepubescent boys, training effects were significantly higher when the American College of Sports Medicine [2] criteria were followed, but not at the same level as in elite athletes. In most of the studies reviewed, training protocol was based on submaximal and continuous exercises and a few studies focused on the effects of intermittent training at high percentage of the maximal aerobic speed (MAS) in children. Indeed, as for continuous running, the repetition of short bouts of exercise at high percentage of MAS, alternating with identical passive recovery time, allows subjects to reach high levels of $\dot{V}O_2$ and even to elicit peak $\dot{V}O_2$ [12]. In addition, intermittent exercises at these velocities and of short duration can be linked to children's spontaneous activity, as demonstrated by Bailey et al. [5]. These exercises might be an alternative to continuous exercises. Therefore, this study was designed to investigate the effects of high-intensity short intermittent training, respecting children's physical activity patterns, on aerobic power and performances of prepubescent boys and girls.

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Bibliography
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Methods

Subjects

Fifty-three prepubescent boys and girls (8–11 years old) (23 boys and 30 girls) volunteered to participate in this study that had received approval from the "Comité Consultatif de Protection des Personnes dans la Recherche Biomédicale de Lille". Parents and children gave their written, informed consent prior to any involvement in the study.

Height and body mass were measured with a wall stadiometer (Vivioz medical) and a calibrated beam balance (Tanita TBF 543). Percentage of body fat was estimated from skinfold thickness measured at three sites (biceps, triceps and calf), according to Lohman [19].

Sexual maturity was evaluated from pubertal stages: indices of breast, pubic hair and genital development [31]. The same physician made all the observations visually, before the training period.

Experimental design

The volunteer school children were taken from three different classes. One served as a control group (CG) (10 boys and 10 girls) and two as a high intensity experimental group (HIEG) (13 boys and 20 girls). Before entering the study, the children were familiarized with the testing modality and gas analyzer. They performed a maximal graded field test, with measurement of gas exchanges, on two occasions separated by a 7-week training period (pre- and post-training, respectively). Before and after training, these tests were completed within two weeks. The graded tests and high intensity intermittent training were performed outside physical education lessons. HIEG had two additional 30-min physical education (PE) sessions per week specifically devoted to high intensity intermittent running exercises.

Maximal aerobic performance

The peak $\dot{V}O_2$ was measured during the maximal graded field test. The test was performed twice one week apart in random order, with or without a gas analyzer (K4 b^2, Cosmed, Rome, Italy). It was performed in a covered and non-slick place with ambient temperature ranging from 18 to 22 °C. For this test, subjects had to run between two lines 20 m apart. A pre-recorded soundtrack indicated using brief sounds the instant when the subject had reached a line to maintain a constant speed. A longer sound marked the changes in stage. The speed of the soundtrack was checked before each session. The test began with a 3-min shuttle run at 7 $km \times h^{-1}$. Then, the speed was set at 8.5 $km \times h^{-1}$ and increased by 0.5 $km \times h^{-1}$ per 1-min stage [18]. The test ended when the subject was no longer able to maintain the imposed running speed. During the test, subjects ran with an adult and were continuously encouraged. The speed at the last completed stage was considered as the maximal speed (MS in $km \times h^{-1}$). The fastest MS (with or without gas analyzer) was retained. As it had previously been demonstrated that MS underestimated the maximal aerobic speed (MAS, i.e. the lowest speed which elicits $\dot{V}O_2max$ for conventional runs), we used the formula proposed by Gerbeaux et al. [14] to convert MS ($km \times h^{-1}$) into MAS ($km \times h^{-1}$): MAS = 2.4 × MS–14.7. The MAS was used as a criterion velocity [11] to set running paces for high-intensity short intermittent exercises. The correction was only applied to the results of the subjects who had a MS strictly higher than 10 $km \times h^{-1}$. As it has been previously demonstrated with velocities equal or lower than 10 $km \times h^{-1}$, there is no difference between MS and MAS [1,6,14]. The use of the MAS to control velocities for training has been described in a previous paper [7,10].

Pulmonary gas exchange and heart rate

During the graded test, inspired and expired gases were monitored continuously, breath by breath, through a K4 b^2 analyzer (Cosmed, Rome Italy), which had previously been validated [21]. Before each test, the O_2 and CO_2 analysis systems were calibrated using ambient air and a gas of known O_2 concentration (16.7%) and CO_2 concentration (5.7%). The calibration of the turbine flowmeter of the K4 b^2 was performed using a 3-l syringe (Quinton Instruments, Seattle, Wash., USA). The $\dot{V}O_2$ and $\dot{V}CO_2$ values were averaged on 15 s. Heart rate (HR) was continuously monitored (Polar Accurex+, Polar Electro, Kempele, Finland). This compact device was easy to attach without constricting the children's movements. Peak $\dot{V}O_2$ was determined as the mean of the two highest $\dot{V}O_2$ values. $\dot{V}O_2$ was accepted as a maximal index, when HR reached a value above 195 bpm or when the respiratory exchange ratio (RER) was >1 associated with visible exhaustion [32].

Energy cost of running

The energy cost of running (Cr) was determined as the mean $\dot{V}O_2$ during the last minute of the 7 $km \times h^{-1}$ ($\dot{V}O_2 - 7$) run, minus estimated resting $\dot{V}O_2$ [29], divided by the velocity. In addition, mean HR (HR-7) and RER (RER-7) measured at 7 $km \times h^{-1}$ were reported.

Training programme

Over 7 weeks, HIEG followed a high-intensity training programme with two 30-min specific sessions per week. The programme consisted of short intermittent exercises (10 or 20 s), at velocities ranging in intensity from 100 up to 130% of MAS. These exercises were performed on a short track. On this track, the children were placed in different corridors according to their MAS. They had to cover the distance between the two extremities in 10 or 20 s. For example, a subject with a 9 $km \times h^{-1}$ MAS had to run over 25 m in 10 s, at 100% of MAS. After 10 or 20 s of recovery, s/he turned back and repeated the run in the opposite way. The training programme is outlined in Table **1**. To characterize the short intermittent exercises, the cardiorespiratory response of a sample of 17 children was monitored over a typical training session, which consisted of 5 sets of 10 bouts in 10 s run periods alternated with 10 s of passive recovery at 100%, 110%, 110%, 120% and 130% of MAS. Each set was interrupted by 3min of passive recovery. An example of a child's oxygen consumption for a session is presented in Fig. **1**. The means for $\dot{V}O_2$ and HR during each set are presented in Table **2**. The mean $\dot{V}O_2$ ranged between 66.4 ± 8.6 and 77.8 ± 10.0% of peak $\dot{V}O_2$ at set 1 and set 5, respectively. However, all subjects elicited peak $\dot{V}O_2$ during the last sets of the session.

Statistical analysis

The data are expressed as mean ± standard deviation (mean ± SD). A one-way analysis of variance (ANOVA) was used to check if the two groups were the same at baseline. The effects of training were analyzed for statistical significance by using a three-way (gender × group × time) analysis of variance (ANOVA) that

Table **1** Details of the 7-week training programme

	Short intermittent exercise training		*Short intermittent exercise training*
Session 1	4 × (10 × 10s) at 110 % of MAS	Session 2	3 × (10 × 10s) at 110 % of MAS 1 × (10 × 10s) at 120 % of MAS
Session 3	2 × (10 × 10s) at 110 % of MAS 2 × (10 × 10s) at 120 % of MAS	Session 4	1 × (10 × 10s) at 110 % of MAS 3 × (10 × 10s) at 120 % of MAS
Session 5	4 × (10 × 10s) at 120 % of MAS	Session 6	3 × (10 × 10s) at 120 % of MAS 1 × (10 × 10s) at 130 % of MAS
Session 7	2 × (10 × 10s) at 120 % of MAS 2 × (10 × 10s) at 130 % of MAS	Session 8	1 × (10 × 10s) at 120 % of MAS 3 × (10 × 10s) at 130 % of MAS
Session 9	4 × (5 × 20s) at 110 % of MAS	Session 10	3 × (5 × 20s) at 110 % of MAS 1 × (5 × 20s) at 120 % of MAS
Session 11	2 × (5 × 20s) at 110 % of MAS 2 × (5 × 20s) at 120 % of MAS	Session 12	1 × (5 × 20s) at 110 % of MAS 3 × (5 × 20s) at 120 % of MAS
Session 13	1 × (5 × 20s) at 110 % of MAS 2 × (5 x 20s) at 120 % of MAS 1 × (5 × 20s) at 130 % of MAS	Session 14	1 × (5 × 20s) at 110 % of MAS 1 × (5 × 20s) at 120 % of MAS 2 × (5 × 20s) at 130 % of MAS

Each session was preceded by a standardized warm-up: 1 × (10 × 10s) or (5 × 20s) at 100 % of MAS (one set of 10 repetitions of 10 s or 5 repetitions of 20 s of running at 100 % of MAS, punctuated by 10 s or 20 s of recovery). Between each set, the recovery was of 3 min. Exercise time was 30 min for each session.

Table **2** Mean±SD cardiorespiratory response of children (n = 17) for a typical training session. The results presented do not include resting periods (3 min) between sets. The duration of each set is 190 s (ten bouts of 10 s and nine 10-s recovery period between bouts)

	Intermittent exercises				
	100 % MAS	*110 % MAS*	*110 % MAS*	*120 % MAS*	*130 % MAS*
$\dot{V}O_2$ (% peak$\dot{V}O_2$)	66.4 ± 8.6	72.9 ± 10.1	73.1 ± 7.9	74.9 ± 9.4	77.8 ± 10
HR (% HR_{max})	77.9 ± 10.5	85.2 ± 5.2	87.9 ± 4	91.8 ± 3.7	94.5 ± 1.9

MAS: maximal aerobic speed (i. e.: the maximal 20-m shuttle run velocity converted into conventional speed for training purposes).

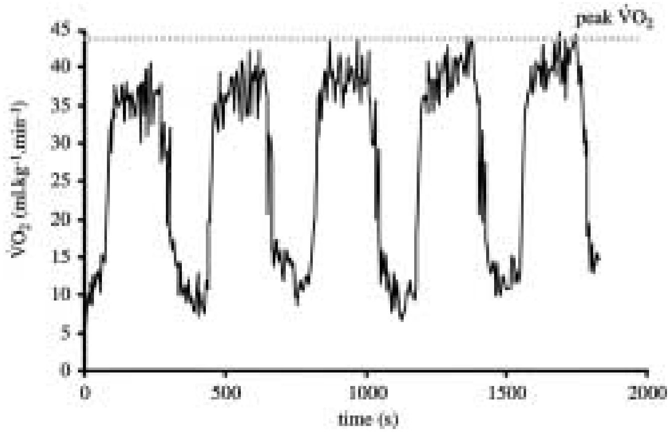

Fig. **1** An example of a child's oxygen consumption for a training session (1 × 100 % MAS, 2 × 110 % MAS, 1 × 120 % MAS, 1 × 130 % MAS). The dashed line indicates the value for peak $\dot{V}O_2$ measured during the graded field test.

was applied to the pre- and post-training values (time effect). In all cases, there was no effect that could be attributed to gender by time interaction. Therefore data for boys and girls in both groups were pooled and analyzed through a two-way ANOVA (group × time). If necessary, Scheffé *post hoc* analyses were conducted to identify where differences occurred. Data were analyzed with Super ANOVA software (Abacus Concepts). The threshold for statistical significance was set at $p < 0.05$.

Results

The ANOVA revealed no group effect between HIEG and CG at baseline, for any anthropometric or physiologic data, indicating that the groups were the same before training. In addition, no group by time interaction was observed between changes in anthropometric data before and after training (Table **3**).

Maximal values

Mean cardiorespiratory values by group and time are presented in Table **4**. A group by time interaction ($p < 0.001$) was found for absolute peak $\dot{V}O_2$ and relative to body mass peak $\dot{V}O_2$. Scheffé analysis indicated that, in the HIEG, absolute peak $\dot{V}O_2$ (1.54 ± 0.35 vs. 1.68 ± 0.36 l × min^{-1}) and relative-to-body-mass peak $\dot{V}O_2$ (43.9 ± 6.2 vs. 47.5 ± 7.2 ml × kg^{-1} × min^{-1}) increased significantly ($p < 0.001$) over the training programme; it was unchanged in the CG. In contrast, for both groups the mean values for RER, peak VE and HR_{max} showed no significant difference over time. A significant ($p < 0.001$) group by time interaction was observed for MS. In HIEG only, subsequent Scheffé analysis revealed a significant ($p < 0.001$) increase for MS (9.9 ± 0.9 vs. 10.4 ± 0.9 km × h^{-1}).

Submaximal values

The mean results for the submaximal exercises by group and time are shown in Table **5**. There was no group by time interaction for absolute or relative to body mass $\dot{V}O_2$ – 7, HR-7 and Cr, which remained unchanged after 7 weeks. A significant group

Table **3** Mean±SD anthropometric values before and after the 7-week programme

	Control group (n = 20)					***High intensity experimental group (n = 33)***					***Interaction (group × time)***
	Pre-training		***Post-training***			***Pre-training***		***Post-training***			
	Mean ± SD	***Range***	***Mean ± SD***	***Range***	**Δ**	***Mean ± SD***	***Range***	***Mean ± SD***	***Range***	**Δ**	***P (F)***
Age (year)	9.9 ± 0.4	9.2–11.0	10.1 ± 0.4	9.4–11.2		9.5 ± 0.9	8.3–11.1	9.7 ± 0.9	8.5–11.2		
Height (cm)	141.1 ± 6.7	131–157	143.3 ± 7.2	132–158	2.2 ± 1.3	139.4 ± 8.4	119–158	141.6 ± 8.4	120–160	2.2 ± 1.1	ns (0.09)
Body mass (kg)	36.4 ± 8.1	26.0–58.1	36.9 ± 8.4	26.2–61.4	0.5 ± 1.3	35.7 ± 9.4	19.7–64.4	36.0 ± 9.6	20.6–65.7	0.3 ± 0.9	ns (0.4)
% Body fat	22.1 ± 7.8	9.8–39.0	21.4 ± 7.4	10.5–39.0	−0.7 ± 1.1	23.1 ± 9.0	10.0–45.6	22.2 ± 8.8	9.3–44.8	−0.9 ± 1.2	ns (0.8)

Δ: difference between post- and pre-training.

Table **4** Mean±SD cardiorespiratory values and maximal velocity at the end of the graded field test measured before and after the 7-week programme

	Control group (n = 20)					***Experimental group (n = 33)***					***ANOVA one-factor (group)***
	Pre- test		***Post- test***			***Pre- test***		***Post- test***			
	Mean ± SD	***Range***	***Mean ± SD***	***Range***	**Δ**	***Mean ± SD***	***Range***	***Mean ± SD***	***Range***	**Δ**	***P (F)***
Peak $\dot{V}O_2$ (l × min^{-1})	1.62 ± 0.19	1.26–1.97	1.62 ± 0.19	1.32–2.03	−0.01 ± 0.13	1.54 ± 0.35	0.84–2.40	1.68 ± 0.36***	0.66–1.85	0.14 ± 0.13	< 0.001 (14.1)
Peak $\dot{V}O_2$ (ml × kg^{-1} × min^{-1})	46.2 ± 8.5	31.8–61.9	45.3 ± 7.2	31.6–56.5	−0.9 ± 3.6	43.9 ± 6.2	29.9–56.2	47.5 ± 7.2***	29.0–66.7	3.6 ± 3.9	< 0.001 (17.1)
RER	1.04 ± 0.08	0.92–1.26	1.05 ± 0.08	0.88–1.18	0.01 ± 0.07	1.03 ± 0.07	0.87–1.14	1.01 ± 0.07	0.90–1.13	−0.02 ± 0.06	ns (1.4)
Peak VE (l × min^{-1})	64.0 ± 8.4	45.6–81.6	63.8 ± 8.1	51.6–84.2	−0.2 ± 7.2	59.2 ± 12.1	38.5–89.7	61.1 ± 11.2	39.6–90.1	1.9 ± 5.1	ns (1.5)
HR_{max} (bpm)	205 ± 8	190–223	204 ± 7	192–222	−1 ± 7	202 ± 8	187–223	201 ± 7	183–212	−1 ± 7	ns (0.05)
MS (km × h^{-1})	10.0 ± 0.6	9–11	10.1 ± 0.8	9–12	0.1 ± 0.4	9.9 ± 0.9	8.5–12	10.4 ± 0.9***	9–12.5	0.5 ± 0.4	< 0.001 (15.5)

Δ: difference between post- and pre-training; Peak $\dot{V}O_2$: Maximal oxygen uptake, RER: Respiratory exchange ratio, Peak VE: Maximal ventilatory exchange, HR_{max}: Maximal heart rate, MS: Maximal Speed. ***: significantly different from pre-test ($p < 0.001$).

Table **5** Mean±SD cardiorespiratory values at submaximal exercise measured before and after a 7-week training programme

	Control group (n = 20)					***High intensity experimental group (n = 33)***					***Interaction (group × time)***
	Pre-training		***Post-training***			***Pre-training***		***Post-training***			
	Mean ± SD	***Range***	***Mean±SD***	***Range***	**Δ**	***Mean ± SD***	***Range***	***Mean ± SD***	***Range***	**Δ**	***P (F)***
$\dot{V}O_2 - 7$ (l × min^{-1})	1.33 ± 0.19	1.00–1.79	1.28 ± 0.20	1.06–1.89	−0.05 ± 0.12	1.26 ± 0.28	0.64–1.81	1.25 ± 0.29	0.66–1.85	−0.01 ± 0.12	ns (0.8)
$\dot{V}O_2 - 7$ (ml × kg^{-1} × min^{-1})	37.2 ± 4.7	29.7–44.5	35.5 ± 3.9	26.5–43.4	−1.7 ± 3.5	36.0 ± 4.9	25.9–47.7	35.2 ± 3.8	25.9–41.2	−0.8 ± 3.5	ns (0.7)
$\dot{V}O_2 - 7$ (% peak $\dot{V}O_2$)	82 ± 9	66–99	79 ± 8	61–93	−3 ± 7	82 ± 8	60–96	75 ± 9***	51–97	−7 ± 7	< 0.05 (5.6)
HR-7 (bpm)	176 ± 13	160–215	175 ± 13	160–202	−1 ± 9	177 ± 12	157–212	170 ± 14	138–203	−7 ± 11	ns (3.5)
HR-7 (% HR_{max})	86 ± 5	79–96	85 ± 4	79–93	−1 ± 4	88 ± 5	76–96	85 ± 5**	73–96	−3 ± 5	< 0.05 (4.3)
RER-7	0.86 ± 0.07	0.68–0.98	0.87 ± 0.09	0.74–1.06	0.01 ± 0.08	0.88 ± 0.09	0.73–1.05	0.86 ± 0.07	0.65–1.01	−0.02 ± 0.06	ns (1.9)
Cr (ml × kg^{-1} × m^{-1})	0.286 ± 0.041	0.22–0.35	0.271 ± 0.035	0.19–0.34	−0.015 ± 0.031	0.275 ± 0.042	0.19–0.37	0.268 ± 0.033	0.19–0.32	−0.07 ± 0.03	ns (1.0)

Δ: difference between post- and pre-training; $\dot{V}O_2 - 7$: oxygen uptake at 7 km × h^{-1}; HR-7: heart rate at 7 × km × h^{-1}; RER-7: respiratory exchange ratio at 7 × km × h^{-1}; Cr: Energy cost of running. **: significantly different from pre-training ($p < 0.01$); ***: significantly different from pre-training ($p < 0.001$).

by time interaction ($p < 0.05$) was observed for $\dot{V}O_2 - 7$ expressed as a percentage of peak $\dot{V}O_2$ and for HR-7 expressed as a percentage of HR_{max}. In the HIEG, Scheffé analysis indicated a significant decrease in relative $\dot{V}O_2 - 7$ (82 ± 8 vs. 75 ± 9% peak $\dot{V}O_2$) and relative HR-7 (88 ± 5 vs. 85 ± 5% HR_{max}) in HIEG, whereas it remained unchanged in the CG.

Discussion

The main finding from this study was that a 7-week training programme significantly improved children's absolute peak $\dot{V}O_2$ and relative to body mass peak $\dot{V}O_2$. In contrast, for the CG, absolute and relative to body mass peak $\dot{V}O_2$ remained unchanged. The peak $\dot{V}O_2$ changes for the HIEG were independent of gender and were associated with significant improvement of MS as a measurement of aerobic performance without a concomitant change in the energy cost of running.

This study was conducted in a school environment that is characterized by a large heterogeneity of children's performances. Before training, the mean peak $\dot{V}O_2$ was 46.2 $ml \times kg^{-1} \times min^{-1}$ for CG and 43.9 $ml \times kg^{-1} \times min^{-1}$ for HIEG. These values were characteristic of a population of children 8 to 11 years old. For the two groups, the coefficient of variation associated to peak $\dot{V}O_2$ ($ml \times kg^{-1} \times min^{-1}$) ranged between 14.1% and 18.3%. These values were in the same range as those reported by Mandigout et al. (15 to 18%) [22] and Rowland and Boyajian (13 to 14%) [26].

For absolute or relative-to-body-mass peak $\dot{V}O_2$, the ANOVA revealed no interaction between gender and time, indicating that HIEG boys (respectively, + 9.4% and + 9.5%) and girls (respectively, + 7.3% and + 7.2%) had similar improvements in peak $\dot{V}O_2$. It may therefore be concluded, as by Rowland and Boyajian [26], that training improvements in peak $\dot{V}O_2$ were similar in prepubescent boys and girls.

The improvement in relative to body mass peak $\dot{V}O_2$ reported in this study (+ 8.2%) was similar to those of Rowland and Boyajian [26] (+ 6.3%) or Lussier and Burskirk [20] (+ 6.8%) and in the range of that reported by Kemper and Van de Kop [16], when training studies are conducted following the American College of Sports Medicine recommendations [2] (range: –2% to 21%, average: + 8.4%). Moreover, some authors reported no changes in peak $\dot{V}O_2$ [15, 32, 35]. Also, it is difficult to compare our results with others, because, as reported by Pate and Ward [23] or Williams et al. [35], few studies have analyzed well-monitored training effects on prepubescent peak aerobic power. The magnitude of peak $\dot{V}O_2$ increases resulting from endurance training depends on several factors like the initial level of physical fitness, the duration of the training program and the intensity, duration and frequency of the training sessions [34]. Armstrong [3] had suggested that exercise intensity had a fundamental influence on training responses. Wenger and Bell [34] had suggested that intensity ranging from 80 to 100% of peak $\dot{V}O_2$ was sufficient to cover the minimal training volume. They concluded that although the maximal gains in aerobic power were elicited with intensities ranging between 90 to 100% of peak $\dot{V}O_2$, 4 times per week with exercise duration of 35 to 45 min, lower intensities still produced effective changes. In the literature, most of the protocols described, addressing the trainability of children and youths, are based on continuous exercises at submaximal [8, 20, 26, 28, 32] or unspecified intensities [25]. However, in these studies, exercise intensities and/or duration were probably not of sufficient intensity to elicit high percentages of peak $\dot{V}O_2$. For example, Tolfrey et al. [32] proposed a training protocol which consisted in the repetition of stationary cycling for 30 min, 3 times per week over 12 weeks at 79.3 ± 1.2 %HR_{max}. In the present study (Table **2** and Fig. **1**), the compromise between short bursts of exercises and short period of recovery allowed the subjects to reach a high level of $\dot{V}O_2$ (from 66 to 78% of peak $\dot{V}O_2$ between set 1 and set 5) and to elicit peak $\dot{V}O_2$ for the sets of exercises at the higher percentages of MAS. In a recent study, Williams et al. [35] have compared a continuous protocol to a protocol based on high intensity intermittent exercises which were designed to reproduce children's spontaneous activity patterns [5]. However, they failed to show any significant effect of either sprint interval running or continuous cycle ergometer-training program on maximal and submaximal measures of aerobic performance. It could be hypothesized that the high intensity exercises proposed for children, 10 s or 30 s sprints separated by relatively long recovery periods (30 s or 90 s), were not the adequate combination to allow subjects to elicit high percentages of peak $\dot{V}O_2$.

Energy cost of running was measured during the last minute of a 3-min run at 7 $km \times h^{-1}$. A 3-min run provides a steady state at low intensity of running [27]. Absolute and relative $\dot{V}O_2 - 7$ were in line with those found by Armstrong et al. [4]. The ANOVA revealed no significant changes in Cr after training. This finding agrees with those of others [17, 24, 30] who had shown that short-term (less than 12 weeks) running training did not significantly modify the children's Cr. As found by Williams et al. [35], there was a trend of lower HR after training. However, the analysis of data failed to reveal a significant difference. When expressed as a percentage of peak $\dot{V}O_2$, $\dot{V}O_2 - 7$ decreased significantly for HIEG. However, this decrease could be associated with an increase in peak $\dot{V}O_2$ together with no change in $\dot{V}O_2 - 7$. These results indicated that the repetition of short intermittent exercises at maximal to supramaximal velocities is not a sufficient stimulus to decrease the Cr of children over a 7-week period.

The high-intensity intermittent running exercise induced a significant improvement in aerobic performance for HIEG. The MS was significantly increased (5.1%, $p < 0.001$), while intermittent training had no effect on Cr. It might be suggested that the improvement in MS was only due to the increase in peak $\dot{V}O_2$ [13]. This result is consistent with those of Berthoin et al. [10] who demonstrated significant improvement of maximal aerobic speed (+ 6%) after a 12-week training programme in adolescents performing similar short intermittent exercises. The specificity of the present study was the use of short intermittent exercises (100% to 130% of MAS) as an attempt to improve the children's peak $\dot{V}O_2$. The exercises are original and may be used as an alternative to continuous exercise. Exercise variety enhances the attractiveness of the programme and is therefore more motivating for children. In addition, the use of MAS is of particular interest to check running paces during training and to adapt velocity (% MAS) to the abilities of each subject. Well-monitored, adequately-intensive training is necessary for a more desirable functional development.

Conclusion

In summary, this study demonstrated that prepubescent boys' and girls' responses to high-intensity intermittent aerobic training were similar and that peak $\dot{V}O_2$ values were significantly increased. The high intensity aerobic intermittent training programme, with 2 sessions per week over 7 weeks, was of short duration and frequency compared to the majority of that reported in the literature. However, it resulted in significant peak $\dot{V}O_2$ improvement. This improvement was associated with an increase in aerobic performance (MS) without a concomitant change in Cr.

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