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**Title:** Active versus Passive Recovery in High-Intensity Intermittent Exercises in Children: an exploratory study

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**Running head:** Intermittent time to exhaustion

## Abstract

The study aimed to compare the effect of active versus passive recovery on time to exhaustion (TTE) and time spent at high percentages of peak oxygen uptake during short high-intensity intermittent exercises (S-HIIE) in children. Twelve children ( $9.5 \pm 0.7$  years) underwent a graded test and two S-HIIE (15 s at 120% of maximal aerobic speed (MAS)), interspersed with either 15-s of active recovery (AR, 50% of MAS) or 15-s passive recovery (PR) until exhaustion. A very large effect ( $ES=2.42$ , 95% CI [1.32 to 3.52]) was observed for TTE in favour of longer TTE with PR compared to AR. Trivial or small effect sizes were found for peak $\dot{V}O_2$ , peakHR and peakVE between PR and AR, while a moderate effect in favour of higher average  $\dot{V}O_2$  values ( $ES= -0.87$ , 95% CI [-1.76 to -0.01]) was found using AR. The difference between PR and AR for the time spent above 80% (t80%) and 90% (t90%) of peak $\dot{V}O_2$  was trivial. Despite the shorter running duration in AR, similar t80% and t90% were spent with AR and PR. Time spent at a high percentage of peak $\dot{V}O_2$  may be attained by running 3-fold shorter using AR compared using PR.

**Key Words:** Interval training, Aerobic fitness, Maximal oxygen uptake, Field tests

## Introduction

Intermittent exercises are frequently used by athletes to improve aerobic fitness. They are defined by their exercise intensity and duration, recovery intensity and duration, number of repetitions and number of series. Intermittent exercise is also an intrinsic characteristic of children's spontaneous physical activity. In almost all daily physical activities, free games in the playground, or sports, intermittent activity is more likely to characterize their behavior than continuous activity (37). Bailey et al. (1) and Baquet et al. (4) demonstrated that children's activity is highly transitory, including repeated bursts of activity with rapid recovery.

Short high-intensity intermittent exercise (S-HIIE) allows a high percentage of maximal oxygen uptake ( $\dot{V}O_{2max}$ ) to be elicited in both adults (30) and children (2) and, therefore may be an efficient tool to improve children's aerobic fitness when used during training programs (3). Several studies have suggested a possible link between time spent at high percentage of  $\dot{V}O_{2max}$  ( $t\dot{V}O_{2max}$ , i.e between 80% and 100% of  $\dot{V}O_{2max}$ ) during training and training efficiency (12, 24). In adults, this parameter has been measured during continuous or intermittent exercises performed until exhaustion (40).

For S-HIIE, active recovery (AR) is generally recommended rather than passive recovery (PR) to reduce blood lactate concentration (8). Active recovery at around 30%-60% of individual  $\dot{V}O_{2max}$  (26) aimed increasing blood lactate removal allowing a potential improvement of recovery (17) and/or maintaining  $\dot{V}O_2$  at a sufficient level to allow physiological adaptations. However, when performing S-HIIE (15 s) at 120 % of maximal aerobic speed (MAS) intercepted with either AR (50 % MAS) or PR, Dupont and Berthoin (15) and Dupont et al. (14) have measured longer time to exhaustion (TTE) with PR compared with AR and similar  $t\dot{V}O_{2max}$  whatever the recovery mode in adults. With adolescents, when performing S-HIIE (30 s) at 105 % of MAS intercepted with either AR (50 % MAS) or PR, AR yielded a shorter TTE with a proportionally longer  $t\dot{V}O_{2max}$ , while PR allowed a longer TTE for similar  $t\dot{V}O_{2max}$  (32). A significant reduction in the slope describing the increase in  $\dot{V}O_2$  with lower recovery intensity (9) and faster  $\dot{V}O_2$  kinetics and a higher  $\dot{V}O_{2peak}$  with AR (10) may explain these differences in TTE between S-HIIE with AR and PR. During AR, the higher level of  $\dot{V}O_2$  throughout the end of exercise, which may significantly limit the replenishment of the alactacid and oxyhemoglobin energy sources, which are partially depleted during the previous run interval, and the lower acidosis level could account for the shorter TTE (9, 14).

What's about children? To our knowledge, no study has examined the effect of recovery mode in this population. Compared to adults, children show specific physiological responses to exercise, such as faster rest-to-exercise  $\dot{V}O_2$  transitions (19), faster recovery (27, 38), lower anaerobic capacity (38), higher ability to repeat supramaximal exercises (28) and differences in ratings of perceived exertion as a function of exercise duration (34). All these factors may have a potential significant influence on intermittent performances (18) and on time spent at high percentages of  $\dot{V}O_{2max}$  during such exercises.

The primary endpoint for determining which recovery modality was the most relevant in terms of performance was TTE. Since there were no studies in children, we relied on a study in adults by Dupont et al. (14). Thus, the effects of recovery mode on TTE and  $t\dot{V}O_{2max}$  reported for adolescents and adults should not be inferred to the children. It could be expected that they demonstrate longer TTE than adolescents and adults with PR or AR and maybe longer  $t\dot{V}O_{2max}$  than adults. Moreover, as demonstrated in adolescents and adults, S-HIIE with PR would allow children to show longer TTE than with AR and to remain at a high percentage of  $\dot{V}O_2$  as long as with AR. Baquet et al. (5) have shown that S-HIIE protocols of exercise bouts of either 10-s or 20-s at an intensity above MAS, of total equal duration and using PR generate similar exercise time above 95 % of peak oxygen uptake ( $VO_{2peak}$ ). It would be interesting to compare such exercises using AR and PR. Under what conditions can these S-HIIE exercise modalities be used interchangeably to get the same cardiorespiratory solicitation in children and so to vary the workouts? The manipulation of exercise characteristics (intensity, duration), and of work and recovery periods during S-HIIE protocols determines the amount of time spent at exercise intensity close to  $VO_{2peak}$ . It is therefore important to determine which recovery modality elicits the largest amount of time at a high percentage of  $VO_{2max}$  over exercise duration typically shorter than 30 min. In addition, 120% of MAS in a S-HIIE seems an interesting intensity for the time spent at high percentages of  $VO_{2peak}$  compared to a continuous exercise at 80-85% MAS of the same duration (5).

Therefore, this study was designed to compare the effects of active vs. passive recovery on TTE, and time spent at high percentages of  $\dot{V}O_2$ , during short-term intermittent runs (15s) interspersed with short recovery periods (15s) in children. An additional goal of this study was also to show how these two exercises were perceived. The knowledge of these results could be of particular importance to calibrate exercises duration when S-HIIE are used for training purpose. From Dupont's et al. data (14), a sample of 12 children was chosen and a statistical

power of 80% was expected. Also, the present study was considered as exploratory.

## Methods

### *Participants*

Eleven 8-to-11-year-old children (5 boys and 6 girls) volunteered to participate in this study, which had received approval from the Local Committee for Person's Protection in Biomedical Research. The children and their parents signed written informed consent in accordance with the ethical standards of the Helsinki Declaration of 2013. They were informed of the assessment of sexual maturity using breast, pubic hair and genital development by a physician. Height and body mass were measured with a wall stadiometer (Vivioz Medical) and a calibrated beam balance (Tanita TBF 543), respectively. Percentage body fat was estimated from skinfold thickness measured at three sites (biceps, triceps and calf), in line with Lohman recommendations (21). Sexual maturity was evaluated based on pubertal stages: indices of breast, pubic hair and genital development (31). The same physician undertook all observations visually. At the beginning of the study, all participants were at stage 1 of sexual maturity. The anthropometric data were combined, as no difference was found between boys and girls. The mean values for age, body mass, height, and estimated percentage body fat were:  $9.6 \pm 0.8$  years,  $1.38 \pm 0.07$  m,  $37.7 \pm 11.2$  kg and  $22.8 \pm 4.5$  %, respectively.

### *Overview*

The children performed three field tests over a three-week period, one maximal graded field test and two S-HIIEs. The tests were performed at the same time of the day ( $\pm 1$ h). Before entering the study, the children were familiarized with the testing modalities and the gas analyzer device. All tests were performed outdoors on a covered and non-slick surface with an ambient temperature ranging from 16 to 22°C. During the first session, peak oxygen uptake (peak $\dot{V}O_2$ ) and MAS (6) were assessed. The 2 S-HIIE, with PR or AR, were performed in a random order. During all the tests, the children were verbally encouraged to run until exhaustion. To avoid any problem linked to a child's inability to maintain a constant speed, they always ran with a trained adult. In all cases, the tests ended when the children could no longer maintain the required running velocity, despite vigorous encouragements. The outcome measures were peak $\dot{V}O_2$ , peak HR, TTE, and time spent at a high percentage of peak $\dot{V}O_2$ : higher than 80% of peak $\dot{V}O_2$  (t80%) or higher than 90% of peak $\dot{V}O_2$  (t90%).

During all tests, Children's OMNI perceived exertion scale (RPE, 36) and the feeling scale (FS, 29) were used to assess subjective measurement of the physiological stress induced by both S-HIIE and ongoing affective responses. The two scales were displayed in a random order within the first minute by the end of each test.

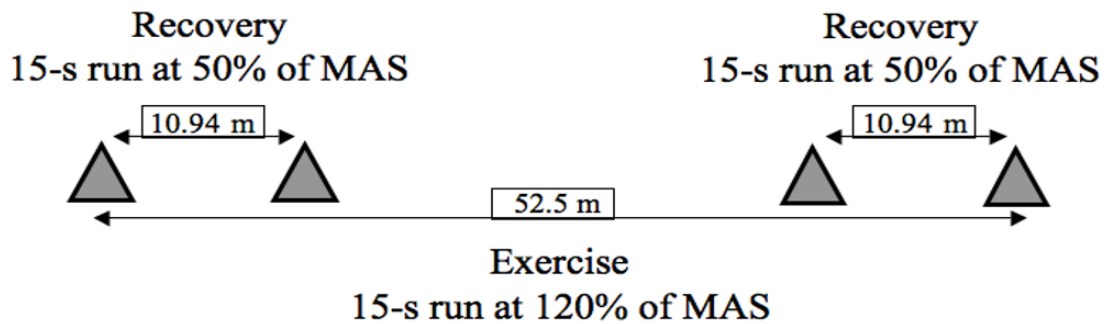
### *Procedure*

*Maximal graded field test.* The test started with an initial velocity of  $6 \text{ km}\cdot\text{h}^{-1}$ , and then the speed was increased by  $1.5 \text{ km}\cdot\text{h}^{-1}$  per 3-min stage. The speed in the last completed stage was considered as the MAS (6). MAS was increased by  $0.5 \text{ km}\cdot\text{h}^{-1}$ , if the child was able to run for 1 min during the last stage; or  $1 \text{ km}\cdot\text{h}^{-1}$ , if he or she was able to run for 2 min. During the test, the velocities were controlled using a computer. This test was performed on a 150-m track marked with cones every 25 m. The computer emitted a brief sound that indicated to the children the moment when they had to pass by a cone to maintain a constant speed. During the graded test, respiratory gas exchange values were measured breath by breath using a portable system (Cosmed K4b<sup>2</sup>, Rome, Italy) to determine ventilation ( $\dot{V}_E$ ), oxygen uptake ( $\dot{V}O_2$ ), and carbon dioxide production ( $\dot{V}CO_2$ ) (22). Before each test, the O<sub>2</sub> and CO<sub>2</sub> analysis systems were calibrated using ambient air and gases of known O<sub>2</sub> (16%) and CO<sub>2</sub> (5%) concentrations. For the calibration of the turbine flowmeter of the K4 b<sup>2</sup>, a 3-l syringe (Quinton Instruments, Seattle, Wash., USA) was used. Heart rate (HR) was continuously monitored (Polar Accurex+, Polar Electro, Kempele, Finland). The compact device was easy to attach without constricting the children's movements. For subsequent analysis,  $\dot{V}O_2$  and HR values were averaged at 15-s periods.

The peak $\dot{V}O_2$  was determined as the highest 15s  $\dot{V}O_2$  value measured during the graded test. Peak $\dot{V}O_2$  was accepted as a maximal index, when the maximal HR (HR<sub>max</sub>) reached a value above 195 bpm or when the respiratory exchange ratio (RER) was higher than 1, associated with visible exhaustion (35).

*High-intensity intermittent exercises.* The S-HIIE consisted of repeated (until exhaustion) 15-s runs at 120% of

MAS, interspersed with 15-s of either PR or AR. The AR period was set at 50% of MAS. These two tests were performed in a random order and were preceded by a standardized warm-up involving a 3-min run at  $7.5 \text{ km}\cdot\text{h}^{-1}$ . To complete the two S-HIEs, running paces were given by a manual timer, producing a sound every 15-s from the start to the end of the exercise. During the 15-s exercise period, the child had to cover a distance based on their own MAS (Figure 1). For the PR procedure, a 15-s PR period was allowed between each 15-s run. After the 15-s rest, the children started to run again in the opposite direction for 15-s. In contrast, in line with Dotan et al. (11), the AR procedure consisted of a 15-s shuttle run at 50% of MAS (see Figure 1 for more details)



**Figure 1.** An example of the pattern for intermittent runs for a child with a MAS of  $10.5 \text{ km}\cdot\text{h}^{-1}$

For PR, the child had to run between the two outer cones separated by 52.50m (120% of MAS) and stop at the outer cone. For AR, the child returned to the opposite end and slowed down to run 21.88m within 15s in the form of a shuttle run between the outer and the inner cone.

During the tests, respiratory gas exchange values were measured as for the graded field test. TTE and distance to exhaustion (DTE) were measured for AR and PR. Recovery periods were included in the TTE which was measured to the nearest second. For the AR session, the run at 50% of MAS was included in DTE.  $\dot{V}O_2$  was averaged per 15s periods and the highest values of HR and  $\dot{V}O_2$  were retained as peakHR<sub>PR</sub> and peak $\dot{V}O_{2PR}$  for PR, and peakHR<sub>AR</sub> and peak $\dot{V}O_{2AR}$  for AR.

The time spent above 80% peak $\dot{V}O_2$  (t80%), or higher than 90% peak $\dot{V}O_2$  (t90%) were calculated for both S-HIEs and corresponded to the amount of time spent (number of 15s bouts) above 80 and 90% of the peak $\dot{V}O_2$  (15). The time to reach peak $\dot{V}O_2$  was also assessed.

### Statistical analysis

The normality distribution of the data was checked with the Kolmogorov-Smirnov test. Then, a Wilcoxon matched-pairs signed rank test was used to compare TTE, DTE, number of runs, average  $\dot{V}O_2$ , peak $\dot{V}O_2$ , average HR, peakHR, PeakVE, t80%, t90%, time to reach peak $\dot{V}O_2$ , time spent above 80% and 90% of peakHR, RPE and FS values between PR and AR. Data are expressed as mean  $\pm$  SD. Regression analysis was used to assess the relationship between TTE of the PR and AR. In all analyses, the level of significance was set at  $p < 0.05$ . Data were analyzed with Prism 7.1d (Graphpad Software Inc, La Jolla). The threshold for statistical significance was set at  $p < 0.1$ , as the present study was considered as exploratory.

The statistical analysis reached a power from 38 to 80% for the measured parameters.

Cohen's d corrected by Hopkins was calculated to determine the effect size (ES) that was assessed using the following criteria:  $0 \leq ES \leq 0.2$  = trivial,  $0.2 < ES \leq 0.6$  = small,  $0.6 < ES \leq 1.2$  = moderate,  $1.2 < ES \leq 2.0$  = large,  $2.0 < ES \leq 4.0$  = very large,  $> 4.0$  = nearly perfect (20). To calculate the ES, the mean difference was defined as the PR value less the AR value for all the outcomes. The confidence interval (CI) was set at 95%.

### Results

The cardiorespiratory data were combined, as no difference was found between gender. The maximal values measured during the graded field test for  $\dot{V}O_2$ ,  $\dot{V}E$ , HR, RER, and MAS were:  $44.5 \pm 6.2 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ,  $1932 \pm 451$

ml·kg<sup>-1</sup>·min<sup>-1</sup>, 199±5 bpm, 1.15±0.1, 10.4±1.0 km·h<sup>-1</sup>, respectively.

The mean and peak cardiorespiratory values ( $\dot{V}E$ ,  $\dot{V}O_2$ , and HR), TTE, DTE, t80%, t90%, time to reach peak $\dot{V}O_2$  and times spent above 80% and 90% of peakHR, for AR and PR, are displayed in Table 1.

A very large effect for TTE ( $p < 0.001$ ) and a large one for DTE ( $p < 0.001$ ) were found in favour of higher PR values when compared with AR. No significant relationship was found between TTE of AR and TTE of the PR ( $r^2 = 0.08$ ,  $p > 0.05$ ).

Trivial or small effect sizes were found for cardiorespiratory responses between PR and AR ( $p > 0.05$ ), while a moderate effect in favour of higher AR values (ES= -0.87, 95% CI [-1.76 to -0.01]) was found for the average  $\dot{V}O_2$  ( $p < 0.05$ ). Figure 2 shows an example of the  $\dot{V}O_2$  vs time relationship for AR and PR.

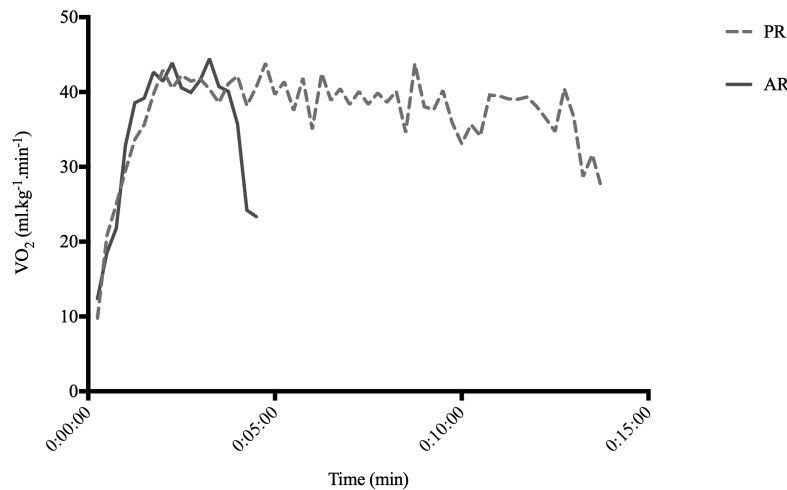


Figure 2: An example of the  $\dot{V}O_2$  vs. time relationship during the AR (—) and the PR (--)

The difference between the two intermittent exercises for t80% and t90% was trivial ( $p < 0.05$ ). The time spent above 80% of peakHR showed a very large effect ( $p < 0.01$ ) and time spent above 90% of peakHR a large effect in favour of higher PR values when compared with AR ( $p < 0.1$ ).

Eight and six children elicited peak $\dot{V}O_2$ , during S-HIIE, with AR and PR respectively. The time to reach peak $\dot{V}O_2$  showed a large effect ( $p < 0.01$ ) in favor of a higher value for PR (322±202s) when compared to AR (112±45s).

RPE values showed a small effect and FS values a trivial one ( $p > 0.05$ ).

**Table 1.** Comparison of mean ± SD values for time to exhaustion, cardiorespiratory measurements, time spent above 80% and 90% of peak $\dot{V}O_2$ , peakHR, time to reach peak $\dot{V}O_2$ , Ratings of Perceived Exertion and Feeling scale values between S-HIIE

Number of participants: 11	S-HIIE with PR	S-HIIE with AR	Mean of differences [95% CI]	Effect size [95% CI]
TTE (s)	622±215****	201±92	421 [273.9 to 568.1]	2.42 [1.32 to 3.52]
DTE (m)	1070±418****	428±226	642 [343.1 to 940.9]	1.81 [0.82 to 2.81]
Number of runs (n)	41.5±14.3****	13.3±6.1	28.82 [17.46 to 40.17]	2.31 [1.28 to 2.35]
Average $\dot{V}O_2$ (ml.kg <sup>-1</sup> .min <sup>-1</sup> )	31.1±5.2	35.8±4.9**	-4.61 [-9.28 to -0.12]	-0.87 [-1.76 to -0.01]

Peak $\dot{V}O_2$ (ml·kg <sup>-1</sup> ·min <sup>-1</sup> )	41.3±6.1	44.3±4.4	-3.0 [-7.73 to 1.73]	-0.54 [-1.39 to 0.32]
Average HR (bpm)	180±4	177±10	3 [-3.77 to 9.77]	0.37 [-0.47 to 1.22]
Peak HR (bpm)	191±4	191±4	0 [-3.56 to 3.56]	0 [-0.84 to 0.84]
Peak $\dot{V}E$ (ml·kg <sup>-1</sup> ·min <sup>-1</sup> )	1703±343	1712±244	-9 [-273 to 255]	-0.03 [-0.86 to 0.81]
Time spent above 80% of peak $\dot{V}O_2$ (s)	151±173	113±111	38 [-91.28 to 167.28]	0.25 [-0.59 to 1.09]
Time spent above 90% of peak $\dot{V}O_2$ (s)	41±56	72±116	-31 [-112.01 to 50.01]	-0.32 [-1.16 to 0.52]
Time to reach peak $\dot{V}O_2$ (s)	322±202***	112±45	210.0 [79.84 to 340.16]	1.36 [0.43 to 2.29]
Time spent above 80% of peakHR (s)	568±230**	173±106	395 [235.72 to 554.28]	2.09 [1.05 to 3.13]
Time spent above 90% of peakHR (s)	318±230*	126±105	192 [32.98 to 351.02]	1.02 [0.13 to 1.91]
Ratings of Perceived Exertion	8.0±2.5	7.3±2.4	0.7 [-1.17 to 3.37]	0.41 [-1.48 to 2.88]
Feeling Scale	-0.7±4.1	-0.2±4.2	-0.50 [-4.19 to 3.19]	-0.11 [-0.95 to 0.72]

CI: confidence interval; TTE: time to exhaustion; DTE: distance to exhaustion;  $\dot{V}O_2$ : oxygen uptake; Peak  $\dot{V}O_2$ : peak oxygen uptake; HR: heart rate; PeakHR: peak heart rate; Peak  $\dot{V}E$ : peak ventilation.

\*\*\*\*: significantly different at  $p < 0.001$ ; \*\*\*: significantly different at  $p < 0.01$ ; \*\*: significantly different at  $p < 0.05$ ; \*: significantly different at  $p < 0.1$

## Discussion

The aim of this study was to investigate the effects of the type of recovery (active vs. passive) on TTE and peak  $\dot{V}O_2$  during high-intensity intermittent runs (15s) at 120% of MAS in prepubertal children. The main results of the study were that, for this type of exercise, peak  $\dot{V}O_2$  achieved and t80% or t90% were not different between PR and AR, while time to reach peak  $\dot{V}O_2$  was faster in AR compared to PR, and TTE and DTE were greater with PR than with AR.

### Times to Exhaustion

The TTE for PR was significantly longer than for AR. The children ran three times as long and covered double distance with PR as with AR. In a previous study, during S-HIIE with PR at 120% of MAS, Berthoin et al. (7) have found a comparable TTE (421±121s) with prepubertal children. Moreover, TTE, reported in the present study, were similar to those found by Berthoin et al. (7) during continuous running at 90% (667±311s) and 100% of MAS (244±79s). Children seemed to respond to the same manner whether using continuous or intermittent exercises. With a 30-s interval runs at 110% of MAS, interspersed with 30s of either PR or AR, Thévenet et al. (32) showed double TTE values with PR than with AR (2145±829s vs 1072±388s). These results suggest that for S-HIIE (equal or shorter than 30s) with equal exercise/recovery ratio, AR lead to shorter TTE in children compared to PR, that is similar to previously results reported for adolescents. In adults, Dupont (16) showed also a shorter TTE in similar S-HIIE followed by AR. They suggested that this shorter TTE might partly be explained by a higher energy requirement during the AR procedure.

In the present study, AR resulted in moderately greater average  $\dot{V}O_2$  than PR (ES=-0.87, 95% CI [-1.76 to -0.01],  $p < 0.05$ ). For comparable exercises, Dupont et al. (16) showed that deoxygenation during AR was higher than during PR and suggested that  $\dot{V}O_2$  necessary for AR impaired myoglobin and hemoglobin oxygen replenishments,



as well as the resynthesis of phosphocreatine stores.  $\dot{V}O_2$  kinetics, myoglobin and hemoglobin oxygenation and phosphorylcreatine resynthesis certainly contribute to the performance during S-HIIE. However, no significant relationship was found between TTE between AR and PR, indicating that children who maintained the longest TTE with AR were not those who maintained the longest time with PR. During the exercise phase, children who reached a high percentage of  $\dot{V}O_{2max}$  faster might have a lower  $O_2$  deficit and hence could maintain the exercise longer. During the recovery period, children who experience faster phosphocreatine resynthesis and in whom replenishments in oxygen are greater should show less fatigue (16, 27).

Even if children are characterized by a faster adjustment of oxygen uptake to oxygen requirement at the onset of exercise (19) and a faster recovery after S-HIIE (27, 38), which could partly be explained by the children's ability to regulate the changes in acid-base balance more efficiently (28), Zafeiridis et al. (40) have shown, with 30s-runs at 110% of MAS with 30 s of recovery at 50% of MAS, that they are not able to perform for as long as adults. At 120% of MAS, there is certainly a high anaerobic contribution in terms of the energy requirement and children have a lower anaerobic capacity (38).

#### *Time Spent at a high percentage of peak $\dot{V}O_2$ .*

In adults, several authors (12, 13, 25) demonstrated that it was possible to reach and spend time at  $\dot{V}O_{2max}$  with S-HIIE. The time maintained at a high percentage of  $\dot{V}O_{2max}$  can be a key factor in improving  $\dot{V}O_{2max}$  during training. Using a similar S-HIIE, Baquet et al. (2) showed that children elicited a high percentage of peak  $\dot{V}O_2$  and even reached peak  $\dot{V}O_2$ . This may explain training programs with such exercises are efficient to increase peak  $\dot{V}O_2$  and/or aerobic performance in children (3). In previous studies investigating the peak  $\dot{V}O_2$  response using S-HIIE (2, 5), short bursts of exercises were interspersed with PR periods only. The nature and the intensity of the recovery might be another key factor in the increase in  $\dot{V}O_{2max}$  or performance (33). If the recovery intensity is too high, TTE and then  $t\dot{V}O_{2max}$  may be reduced (23). Thévenet et al. (33) have suggested that AR at 50% of MAS seems to be the best compromise to induce substantial solicitations of the aerobic system.

Over a single exercise session, physiological stress is often quantified by the amount of time spent above various thresholds of  $\dot{V}O_{2max}$ , ranging from 80% to 95% (39). Anyway, to elicit significant improvement in peak  $\dot{V}O_2$  in children and adolescents, the exercise intensity higher than 80% of the peak heart rate (3) has been suggested. In the present study, all the children have reached 80% of peak  $\dot{V}O_2$  whatever the recovery mode. With AR, 11 children have reached 90% of peak  $\dot{V}O_2$  and 8 children reached peak  $\dot{V}O_2$ . With PR, 7 children have reached 90% of peak  $\dot{V}O_2$  and 6 children reached peak  $\dot{V}O_2$ . For both S-HIIE, the interaction between intensity and duration of exercise and recovery periods was adequate to allow participants to reach and to maintain a high percentage of peak  $\dot{V}O_2$ .

During S-HIIE, our findings suggest that AR and PR allow similar amounts of time spent at a high percentage of peak  $\dot{V}O_2$ , although time to reach peak  $\dot{V}O_2$  was significantly shorter with AR ( $318 \pm 230$  vs  $126 \pm 105$ s for PR and AR, respectively). Recovery mode had no influence on  $t_{90\%}$  and  $t_{80\%}$ . This result can be explained by the smallness of our sample. From data of Dupont's et al. (14), a sample of 12 children was chosen and a statistical power of 80% was expected. This sample was sufficient to see a difference in TTE, but not to highlight a significant difference between the two recovery modalities for time spent at a high level of  $VO_{2peak}$ . For this parameter, we only reached a power of 38%, which confirmed the exploratory nature of this study. With similar exercises, Dupont & Berthoin (15) reported longer  $t_{90\%}$  in adults compared to children, whatever the recovery mode ( $282 \pm 117$ s and  $317 \pm 132$ s, for AR and PR respectively). However, they did not show a significant difference in  $t_{90\%}$  between the two types of recovery. The present results are also in line with those by Thévenet et al.'s (32) study which also showed no difference in  $t_{90\%}$  ( $746 \pm 417$ s and  $548 \pm 499$ s, for AR and PR respectively) using a short intermittent exercise (30s at 105% of MAS with 30s of recovery).

To spend equal time at high percentages of peak  $\dot{V}O_2$  with active recovery mode, a greater number of shuttles is required with PR. Thus, S-HIIE with AR seems to be more efficient than PR when the sole objective of training is to sustain at a high percentage of peak  $\dot{V}O_2$  as children run less time for the same value of  $t_{peak\dot{V}O_2}$ . In contrast, S-HIIE with PR allows a longer TTE at a high intensity (120% of MAS) and longer time spent at 80% and 90% of peak HR, that should increase endurance performance by further soliciting the neuromuscular system (32) and the cardiorespiratory system. With short intermittent runs of 15s at velocities ranging from 110 to 140% of MAS, Dupont et al. (12) demonstrated that the longest  $t\dot{V}O_{2max}$  in adults was obtained at 120% of the MAS. Further studies are needed to investigate the best interaction between, intensity, duration and recovery in S-HIIE to allow

children to reach and maintain the highest time at a high percentage of peak $\dot{V}O_2$ .

#### *Rating of Perceived Exertion and affective response*

Despite TTE difference between AR and PR and the higher average cardiorespiratory response in AR, no difference was observed between recovery modalities for RPE and SE. Children perceived the two exercises to be very difficult but seemed to have no negative feeling for this kind of exercise, whatever modality. Trainers can therefore use both S-HIIE interchangeably in a perspective to maintain the motivation of children during training.

#### *Practical applications*

AR is a particular form of continuous activity with variation of velocity while PR is a sequence of repeated exercise periods interspersed with intervals of incomplete rest (14). In S-HIIE with short recovery periods the recovery mode has a significant influence on performances (i.e: TTE) and cardiorespiratory responses (i.e: average  $\dot{V}O_2$ ). For training applications, these exercises are different. During training, it could be recommended that the number of repetitions with PR should be greater than with AR to spend a similar time at high percentages of peak $\dot{V}O_2$ . As improvements in peak $\dot{V}O_2$  are explained by the high level of  $\dot{V}O_2$  afforded by the exercises, trainers can use the two modalities to improve aerobic fitness. However, the choice of the recovery depends on training aim. Active recovery can be chosen when trainers want to improve peak $\dot{V}O_2$ .

#### **Conclusion**

In summary, children performing high intensity (120% of MAS) short duration (15s) exercises interspersed with AR exhibited a significant decrease in their running time and distance, compared with the PR protocol. Despite the shorter running duration in AR, an equal time was spent at high percentage of peak $\dot{V}O_2$  with AR and PR. Time spent at a high percentage of peak $\dot{V}O_2$  may be attained by running 3-fold shorter using AR compared using PR.

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