Cardiorespiratory Responses to Continuous and Intermittent Exercises in Children

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PMID: 28783846**Abstract**

The aim of the present study was to characterize aerobic responses to HIIE and CE in prepubertal children. Twenty-five 8 to 11-year-old children took part to a preliminary visit to determine peakVO_2 and Maximal Aerobic Velocity (MAV). During the 5-following experimental visits, the participants completed 2 CE and 3 HIIE sessions in a randomized order. The HIIE consisted of short intermittent 10 and 20-s running bouts from 100 to 130% of MAV, interspersed with recovery periods of equal duration (S-HIIE1 and S-HIIE2 respectively) and 5-s sprinting and jumping at maximal intensity with 15-s recovery periods (S-HIIE3). Continuous submaximal exercises consisted of two 10-min running periods at 80% and 85% of MAV with a 5-min recovery period. CE protocols elicited higher average VO_2 and exercise time spent above 95% of peakVO_2 than HIIE protocols. S-HIIE 1 and S-HIIE 2 elicited similar average VO_2 response and higher than S-HIIE 3. Our study has shown that CE activated the aerobic system to a greater extent than S-HIIE in prepubertal children, as reflected by exercise time above 95% of peakVO_2. However, isotime S-HIIE protocols of either 10 or 20-s exercise bouts at an intensity above MAV result to similar exercise times at high oxygen consumption rates (above 95% VO_2peak).

Keywords: Oxygen uptake, Exercise modalities, Maximal Aerobic Velocity, Children.

Introduction

The manipulation of exercise intensity, duration, and of work and recovery periods characteristics during High Intensity Intermittent Exercise (HIIE) determines the amount of time spent at exercise intensity close to peak oxygen uptake (VO_{2peak}). The accumulation of time near VO_{2peak} over repeated exercise sessions is recognized as an important factor contributing to the gain in aerobic capacity in response to exercise training [20]. There is growing evidence that both continuous submaximal intensity exercise (CE) and HIIE training protocols are effective in improving peakVO_2 in children [2, 9, 11], which raise the question of the relative efficacy of these two modalities of exercise training.

Over a single exercise session, the physiological stress is often quantified by the amount of time spent above various threshold, ranging from 80% to 95% of VO_{2max} [23, 28, 30]. HIIE typically consists of exercise bouts at intensity of at least 90% peakVO_2 interspersed with periods of passive or active recovery [5]. HIIE with short duration work and recovery periods (S-HIIE) at intensity ≥100 %VO_{2max} is especially used in children, and is effective to improve VO_{2max} [3]. During CE, Baquet et al. [2] previously indicated in a review that the exercise intensity needs to be above 80% of maximal heart rate to elicit significant improvement of VO_{2max} in children and adolescents. Adolescents were then showed to spend more time above 80%VO_{2max} during heavy intensity continuous exercise relative to 30-s HIIE protocol performed at 110% of MAV conducted to exhaustion, which provides support for CE as an effective exercise modality to strongly activate the cardiorespiratory system [30]. However, adolescents have to exercise for 1.5 to 2 times longer during CE than during S-HIIE to elicit such responses [30]. Although young endurance athletes can perform such exercise to exhaustion to maximize physiological stress during training sessions, the amount of time devoted to aerobic conditioning is limited in many team sports or during PE classes. Moreover, when the accumulated exercise time at near maximal aerobic system activation (95 %VO_{2max}) was examined , the 30-s HIIE protocol was equally effective to CE to activate the cardiorespiratory system, despite shorter time to exhaustion [30]. It is therefore important to determine which exercise modalities elicit the largest amount of time at a high percentage of VO_{2max} over exercise duration typically shorter than 30 minutes. In this regard, Nicolò et al. [20] have reported that overall effort and total duration of exercise are two critical parameters that should both be controlled when comparing continuous and intermittent exercise modalities.

The purpose of the present study was therefore to determine the exercise modality that elicited the greatest cardiorespiratory system activation among 3 S-HIIE differing for exercise and recovery durations at intensity ≥100%MAS and 2 modalities of CE at intensity ≥80% MAS matched for total duration in 8-11year-old prepubertal children. The time spent above 95% VO_{2max} was used as the primary outcome, and average VO_2 and Heart Rate were used as secondary outcomes. We hypothesized that S-HIIE with the longest duration work periods would result in higher cardiorespiratory system activation relative to CE and S-HIIE with shorter work period duration.

Methods

Experimental approach to the problem

Subjects

Twenty-five 8 to 11- year-old children (12 boys and 15 girls) participated in the study. The children's parents signed a written informed consent after being fully informed for possible risks and discomforts associated with the exercise protocols and testing procedures of the study. The study was designed in accordance with the ethical standards of the Helsinki Declaration of 2013, received the approval of the local "Consultative Committee for the Protection of Persons in Biomedical Research" and met the ethical standards of the IJSM [13]. Stature and body mass were measured with a wall stadiometer (Vivioz Medical, Paris, France) and a calibrated beam balance (Tanita TBF 543, Tokyo, Japan), to the nearest 0.1 cm and 0.1 kg, respectively. Percentage of body fat was estimated from skinfold thickness measured at three sites (biceps, triceps and calf; Harpenden skinfold caliper HSK-BI), according to Slaughter-Lohman equations [16]. Sexual maturity was assessed from pubertal stages: indices of breast, pubic hair and genital development [22]. All boys (n=11) were at stage 1 for genital development and pubic hair. Thirteen girls were at stage 1 for breast and pubic hair, while for the remaining girls (n=2) the combined stage assessment was ≤ 3.

Experimental design

Before entering the study, the children were familiarized with the exercise testing procedures. After a preliminary visit to determine peakVO_2 and Maximal Aerobic Velocity (MAV), the children took part to five experimental sessions conducted in a randomized order. They performed three S-HIIE with distinct work duration, exercise intensity and work-to-recovery duration ratio, and two CE. Each session lasted between 25 and 27 minutes. During the preliminary visit and each of S-HIIE and CE protocol, respiratory gas exchange values were measured breath-by-breath using a portable system (Cosmed K4b^2, Rome, Italy) [17]. Before each test, the O_2 and CO_2 analyzers were calibrated using ambient air and a gas of known O_2 (16%) and CO_2 (5%) concentrations. For the calibration of the turbine flowmeter of the K4 b^2, a 3-l syringe (Quinton Instruments, Seattle, Wash., USA) was used. VO_2 and CO_2 values were averaged at 5s periods. Heart rate (HR) was continuously monitored (Polar Accurex+, Polar Electro, Kempele, Finland).

For each exercise test, average VO_2, average HR, peakVO2, peakHR, peakVE, energy expenditure and time spent above 95% peakVO_2 (t_{95}peakVO_2) were calculated [10].

Peak oxygen uptake and Maximal Aerobic Velocity

Before the five experimental visits, children underwent a maximal graded test on a treadmill, to determine peakVO_2 and MAV. The children were familiarized with treadmill running before the start of the test. The test started with an initial velocity of 6 $km.h^{-1}$, and the speed was then increased by 0.5 $km.h^{-1}$ every 1-min. The speed at the last completed stage was considered as the MAV [6]. PeakVO_2 was determined as the mean of the two highest 5s VO_2 values. Criteria for considering that peakVO_2 had been reached were maximal heart rate (HRmax) above 195 bpm, respiratory exchange ratio (RER) above 1.00, associated with visible exhaustion [24]. PeakVO_2, HRmax, RER and maximal Ventilation (VEmax) obtained for the graded test were, respectively, 54.9±6.8 $ml.kg^{-1}.min^{-1}$, 215±7 bpm, 1.02±0.06 and 71.0±10.1 $l.min^{-1}$. MAV was 11.7±1.1 $km.h^{-1}$.

High Intensity Intermittent exercise

S-HIIE1 consisted of short intermittent runs with work and recovery duration lasting 10-sec/10-sec. The exercise session consisted of five sets of 10 repetitions interspersed with 3 min recovery between sets. Intensity increased by 10% of MAV at each set, from 100% of MAV during the 1^{st} set to 130% of MAV during the 5^{th} set. S-HIIE2 consisted of short intermittent runs with work and recovery duration lasting 20-sec/20-sec. The exercise session consisted of five sets of 5 repetitions interspersed with 3 min recovery between sets. Intensity increased by 10% of MAV at each set, from 100% of MAV during the 1^{st} set to 130% of MAV during the 5^{th} set.

S-HIIE1 and S-HIIE2 were performed on a track. Each child had to cover the distance corresponding to 10s (S-HIIE1) or 20s (S-HIIE2) at the required MAV. For example, a subject with a 9 $km.h^{-1}$ MAV had to run over 50 m in 20 s, at 100% of MAV. After 20s of recovery, the child turned back and repeated the run in the opposite direction. S-HIIE3 consisted of all-out sprint running and jumping with exercise to recovery sequences lasting 5s and 15s, respectively. For S-HIIE3, each child sprinted or performed maximal vertical jumps during 5s interspersed with 15s of recovery. Each child was continuously encouraged with an experimenter running next to him for each experimental session. Details of the experimental sessions are outlined in Table 1.

Continuous Exercise

CE sessions included two sets of 10 min with 5-min recovery between each set. Intensity was set at 80 (CE80) and 85% of MAV (CE85). CE were performed on a 250m track marked with cones every 25m. Each child was continuously encouraged by an experimenter (using a timer) who ran next to him for each session. The timer emitted a brief sound that indicated to the children the moment they had to pass near a cone to maintain a constant speed. Details of the training sessions are outlined in Table 1.

Statistical analysis

The normality of the data distribution was checked using the Kolmogorov-Smirnov test. The experimental values were expressed as mean ± standard deviation (mean ± SD). Data were analyzed using a one-way ANOVA (training session) with repeated measures. Bonferonni post hoc analyses were conducted to identify a difference between training sessions and training sets. 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 [14]. Data were analyzed with InStat (Graphpad Software Inc, La Jolla). The threshold for statistical significance was set at $p < 0.05$.

Results

Cardiorespiratory responses and energy expenditure values attained during S-HIIE and CE sessions are reported in Table 2. Effect size and 95% confidence intervals for average oxygen uptake (VO_2), average Heart Rate (HR) and $t_{95}peakVO_2$ between each session are reported in Table 3.

Oxygen uptake

Table 2 presents average VO_2 and peakVO_2 during S-HIIE and CE sessions. Average VO_2 (ml.kg^{-1}.min^{-1}) was significantly higher ($p<0.001$) in CE80 and CE85 than all three S-HIIE, and in S-HIIE1 ($p<0.05$) and S-HIIE2 ($p<0.001$) than in S-HIIE3. The attained peakVO_2 was similar between CE80, CE85, S-HIIE1 and S-HIIE2. The participants during S-HIIE3 attained a significantly lower peakVO_2 value than in CE85 ($p<0.01$) and S-HIIE2 ($p<0.001$) protocols. PeakVE values are reported in Table 2. The attained peakVE was similar in CE80, CE85, S-HIIE1 and S-HIIE2 protocols; whereas it was significantly lower in S-HIIE3 than CE85 ($p<0.01$) and S-HIIE2 ($p<0.001$) (Table 2).

Table 3 shows the effect sizes and 95% confidence intervals for average VO_2. Very large effects were found in average VO_2 between CE80 and S-HIIE sessions (ES CE80 vs S-HIIE1 = 2.47, 95%CI = 1.72, 3.22; ES CE80 vs S-HIIE2 = 2.34, 95%CI = 1.57, 3.03; ES CE80 vs S-HIIE3 = 3.34, 95%CI = 2.42, 4.16). Very large to nearly perfect effects were found in average VO_2 between CE85 and S-HIIE (ES CE85 vs S-HIIE1 = 3.38, 95%CI = 2.35, 4.27; ES CE85 vs S-HIIE2 = 3.46, 95%CI = 2.43, 3.47; ES CE85 vs S-HIIE3 = 4.24, 95%CI = 3.05, 4.25). Comparisons among S-HIIE protocols for average VO_2 showed a moderate effect between S-HIIE1 and S-HIIE3 (ES = 0.95, 95%CI = 0.33, 1.53) and a large effect between S-HIIE2 and S-HIIE3 (ES=1.61, 95%CI = 0.96, 2.27). Figure 1 shows the kinetics of oxygen uptake during S-HIIE1, S-HIIE2 and S-HIIE3 and CE85. The data were representative from the same subject

HR

Table 2 presents average HR and peakHR during S-HIIE and CE sessions. Average HR (bpm) was significantly higher ($p<0.001$) in CE80 and CE85 than S-HIIE sessions. No significant difference was found between S-HIIE sessions. PeakHR was similar between CE80, CE85, S-HIIE1 and S-HIIE2. S-HIIE3 showed significantly lower peakHR than CE80 ($p<0.05$), CE85 and S-HIIE2 ($p<0.001$). Table 3 shows the effect size and 95% confidence intervals for average HR between each session. Comparisons among protocols for average HR showed large effects between CE80 and HIIE (ES CE80 vs S-HIIE1 = 2.08, 95%CI = 1.30, 2.87; ES CE80 vs S-HIIE2 = 1.99, 95%CI = 1.27, 2.71; ES CE80 vs S-HIIE3 = 2.19, 95%CI = 1.46, 2.53) and very large effects between CE85 and S-HIIE (ES CE85 vs S-HIIE1 = 2.87, 95%CI = 1.76, 3.92; ES CE85 vs S-HIIE2 = 3.10, 95%CI = 2.02, 4.18; ES CE85 vs S-HIIE3 = 3.07, 95%CI = 2.03, 4.19).

Time spent above 95% peakVO$_2$

One child and four children did not reach 95% of peakVO$_2$ during S-HIIE1 and S-HIIE3 protocols, respectively. Table 2 presents t_{95}peakVO$_2$ during S-HIIE and CE sessions. Time spent above 95% peakVO$_2$ (s) was significantly higher in CE85 than S-HIIE sessions ($p<0.01$), in CE80 than S-HIIE1 and HIIE3 ($p<0.05$) and in S-HIIE2 than S-HIIE3 ($p<0.05$). Table 3 depicts effect size and 95% confidence intervals of the effect between protocols for exercise time about t95VO$_2$peak between each session. Large effects were found in t_{95}peakVO$_2$ between CE85 and S-HIIE protocols (ES CE85 vs S-HIIE1 = 1.41, 95%CI = 0.70, 2.12; ES CE85 vs S-HIIE2 = 1.15, 95%CI = 0.47, 1.83; ES CE85 vs S-HIIE3 = 1.78, 95%CI = 1.04, 2.53). Moderate effects were showed in t_{95}peakVO$_2$ between CE80 and S-HIIE1 (ES CE80 vs S-HIIE1 = 0.72, 95%CI = 0.12, 1.31) and between CE80 and S-HIIE3 (ES CE80 vs S-HIIE3 = 1.07, 95%CI = 0.46, 1.67). Regarding the difference between S-HIIE sessions, t_{95}peakVO$_2$ showed a moderate effect between S-HIIE2 than S-HIIE3 (ES=1.03, 95%CI = 0.45, 1.61. $p<0.05$).

Energy expenditure

Energy expenditure values are reported in Table 2. Energy expenditure was significantly higher ($p<0.001$) during CE80 and CE85 (182.2±32.3 and 194.7±39.8 kcal, respectively) than during S-HIIE protocols. The total kcals consumed in S-HIIE1 and S-HIIE2 were significantly higher than during S-HIIE3 (153±24.7 and 160.9±26.3 vs 127.5±22.5 kcal, respectively; $p<0.001$).

Discussion

This study was designed to characterize the activation of aerobic metabolism in response to different modalities of exercise commonly used to improve cardiorespiratory fitness in prepubertal children. The key findings of this study were two-fold. Firstly, CE protocols elicited higher average VO_2 and time spent above 95% of VO_2max than S-HIIE protocols. Secondly, the aerobic system activation was lower in response to sprint running and jumping exercises interspersed with short recovery periods relative to the other S-HIIE or CE protocols.

There has been little research in children providing quantitative and comparative analyses of cardiorespiratory responses to S-HIIE and CE. Hence, we compared VO_2, HR responses and exercise time spent above 95% peakVO_2 during S-HIIE and CE. These exercise modalities were matched for total duration of exercise ("isotime") to compare the aerobic system activation. Exercise intensity seems to be a key factor in training design and an intensity of at least 80% HRmax has been suggested to be required to obtain significant increase in aerobic fitness in children [3]. Thus, we were employed CE with intensities of at least 80% of MAV. In the present study, S-HIIE protocols were performed at speeds above MAV using work to rest ratios that were previously shown to improve MAV similarly to CE protocols [3, 4]. Up to date various matching methods, such as work [1], energy expenditure, or time to exhaustion [23, 30] have been used when comparing the physiological responses of continuous and intermittent exercise protocols. Nicolo et al. [20] underlined the influence of the overall effort and total duration of exercise when comparing continuous with intermittent exercise protocols. In the present study, the total exercise duration was similar between the different sessions, but the protocol was not designed to have the same mean intensity, or to be performed at the maximal sustainable intensity (“isoeffort” approach) across all exercise modalities.

Effect of exercise modalities on maximal percentage of peakVO_2 and peakHR reached

Midgley and Mc Naughton [19] have suggested that the percentage of peak VO_2 attained during an acute bout of exercise may be a factor determining the improvement of peakVO_2. In the present study, the percentages of peakVO_2 and peakHR attained were significantly higher in CE than S-HIIE despite that the two protocols had similar total exercise duration. Our results are in accordance with those of Borel et al. [7] who showed significantly higher cardiorespiratory activation in response to continuous exercise when performed at 80% of MAV compared to intermittent exercise performed at 110% of MAV. PeakVO_2 and peakHR responses in the present study were also similar to those reported by Zafeiridis et al. [30] where the adolescents had to run either continuously at 83% of MAV or to perform 30-s runs at 110% MAV with 30-s recovery at 50% of MAV until exhaustion. However, the above study showed that a long intermittent exercise consisting of 3 min runs at 95% of MAV with 3 min recovery at 35% of MAV activated the aerobic system to a greater extent than CE and S-HIIE [30]. Long interval intermittent exercise (LIE) at intensities close to VO_2max has been known to be optimal to activate the aerobic system [1]. However, LIE is less commonly used than S-HIIE in young children, and in contrast to adolescents its effects on aerobic system activation have not been investigated. Wakefield and Glaister [26] have suggested that work period duration longer than 25s at intensities >100% of MAV are needed to optimize time at peakVO_2. Hence, exercise work bouts of at least 30s at 100 and 110% of MAV may be required to provide significant activation of the aerobic system. In young adults, Zafeiridis et al. [28] reported that activation of the aerobic system was also similar during a continuous exercise performed at 70% of cycling power corresponding to VO_{2max} and a short intermittent protocol with 30s at 100% power corresponding to VO_{2max} with 30s passive recovery (84.6±1.1% and 83±7.4% of VO_2max, respectively). Notably, the percentages of VO_2peak attained in Zafeiridis ‘study [28] were similar to those observed in the present study using higher work-bout intensities (120% and 130% of MAV) with shorter durations (10 and 20s).

Effect of exercise modalities on time spent above 95% peakVO₂

Increase in VO_2max following training protocols has been suggested to depend on time spent at VO_2max (tVO_2max) [19] and is greater when using exercise bouts with intensity ranging from 90 to 100% of VO_2max [26]. The calculation of tVO_2max depends on the variability in VO_2max. In the present study, the determination of the VO_2max of the day was not made. However, to calculate in the most accurate way tVO_2max, the sum of times spent above 95% of the VO_2max was used [10]. We found that children spent significantly longer time above 95% of VO_2peak during CE85 protocol compared to S-HIIE protocols employing 10 and 20-s runs at speeds corresponding to 120 and 130% of MAV and to 5s all-out runs. Furthermore, CE performed at 80% of MAV was superior to both 5 and 10-sec HIIE running protocols to elicit longer exercise time above 95% of peakVO_2.

As demonstrated in adults [12], HIIE performed at 90% of VO_2max taxed physiologically to the same manner than steady state exercise at 70% of VO_2max, but is influenced by the work-to-rest duration ratio. Gosselin et al. [12] stated that HIIE may be used as an alternative approach to CE, but with less time commitment. The total time spent at a high percentage of peakVO_2 during S-HIIE determines the adaptive gain of peakVO_2 and power output at peakVO_2 [21]. Seiler et al. [21] have reported interactions on physiological adaptations between intensity and work duration in HIIE, which must be taken into account when designing aerobic training protocols. To our knowledge, three studies have investigated tpeakVO_2 in children [15] and adolescents [29, 30] with exercise of different intensities. However direct comparison with

Leclair' study [15] is difficult as the authors reported the time spent at VO_2peak as the time above 90% VO_2peak. On the other hand, similarly to our study, they also reported a high inter-individual variability for the time spent at high VO_2 rates (47.9±69.1s and 34.2±34.5s for 100% and 110% of MAP, respectively). In Zaferidis studies [29, 30], adolescents had also to run until exhaustion either continuously at 83% of MAV or using 30s runs at 110% MAV. The time spent above 95% of VO_2max was not significantly different between the two protocols (85 ± 200 and 54 ± 66 s, respectively for CE and S-HIIE). Zafeiridis et al. [29, 30] concluded that CE of appropriate intensity and duration might be as effective as S-HIIE for taxing the aerobic system above 90% of VO2 max. In the present study, the duration of S-HIIE (10 or 20s) at 100 and 110% of MAV appeared insufficient to achieve a substantial tpeakVO_2, compared to the 30-s runs in Zafeiridis studies [29, 30].

S-HIIE3 was associated with less tpeakVO_2 than CE and HIIE2. Such an observation may contribute to explain why some [27], but not all [18] failed to observe improved peakVO_2 in response to repeated sprint training. Hence, the potentially lower effect of repeated sprint exercise to elicit a high percentage of peakVO_2 in children may explain the lower peakVO_2 improvement when this type of exercise is used for exercise training. Similarly, to S-HIIE 1 and 2 at 100 and 110% MAV, S-HIIE3 did not allow to spend a substantial amount of time above 95%VO_2peak.

The longer time above 95% of VO_2peak during CE85 and CE80 protocols could be explained by differentially stroke volume responses and the contribution of the metabolic systems to energy production that depends on intensity and duration differences [8]. In a study with adults, Zafeiridis et al. [29] showed that under isoeffort conditions continuous and long-interval (3 min exercise bouts) protocols resulted to higher average cardiac output and stroke volume responses compared to 30-sec exercise bouts with passive recovery. However, if the goal is to improve muscle O2-utilization potentials, all 3 protocols appeared equally effective. In the present study, exercise modalities were matched for total duration of exercise (“isotime”) to compare the aerobic system activation. Further studies are needed to analyze the central and peripheral components of VO_2 in children on isoeffort conditions.

Conclusion

Our study has shown that in prepubertal children, CE performed at 80 and 85% of MAV activated the aerobic system to a greater extent compared to isotime HIIE protocols performed at 100-130%of MAV. However, S-HIIE protocols of total equal duration exercise bouts of either 10 or 20-s at intensity above MAV accumulate similar exercise time above 95% of VO_2peak. Thus, these S-HIIE exercise modalities may be be used interchangeably to decrease the monotony of training.

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TABLE 1 Details of short high-intensity intermittent exercise (S-HIIE) and continuous submaximal exercise (CE) sessions

31.

	Sessions	**Recovery and session duration**
S-**HIIE 1** **Exercises 10/10s**	1 set (10*10s) at 100% of MAV 2 sets (10*10s) at 110% of MAV 1 set (10*10s) at 120% of MAV 1 set (10*10s) at 130% of MAV	10s between each repetition 3’ between each set Session duration: 27’
S-**HIIE 2** **Exercises 20/20s**	1 set (5*20s) at 100% of MAV 2 sets (5*20s) at 110% of MAV 1 set (5*20s) at 120% of MAV 1 set (5*20s) at 130% of MAV	20s between each repetition 3’ between each set Session duration: 27’
S-**HIIE 3** **Exercises 5/15s**	3 sets (15*5s) of sprint or jumping with 15s of recovery between each repetition	15s between each repetition 5’ between each set Session duration: 25’
CE80	2 sets of 10’ at 80% of MAV	5’ between each set Session duration: 25’
CE85	2 sets of 10’ at 85% of MAV	5’ between each set Session duration: 25’

S-HIIE: short high-intensity intermittent exercise; CE: continuous submaximal exercise; MAV: maximal aerobic velocity

TABLE 2 Cardiorespiratory responses during short high-intensity intermittent exercise (S-HIIE) and continuous submaximal exercise (CE) sessions

Parameters		S-HIIE 1 (10s) 5 sets of 10 Repetitions	S-HIIE 2 (20s) 5 sets of 5 Repetitions	S-HIIE 3 (5s) 3 sets of 15 repetitions	CE80 (2 sets of 10min)	CE85 (2 sets of 10min)
	1st set	35.3±4.8 (64.6±6.5)	35.3±5.5 (64.5±7.0)	38.1±5.3 (69.9±8.3)	45.6±5.8 (82.2±7.7)	48.4±7.1 (87.2±8.2)
VO_2	2nd set	40.0±5.3 (73.3±7.4)	41.3±5.8 (75.5±5.9)	37.3±5.8 (68.4±8.9)	47.5±6.4 (85.6±8.4)	49.3±8.3 (87.9 ±8.5)
	3rd set	40.5±5.6 (74.1±7.3)	42.3±5.5 (77.3±5.7)	36.8±6.1 (67.5±10.2)		
Average ($ml.kg^{-1}.min^{-1}$) (% peakVO_2)	4th set	43.5±6.3 (79.6±8.6)	45.0±5.0 (82.3±5.5)			
	5th set	45.4±6.8 (83.0±9.8)	47.0±6.0 (85.9±6.5)			
	Whole session					
		31.1±4.1 (57.0±5.9°)	**32.7±3.9 (59.8±4.3°°°)**	**28.0±4.1 (51.3±6.1)**	**40.5±5.3 (72.9±6.9***)**	**43.1±6.5 (77.0±6.0***)**
Average ($ml.kg^{-1}.min^{-1}$) (% peakVO_2)		**56.58±6.46**	**59.87±6.08°°°**	**52.54±6.43**	**56.51±6.03**	**56.51±6.03**
Peak ($ml.kg^{-1}.min^{-1}$)						
		70.67±10.39	**76.62±8.74°°°**	**67.10±8.96**	**68.21±8.43**	**70.21±9.45°°**
VE Peak ($l.min^{-1}$)						
	1st set	169±9 (78.6±5.0)	171±9 (79.7±5.0)	183±9 (85.3±3.9)	189±10 (88±3.7)	195±7 (90.9±3.0)
HR	2nd set	181±7 (84.1±4.3)	183±8 (85.2±3.9)	184±9 (85.6±4.0)	192±10 (89.8±3.6)	200±7 (93.6±3.0)
Average (bpm) (% HRmax)	3rd set	182±8 (84.6±4.5)	186±9 (86.4±4.2)	185±10 (86.3±4.3)		
	4th set	189±7 (88.1±3.4)	192±9 (89.5±3.5)			
	5th set	195±8 (90.8±3.0)	198±8 (92.1±3.2)			
	Whole session					
Average (bpm) (% HRmax)		**161±8 (75.2±4.2)**	**165±8 (76.6±3.2)**	**161±9 (74.9±3.8)**	**179±9 (83.5±3.6***)**	**186±8 (87.2±3.7***)**
Peak (bpm)		**208±8**	**211±7°°°**	**204±8**	**210±7°**	**211±7°°°**
	1st set	8±14 (4.3±7.5)	8±16 (4.0±8.2)	32±45 (10.8±15.0)	175±157 (29.2±26.1)	282±183 (47.1±30.5)
t_{95}peakVO_2 (s) (% exercise time)	2nd set	24±28 (12.8±13.7)	32±25 (17.0±13.2)	30±37 (10.0±12.4)	226±176 (37.6±29.3)	291±181 (48.5±30.1)
	3rd set	24±25 (12.7±13.4)	42±31 (21.9±16.5)	37±47 (12.4±15.8)		
	4th set	44±38 (23.1±19.9)	68±36 (36.0±19.1)			
	5th set	69±51 (36.3±26.8)	87±41 (45.6±21.5)			
	Whole session					
		169±140 (17.8±14.8)	**237±119 (24.9±12.5)°**	**99±130 (11.1±14.0)**	**401±314 (33.3±26.2*)**	**573±338 (47.8±28.1**)**
Energy Expenditure (kcal)		**153±24.7°°°**	**160.9±26.3°°°**	**127.5±22.5**	**182.2±32.3*****	**194.7±39.8*****
Running distance (m)		**1851±172°°°**	**1851±172°°°**	**741±69**	**3118±290*****	**3313±308*****

S-HIIE: short high intensity intermittent exercise; CE: continuous submaximal exercise; VO_2: oxygen uptake; HR: heart rate; $t_{95}peakVO_2$: time spent at 95% of peak oxygen uptake; MAV: maximal aerobic velocity; VE: ventilatory exchange. ***: significatively different from S-HIIE1, S-HIIE2 and S-HIIE3 at $p<0.001$; **: significatively different from S-HIIE1, S-HIIE2 and S-HIIE3 at $p<0.01$; *: significatively different from S-HIIE1 and S-HIIE3 at $p<0.05$; °°°: significatively different from S-HIIE3, at $p<0.001$; °°: significatively different from S-HIIE3, at $p<0.01$; °: significatively different from S-HIIE3, at $p<0.05$.

TABLE 3 Effect size and 95% confidence intervals for Average oxygen uptake (VO_2), Average Heart Rate (HR) and time spent at 95% of peakVO_2 between each session

	Parameters	**S-HIIE 1 (10s) (100-130% of MAV)**	**S-HIIE 2 (20s) (100-130% of MAV)**	**S-HIIE 3 (5s) (sprints and jumps)**	**CE80 (80% of MAV)**	**CE85 (85% of MAV)**
S-HIIE 1 (10s)	Average VO_2 Average HR t_{95}peakVO_2					
S-HIIE2 (20s)	Average VO_2	ES = 0.56 (95% CI = -0.03, 1.13)				
	Average HR	ES = 0.38 (95% CI = -0.19, 0.95)				
	t_{95}peakVO_2	ES = 0.49 (95% CI = -0.07, 0.49)				
S-HIIE 3 (5s)	Average VO_2	ES = 0.95 (95% CI = 0.33, 1.53)	ES = 1.61 (95% CI = 0.96, 2.27)			
	Average HR	ES = 0.03 (95% CI = -0.57, 0.63)	ES = 0.43 (95% CI = -0.12, 0.98)			
	t_{95}peakVO_2	ES = 0.48 (95% CI = -0.07, 1.04)	ES = 1.03 (95% CI = 0.45, 1.61)			
CE80 (80% of MAV)	Average VO_2	ES = 2.47 (95% CI = 1.72, 3.22)	ES = 2.34 (95% CI = 1.57, 3.03)	ES = 3.34 (95% CI = 2.42, 4.16)		
	Average HR	ES = 2.08 (95% CI = 1.30, 2.87)	ES = 1.99 (95% CI = 1.27, 2.71)	ES = 2.19 (95% CI = 1.46, 2.53)		
	t_{95}peakVO_2	ES = 0.72 (95% CI = 0.12, 1.31)	ES = 0.41 (95% CI = -0.16, 0.99)	ES = 1.07 (95% CI = 0.46, 1.67)		
CE85 (85% of MAV)	Average VO_2	ES = 3.38 (95% CI = 2.35, 4.27)	ES = 3.46 (95% CI = 2.43, 3.47)	ES = 4.24 (95% CI = 3.05, 4.25)	ES = 0.7 (95% CI = -0.01, 1.36)	
	Average HR	ES = 2.87 (95% CI = 1.76, 3.92)	ES = 3.10 (95% CI = 2.02, 4.18)	ES = 3.07 (95% CI = 2.03, 4.19)	ES = 0.98 (95% CI = 0.16, 1.80)	
	t_{95}peakVO_2	ES = 1.41 (95% CI = 0.70, 2.12)	ES = 1.15 (95% CI = 0.47, 1.83)	ES = 1.78 (95% CI = 1.04, 2.53)	ES = 0.50 (95% CI= -0.16, 1.17)	

S-HIIE: short high intensity intermittent training; CE: continuous submaximal exercise; VO_2: oxygen uptake; HR: heart rate; t95peakVO_2: time spent at 95% of peak oxygen uptake; MAV: maximal aerobic velocity. ES: Effect size; CI: confidence interval.