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Adaptation of Aerobic Capacity followed by Adaptation of Perceived Exertion after 6-Week High-Intensity Interval Training

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Abstract

Study purpose: The challenge of monitoring training adaptation has appeared with the demand for a simple, non-exhaustive and efficient approach, since the standardised and sophisticated tools have not been available for athletes in remote area. This study aimed to investigate improvement of the maximum aerobic capacity including heart rate (HR) after 6-week of high-intensity interval training (HIIT) also stimulated the adaptation in rate perceived of exertion (RPE) and furthermore to observe the correlation between these adaptation

Materials and methods: Pre-and post-experimental design has been applied to sixteen healthy adults (21±1.1 yr) that completed three times per week cycling HIIT. Before and after intervention, participants underwent two tests in separate days on the cycling ergometer consist of the incremental maximal test to assess maximal heart rate (HR_{max}) and peak power output (PPO) and the 5-min steady-state exercise (SSE) test with workload 40% and 60% of PPO to assess exercise heart rate ($HR_{exercise}$), $\%HR_{execise}$ and RPE scale.

Results: The HIIT adaptation increased PPO significantly (P<0.001; d=0.41; 302±50.8 to 322±50.9 watt) and decreased HR_{max} (P=0.001; d=0.43; 188±8.53 to 184±6=7.44 bpm). $HR_{exercise}$ was observed slower in SSE 40% (P=0.005; d=0.55; 127±9.41 to 122±11.9 bpm) and SSE 60% (P=0.001; d=0.63; 153±11.7 to 145±12.6 bpm). The RPE adaptation exhibited a decreasing in SSE 40% (P=0.001; d=1.01; 10±1.25 to 9±0.93) and SSE 60% (P=0.001; d=0.97; 13±0.98 to 12±1.41). The correlation between RPE and $HR_{exercise}$ was established in pre- (r=055, P=0.001) and post-intervention (r=061, P<0.001).

Conclusions: Adaptation of HIIT improved the aerobic capacity proved by increase of PPO and decrease HR_{max}, linked to increase of RPE scale and $HR_{exercise}$ in SSE 40% and SSE 60%. The correlation between RPE and $HR_{exercise}$ was consistently strong pre- and post-intervention. Thus, this finding indicated

RPE can be an easy and cost-effective instrument for monitoring intensity and aerobic capacity adaptation.

Keywords: Perceived Exertion, Heart Rate, High-Intensity Training, Steady-State Exercise

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Introduction

For over a century, scientific evidence has been proven the benefit of interval training that induced adaptation of physiological parameters lead to health benefit resembling moderate-intensity continuous training (MICT) with shorten time session (Atakan et al., 2021; MacInnis & Gibala, 2017). Hence, coaches and athletes integrate interval training to training program for improving performance. High-intensity interval training has been applied to part of training as alternative for aerobic exercise. HIIT is characterized by altering bouts of intense anaerobic exercise typically exceeding 85% of HR_{max} or maximum oxygen consumption ($\dot{V}O_{2max}$) with short recovery interval (Bishop et al., 2018; MacInnis & Gibala, 2017). A meta-analysis demonstrated that both endurance training and HIIT produce substantial enhancements in $\dot{V}O_{2max}$ among healthy young to middle-aged adults, with HIIT yielding greater improvements relative to endurance training (Milanović et al., 2015). Given this context, HIIT's time-efficient nature and the physiological adaptations it elicits have established it as an effective and efficient modality for enhancing aerobic capacity and power.

Aerobic endurance performance has been determined by different approaches, such as maximal heart rate HR_{max} maximal oxygen uptake ($\dot{V}O_{2max}$), the fractional utilization of $\dot{V}O_{2max}$ (%$\dot{V}O_{2max}$), ventilatory thresholds (VT), and gross energy cost (Atakan et al., 2021). Those parameters are commonly assessed to evaluate training effects from interventions and individual exercise intensity prescriptions. Typically, those parameters are measured via exhaustive maximal exercise testing, which induces fatigue and requires specialized, costly equipment. Indeed, the portable modern technology has been developed to monitoring these parameters (Carmen et al., 2024; Kharismajati et al., 2025), this poses challenges in elite sport and clinical settings, especially for athletes who are traveling or train in a remote location relative to the primary performance center. Therefore, there is a need for simple, non-exhaustive tests to track aerobic capacity (Akalan et al., 2004; Lee & Zhang, 2021; Zugck et al., 2000).

RPE introduced and developed originally in 1970 by Gunnar Borg, this scale typically ranges from 6 to 20 containing verbal descriptors of effort at RPE_6 (no exertion at all), between RPE_7 and RPE_8 (extremely light), RPE_9 (very light), RPE_{11} (light), RPE_{13} (somewhat hard), RPE_{15} (hard), RPE_{17} (very hard), RPE_{19} (extremely hard) and RPE_{20} (maximal exertion) (Borg, 1970). The Rating of Perceived Exertion (RPE) scale commonly known as the Borg scale serves as a widely adopted psychophysical instrument for measuring individuals' subjective perceptions of physical effort during exercise (Grummt et al., 2024). In session RPE, an indivual utilizes subjective sensations to assign a numerical rating that estimates the overall effort of an exercise bout. RPE, conceptualized as a subjective measure, reflects the relative strain experienced across the musculoskeletal, cardiovascular, and respiratory systems amid physical activity. RPE is primarily gathered to quantify perceptions of effort in laboratory-based incremental exercise protocols. Additionally, clinicians and fitness professionals employ RPE as a supplementary tool alongside objective physiological metrics for exercise prescription (Doherty et al., 2001; Grummt et al., 2024).

More recently, there has been increased interest to the developing RPE scale to estimates exercise intensity. RPE has been shown to increase in both hot and cool environments, as well as following interval exercise matched for total work volume, thereby demonstrating its sensitivity to environmental conditions and acute exercise intensity variations (Green et al., 2007). RPE correlated with physiological parameters and become as a means of estimating aerobic capacity and power, since RPE related strong to oxygen uptake ($\dot{V}O_2$), carbon dioxide output ($\dot{V}CO_2$), ventilatory, heart rate (HR), blood lactate concentration, has been clearly confirmed (Chen et al., 2002; J. B. Coquart et al., 2014; Mcculloch et al., 2015). Further study found relationships between RPE and cardio capacity parameters including HR and $\dot{V}O_2$ during graded exercise tests (GXT) to SSE running in treadmill (Ferri Marini et al., 2024). Even though investigations thus far prove the correlation between RPE and HR, research to date has not assessed adaptation of RPE after a long training period. Hence this study applied 6 weeks HIIT to increase the aerobic capacity and demonstrated the RPE changes along with this adaptation. Moreover, the adaptation the adaptation has been clarified with applying of the similar steady state exercise (SSE) test in 40% (light intensity) and 60% (moderate intensity). Eventually this study implied RPE could be a potential professional measurement provide simple, reliable, and valid estimates of exercise intensity.

Materials and methods

Participants

This study enrolled sixteen generally fit participants Table 1 (age, 28.2±5.1 yr; height, 1.76±8.3 m; weight, 76.3±12.4) including 8 male dan 8 female. All participants recruited from faculty of sport Science, Universitas Negeri Padang and were. Written informed consent was collected from all participants with verbal explanations of the experimental protocol included all potential. Participants had to state free from cardiovascular, respiratory, or metabolic disease and not taking medications affecting hemodynamic responses to exercise. The study obtained approval from the Local Ethics Committee of Padang State University (Registration No. 1656/UNP/2025).

Table 1. Characteristics of participants

Characteristic	n=16 (8 female, 8 male)
	M±SD
Age (year)	21±1.1
Height (cm)	172.8± 6.4
Weight (kg)	67.1± 6.2
BMI (kg/m^2)	22.4±1.5
Systolic blood pressure (mmHg)	122±6.3
Diastolic blood pressure (mmHg)	82± 5.1
HR_{rest} (bpm)	75± 7.7
PO SSE 40% (watt)	120±17.4
PO SSE 60% (watt)	180±26.1

BMI, body mass index; HR, heart rate; PO, Power output: SSE, steady state exercise.

Experimental Design

Pre-and post-intervention tests was conducted over two visits on consecutive days. Participants were required to abstain from caffeine, smoking, exercise for 12 hours and consumed a light meal four hours prior to testing (Harris et al., 2010). During the first visit, body weight, height, resting heart rate and blood pressure was collected followed by an incremental maximal exercise test. On the second visit participants visit performed steady-state exercise (SSE) test in two different of workload intensity including collecting ratings of perceived exertion (RPE) data. The intervention period was comprised of six weeks of cycling exercise training. After six-week high-intensity interval training (HIIT) intervention period, participants repeated the steady-state and incremental test on consecutive days Figure 1.

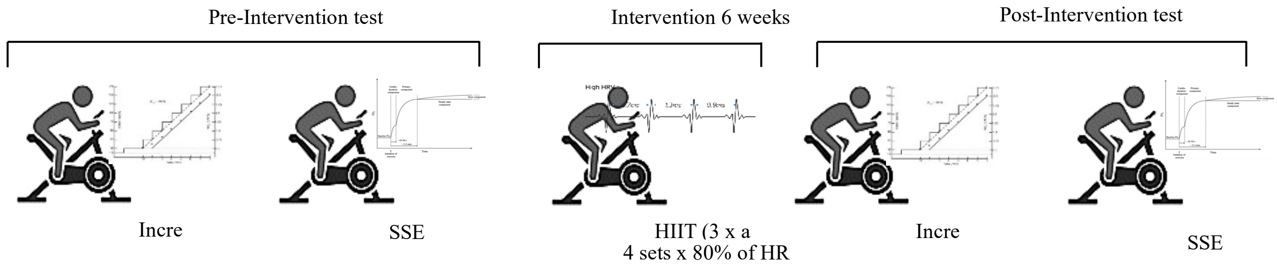

Figure 1. Schematic of experimental design in this study. Incremental max test started at 100W, with 5W increments every 15 seconds until volitional exhaustion or inability to maintain ≥85 rpm, SSE Test with cycling at 40% and 60% of PPO for 3 minutes. SSE= steady-state exercise; HIIT= high-intensity interval training; HR_{max}= maximum heart rate.

Exercise testing sessions

Exercise tests included the incremental maximal test and SSE test on the cycling ergometer (Wahoo Kickr Bike, Atlanta, USA) in a quiet room (~25°C). During the tests A Bluetooth heart rate sensor with chest belt (H7 Polar, Kempele, Finland) was attached to monitor heart rate (HR) beat per minute unit (bpm) linked to Polar Beat App and Power data in watt were recorded and stored using Wahoo SYSTM app. A Borg 6–20 RPE (category) scale was prepared and collected once after 2 minutes at each steady-state exercise began. All detailed instruction regarding RPE scale were explained before the test.

The incremental maximal tests were executed to measure maximum aerobic capacity through maximum heart rate (HR_{max}) and peak power output (PPO). Participants cycled on a bike (Wahoo Kickr Bike, Atlanta, USA) starting at 100W, with 5W increments every 15 seconds until volitional exhaustion or inability to maintain ≥85 rpm and a rating of RPE of at least 18. HR_{max} and PPO were determined as the highest heart rate and load achieved when the minimum cadence was maintained more than 5 seconds. Participants were familiarized with the RPE scale, progressing from minimal to maximal effort, by reporting their RPE rating every minute while assessing the degree of muscle tension and fatigue, shortness of breath, or chest pain during the test.

The same HR monitor and cycling ergometer detailed above were used for two sets SSE at 40% and 60% of PPO. Each SSE was performed for 5 min with 3 min recovery between the set and minimum cadence of 70 rpm. The power output remained fixed for pre- and post-tests. Heart rate data was collected every 10 second during the test figure 2. The exercise heart rate ($HR_{exercise}$) and RPE ware collected once after 3 minutes at each steady-state exercise began. The $\%HR_{exercise}$ were calculated from HR_{max} in incremental test.

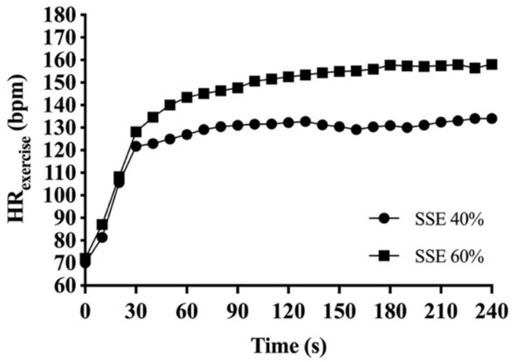

Figure 2. Representative changes in heart rate exercise ($HR_{exercise}$) during steady state exercise (SSE) 40% and 60% of peak power output (PPO).

Interventions

All participants completed a 6-week cycling HIIT program performing of 4-min intervals cycling (Wahoo Kickr Bike, Atlanta, USA) at 90% HR_{max}, interspersed by 3-min period of rest or active recovery, repeated four times. Heart rate was monitored using the sensor sensor (H7 Polar, Kempele, Finland) during all sessions connected to the Polar Beat app to maintain adherence to training zones. During recovery period, participants were allowed to drink water and choose whether to do slow cycling or completely stop cycling (Rodrigues et al., 2025).

Statistical analysis

Data was demonstrated as mean ± standard deviation (SD). The differences of pre- and post- incremental test, SSE 40% and SSE 60% were assessed using paired T-tests. Effect size was calculated to provide strength interpretation based on Cohen's *d* (small >0.2, medium >0.5, large >0.8). Pearson correlations examined relationships between changes hear rate and RPE pre and post during SSE 40% and SSE 60%, with coefficients classified per recommendations (very weak <0.2, weak <0.40, moderate <0.60, strong <0.80, very strong >0.80) (Evans, 1996). Statistical analyses were performed using SPSS (Version 29, IBM, Chicago, IL) and the graphs was created on GraphPad Prism (Version 9.1.1, GraphPad Software, La Jolla, CA, USA) with alpha were set at $p < .05$.

Results

The HITT successfully improved the parameters of aerobic capacity and power showed in table 2 and detail in graph figure 3.

Table 2. Pre- and post-intervention changes in the aerobic capacity and power

Variables	Incremental test			
	Pre	Post	P value	*d*
HR_{max} (bpm)	188±8.53	184±6.44	0.001	0.43
PPO (w)	302±50.8	322±50.9	<0.001	0.41

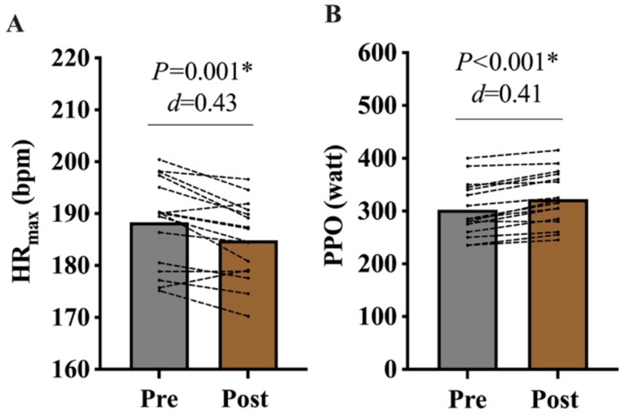

Figure 3. Changes in maximum aerobic capacity; (A) maximum heart rate (HR_{max}) and (B) peak power output (PPO) pre- and post 6-weeks of high intensity interval training (HIIT). * Significantly different ($P<0.05$).

Changes during the SSE could be seen in table 3 and graph figure 4 following the correlation analysis between HR and RPE in figure 5.

Table 3. Pre- and post-intervention aerobic capacity changes in SSE test

Variables	SSE 40%				SSE 60%			
	Pre	Post	P value	*d*	Pre	Post	P value	*d*
$HR_{exercise}$ (bpm)	127±9.41	122±11.9	0.005	0.55	153±11.7	145±12.6	0.001	0.63
PO (w)	120±20.1	120±20.1	-	-	180±30.1	180±30.1	-	-
RPE	10±1.25	9±0.93	0.001	1.01	13±0.98	12±1.41	0.001	0.97

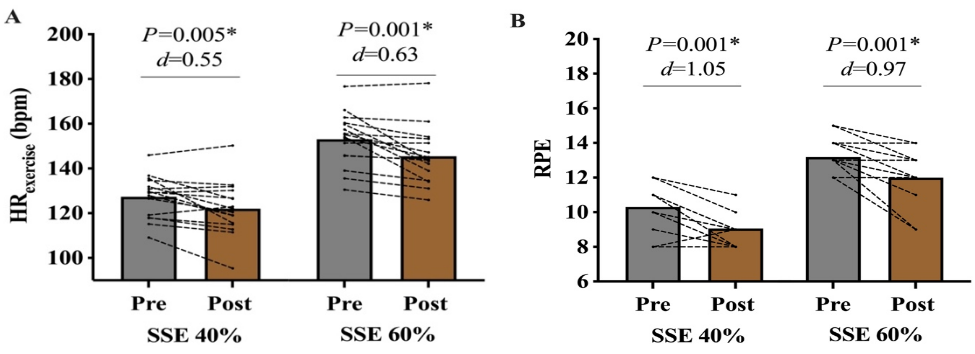

Figure 4. Changes in (A) exercise heart rate ($HR_{exercise}$) and rate of perceived exertion (RPE) pre- and post 6-weeks of high intensity interval training (HIIT) in steady state exercise (SSE) 40% and 60% of peak power output (PPO).

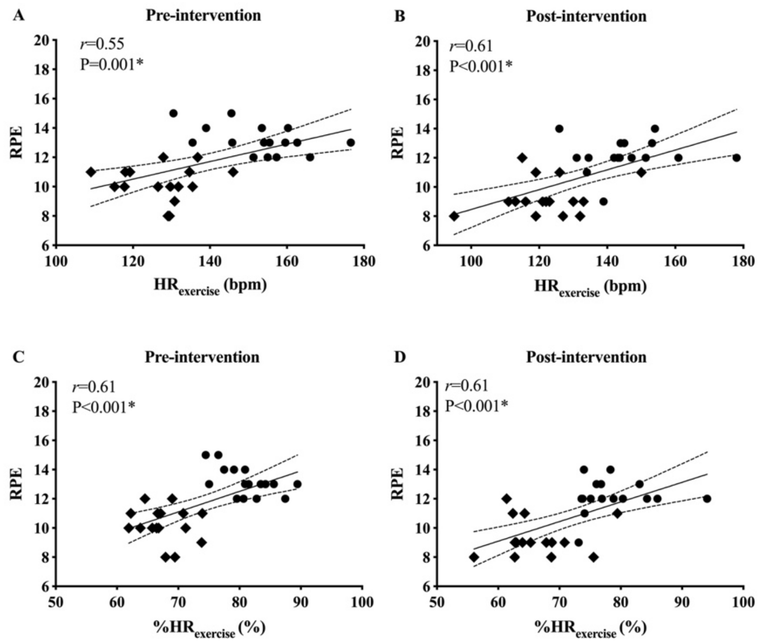

Figure 5. Correlation between rate of perceived exertion RPE and heart rate of exercise ($HR_{exercise}$) and intensity training ($\%HR_{exercise}$) pre and post intervention. *The dotted line represented the 95% confidence interval of the model. Black diamond symbols, SSE 40%; black circle symbols, SSE 60%

Discussion

This study investigated whether adaptations to improved aerobic capacity detected by HR as physiological variables could be followed by adaptation of perceived exertion. Moreover, the study applied SSE 40% and 60% to examine the adaptation providing new insights to understand the adaptation. The main findings were that classic aerobic fitness markers improved, with increased PPO, reduced HR_{max}. During fixed workload SSE, was slower after 6 weeks of HIIT and followed by decreased in RPE. The consistent correlation was established between $HR_{exercise}$ and RPE pre and post intervention.

It is well documented that high-intensity interval training elicits numerous physiological adaptations that enhance exercise capacity ($\dot{V}O_{2max}$, HR and power) (Atakan et al., 2021; Egan & Zierath, 2013; Laursen & Jenkins, 2002; MacInnis & Gibala, 2017). This study supports the similar evidence since the result showed the improvement PPO and reducing HR_{max}. The cycling HITT in 80-90% showed the greatest oxygen consumption ($_{abs}\dot{V}O_{2max}$ and $_{rel}\dot{V}O_{2max}$) compared the sprint interval and continuous aerobic training (Matsuo et al., 2014). Moreover, some investigation concluded increase of $\dot{V}O_{2max}$ usually attributed to increase of maximal cardiac output, stroke volume, maximal a-vO2diff, skeletal muscle oxidative capacity, capillary density, erythrocytes volume, and hemoglobin mass (Egan & Zierath, 2013; Gibala et al., 2019; Hawley et al., 2014; Matsuo et al., 2014; Raleigh et al., 2018). HIIT stimulates mitochondrial biogenesis, thereby reducing glycogen consumption and lactate production, raising the lactate threshold, and enabling longer exercise at the same intensity (Egan & Zierath, 2013; Laursen & Jenkins, 2002). The adaptation of stoke volume stimulates the efficiency of heart rate and eventually, this effect reduce the HR_{max} and futhermore, decreased $HR_{exerxise}$ in SSE 40% and 60% as effect of HITT (Gibala et al., 2019; Matsuo et al., 2014).

RPE collected when the participants were cycling in 40% and 60% of pre-PPO showed reducing as effect of 6 weeks-HIIT. In theory, during the exercise, active musculoskeletal system determines the RPE level (Doherty et al., 2001). Endurance training such as HIIT improves central and peripheral factors (Schmidt & Prommer, 2008) , with particularly enhancing peripheral adaptations including muscle adaptation (Atakan et al., 2021). This would align with previous findings using invasive measures of mitochondrial oxidative capacity (Beever et al., 2020; Gerovasili et al., 2010; Koutlas et al., 2023; Rasica et al., 2022; Soares et al., 2017). HIIT clearly was improvement of muscle and aerobic capacity since this study proved the reduction of RPE following the reduction in HR both in fixed workload SSE 40% and 60%. A study with various level competitive cyclist examined the relation RPE and ventilatory exchange in incremental test and randomized SSE. The study exhibited strong correlation between RPE and $\dot{V}O_2$, VCO_2, Ventilation minutes, HR both in incremental test and randomized SSE (J. B. J. Coquart et al., 2009). Furthermore, in the beginning of SSE, ventilation respiration increased and continues move alight with muscle contraction demand increasing of energetic demand of work and reached a plateau in few seconds showing the change of the balance between oxygen delivery and consumption (Adami et al., 2014; Ding et al., 2001; Paredes-Ruiz et al., 2020). The low intensity highlighted the role of the aerobic system in facilitating phosphocreatine resynthesis and maintaining the heart rate when steady state reached (Putra et al., 2025). It was clearly explained in figure 2 with $HR_{exercise}$ was increase since the cardiac pumped rapidly to deliver oxygen to active muscle since temperature and blood pH level elevated during the exercise (Wilmore & Costill, 1994).

Recently, some studies have been conducted to investigate possibility RPE to be a parameter of training intensity for aerobic training. Comparison study exhibited the consistent relationship between RPE and summated intensity of HR zone during cycle exercise and basketball training (Foster et al., 2001). Studies documented that intensity of exercise is determined by ventilation response during exercise, which mean RPE could reflect intensity of cardiorespiratory exercise (Alberton et al., 2011). Furthermore, RPE was conformed significantly related to the several physiological variables (VO2, r=0.63; ventilation, r=0.61; respiratory rate, r=0.72; HR, r=0.62; lactate concentration, r=0.57) (Chen et al., 2002). To the best our knowledge, none of the aforementioned studies have investigated the consistent of correlation between RPE and HR pre- and post- training intervention. Overall, the result of this study supports the consistent previous observation of strong relationship between RPE and the HR zone during the exercise (Foster, 1998) since the data showed the correlation between RPE and HR also with (%HR) in SSE 40% and 60%. Moreover, the strong correlation between RPE and HR was maintained after HIIT. As practical implications, together classic cardiopulmonary exercise testing demonstrated high accuracy data to determine training intensity and monitor aerobic adaptation, RPE measurement could be applied as a supplemented psychological parameter describing further information. The benefit of RPE could be an alternative to the issue of the high cost and non-user-friendly cardiopulmonary devices. The detailed information about scale and frequently record have to applied to familiarize the scale.

Limitations

The study should be considered some limitations. First, some additional variables related to RPE and aerobic capacity should take to account. The neuromuscular variables, pulmonary ventilation variables such lactate acid, VO_{2max}, energy expenditure and muscle oxygenation could be a key factor to measure in the future study. Second, body and leg composition should be evaluated with some additional measurements such as muscle mass percentage, fat percentage, and skinfold thickness to obtain an overview of the muscle profile. Another potential drawback is that the pre and post SSE were performed at an absolute workload relative to the initial PPO. However, this is important for the applied nature of the current study because the aim was to avoid performing repeated maximal exercise tests to normalize workloads but to clear information the future study should done the adaptation workload for the post intervention. Finally, even though we established the frequency 3 times a week of HITT and recommended a day of recovery between training, some participants ignored the recommendation. Moreover, some extra exercise probably had applied by participants since we didn't control the daily activity. The muscle fatigue probably was occurred and potentially obstructed adaptation of aerobic capacity and power probably in those cases (Egan & Zierath, 2013; Gibala et al., 2019; Heaselgrave et al., 2019).

Conclusions

This study concludes that RPE RPE could be an alternative easy-to- applied and low-budget professional instrument to assess intensity and monitor aerobic adaptation since the adaptation of aerobic capacity that exhibited by increase of PPO, and decrease HR_{max} followed and correlated to RPE in incremental maximum exercise test, SSE 40% and SSE. Potentially in the future the other study could include the various aerobic parameter such as $\dot{V}O_{2ma}$, metabolic rate, and energy expenditure.

Acknowledgment

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Conflict of interest

The authors have no conflict of interest to declare.

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