Journal of Advanced Sport Technology 3(2):9- 18 Received: December. 23, 2019; Accepted: February. 13, 2020

Original Research

A New Fitness Dependent Maximal Protocol for Determination of Heart Rate Deflection Point

Marefat Siahkouhian[1], Rezvan Shams[2], Roghayyeh Gholizadeh[3]

1-3 *Department of Physical Education and Sport Sciences, University of Mohaghegh Ardabili, Ardabil, Iran.*

Abstract

Heart Rate Deflection Point (HRDP) is a downward or upward change from the linear HR-work relationship evidenced during progressive incremental exercise testing which is reported to be coincident with the anaerobic threshold (AT). The aim of this study was to design and introduce a new fitness- dependent maximal treadmill test protocol according to the subjects' status for determining HRDP. Sixteen active young males (Vo2max mean ± SD = 48.31± 8.12 ml·kg·min^{-1}) completed a fitness-dependent HRDP maximal treadmill test protocol to volitional exhaustion (GXT) with continuous respiratory gas measurements. Polar Vantage Sport Tester XL was used to monitor heart rate performance curve (HRPC) throughout the protocol. Mod-Dmax method in light of parallel straight-line slope (PSLS) mathematical model used for determining HRDP. The Bland and Altman plots and intraclass correlation coefficient (ICC) were used to assess the agreement between the HRDP and gas measurements. The results showed that fitness- dependent test protocol results in HRDP in all of the subjects. High agreement revealed between HRDP and end-tidal carbon dioxide (PETCo2) (±1.96; 95% CI = -3.0 to +3.5 b/min; ICC=0.88). According to this study results, designed treadmill time fixed fitness dependent protocol via Mod-Dmax method is an accurate approach for determining HRDP.

Key Words: Heart Rate performance curve (HRPC), Mod-Dmax Method, PSLS mathematical model.

Introduction

The anaerobic threshold is often determined through the invasive use of lactate concentrations which requires blood sample analysis or the non-invasive use of respiratory gas exchange parameters which is complex and expensive. However, a wide variety of diagnostic criteria can be found in the literature for both ventilatory threshold (VT) and lactate threshold (LT) assessment [1-8]. It has been indicated that a field method of assessing the anaerobic threshold is available and can be done from HRDP in speed-heart rate relationship with accuracy either by visual method or by computer programming[9].

HRDP is a downward or upward change from the linear HR-work relationship evidenced during progressive incremental exercise testing which has been widely studied in recent years. The HRDP is reported to be coincident with the anaerobic threshold. It has been suggested that this phenomenon could be used as a noninvasive method to assess the anaerobic threshold [10].

Cheng et al. suggested a new Distance Maximum (Dmax) method to define the lactate thresholds by the means of breathing patterns (VO2) to estimate the LT (i.e., OBLA). An important advantage of the Dmax method is that a threshold point can always be detected in all of subjects [11]. Indeed, in the Dmax method, concomitant with increasing work load, the deflection point of heart rate from a straight line, is considered as a criterion. In other words, two end points of the HR-Time curve were connected by a straight line and the most distant point of the curve to the line was considered as the HRDP [12].

At present, various kinds of field and laboratory protocols are used to determine HRDP. HRDP field studies have incorporated different field activities[13, 14]. Majority of field protocols are similar to the original Conconi et al. (1982) procedure where gradually velocity increased after fixed distances to increase work load. Although field protocols similar to the athlete's normal activity patterns, laboratory protocols incorporated more controlled environment to examines the HRDP. Cycle ergometry, as well as the treadmill running and arm-cranking ergometry are generally the laboratory protocols characterized by "fixed time" and "fixed distance" stages[10].

In fixed time stage protocols, work load increases as a function of constant time intervals. However, in fixed distance stage protocols increases in work load depends on given covered distances. Fixed distance stage protocols mainly aimed to the HRDP occurrence. Since stage distances are constant, any increase in exercise load lead to increase in velocity. Therefore, near the end of the protocol, the stage duration decreases significantly. The decreased stage continued to the extent that the cardio-respiratory system cannot efficiently adjust to the increased workload and finally lead to HRDP [12].

Review of literature showed that wide variety of studies aimed to verify HRDP get executed by individuals with different age, health status and fitness level[15, 16]. Children, adolescents, students and middle-aged men have all demonstrated HRDP. Similarly, trained and untrained subjects, individuals with cystic fibrosis, heart disease and paraplegic athletes revealed HRDP [10, 17, 18].

It should be noted that field and laboratory protocols generally getting started with high loading pattern regardless of subjects health status and fitness level. For instance, Stathus & Sucec [19] as well as Conconi et al. [20] suggest fixed distance and fixed time stage field protocols with the seven miles/h start and 0.5 miles/h increase every 200m and 12-14 km/h start with 0.5 km/min increase, respectively. Similarly, Jones & Doust [21] and Vachon et al. [22] offer exhaustive treadmill fixed distance and fixed time stage protocols with the 12 km/h start and 0.5 km/h increase every 200m and 11-12 km/h start and 0.5 km/h increase every minute, respectively. It is understandable that under these situations suggested field and laboratory protocols have execute high degree of load on organism specifically among aged and sedentary subjects.

Our observations in the sport physiology laboratory showed that many of sedentary subjects cannot able to complete some of the HRDP laboratory protocols. For example, 60% of overweight sedentary young men exhausted during the first stage of the Jones & Doust maximal protocol and test remain inconclusive. It is unclear what the physiological basis for such a heavy initiation of the HRDP protocols. However, Craig et al. [23] were the first to consider LTP1 and LTP2 concept in the HRDP protocol which was later used commonly by the sport scientists [24, 25]. In the Craig et al. method the LT was calculated using the modified Dmax (Mod-Dmax) method and determined by the point on the polynomial regression curve that yielded the maximal perpendicular distance to the straight line connecting the first increase in [La−] above resting level and the final [La−] point[26, 27]. In our recent work [28] we consider the modification (in fact simplification) of Craig et al. procedure by the means of the Narita et al. [29] equation.

Most HRDP protocols regardless of subjects' age, gender and other physiological status have already been prepared[30]. Despite of numerous researches, a few studies considered subjects potential during the HRDP protocols. De Wit et al. [31] considered subjects HR responses during the fixed time stage protocol as the test initiation was 120-130 b/min. In addition, Mafulli et al. used Borg scale in their laboratory fixed time stage protocol for the refinement of loading[10].

According to the literature and lack of information about the HRDP protocols appropriate to the subject physical and physiological status, on the one hand; and in attempt to consider the subjects abilities and organize the test protocol according to the subjects' potential by the means of simplified

Mod-Dmax, on the other hand, the aim of this study was to design and introduce a new fitness-dependent maximal treadmill test protocol according to the subjects status for determining HRDP.

Methods and Subjects

Experimental design and subjects

Sixteen active young males (Vo2max mean ± SD = 48.31± 8.12 ml·kg·min−1) attended the sport physiology laboratory on two separate phases. During the first phase participants undertook body composition and physiological tests[32]. A minimum of 72 h after the initial session, during the second phase, the participants completed a fitness-dependent HRDP maximal treadmill test protocol to volitional exhaustion (GXT) with continuous respiratory gas measurements (Ganshorn Medizin Electronic GMBH, Germany) after giving written informed consent to the board for protection of Human Rights affiliated to the University of Mohaghegh Ardabili. The project was approved by the Iranian Registry of Clinical Trials (ORCID:0000-0002-2166-897X). For seven days prior to the final experimental test, the subjects canceled their training program. The physical and physiological characteristics of the subjects are summarized in Table one.

Table 1. Physical characteristics and physiological responses of the subjects (Mean ± SD, N= 11).

Parameters	Age (Yrs)	Height (cm)	Weight (kg)	Fat (%)	LBM (kg)	RHR (b/min)	MHR (b/min)	Vo2max (ml/kg/min)
Values	22 ±2.41	172 ±3.53	73.80 ±4.47	13.42 ± 4.65	62.78 ±5.10	69.26 ±5.92	189.78 ± 7.55	48.31 ± 8.12

HRDP Determination method

To determine the HRDP, HR was monitored continuously in two second intervals by a cardio frequency meter (Polar Vantage Sport Tester XL) and each subject’s data was recorded during the exercise test and transferred to a personal computer. From this original data the third order curvilinear regression curve was calculated the original HR values vs. the Time [33]. To compute the maximum distance (Dmax)[34] between the straight lines formed by the two end points of HR in each curve, the PSLS mathematical model [35] as well as the Mod-Craig et al. method by the means of Narita et al. equation were used (Figure one). The above computing procedures were performed by a designed computer program.

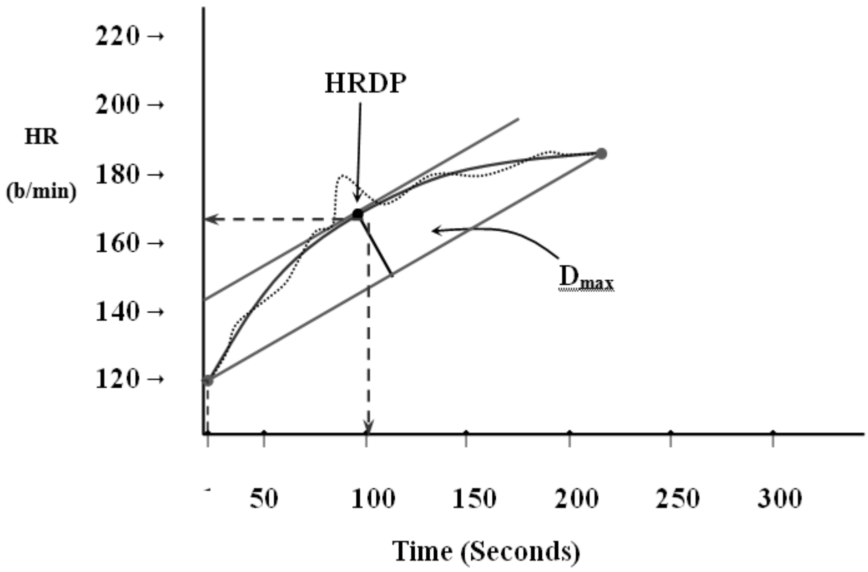

Figure 1. Schematic presentation of the PSLS mathematical model for determining HRDP

Laboratory treadmill protocol

Subjects underwent a 10-15min warm-up at 50% MHR reserve[36]. They then underwent a treadmill (Sport ART, Model 6150E) graded maximal test protocol, beginning at LTP1 (the first increase in lactate accumulation) and finishing at exhaustion[37]. Narita et al. target heart rate equation results [74.8 + 0.76 x (resting heart rate) - 0.27 x (age) + 7.3 x S (male: 0 or female: 1)] were used as first data points of fitness-dependent protocol. The stages duration was held constant at one min. The running speed was increased by two km/h as long as the subject could continue. Polar Vantage Sport Tester XL was used to monitor heart rate performance curve (HRPC) throughout the protocol. The gas analysis data (VE, Vco2, PETCo2) calculated by the continuous respiratory gas measurements (Ganshorn Medizin Electronic GMBH, Germany).

Statistical analysis

Data is presented as mean and standard deviations. The Bland and Altman [38] plots and intraclass correlation coefficient (ICC) [39] were used to assess the agreement between the HRDP and gas measurements.

Results

The results showed that fitness- dependent test protocol in light of parallel straight line slope (PSLS) mathematical model as well as Mod-Craig et al. method using Narita et al. equation results in HRDP in all of the subjects. Determined HRDPs illustrated in figure two among the six subjects as an example.

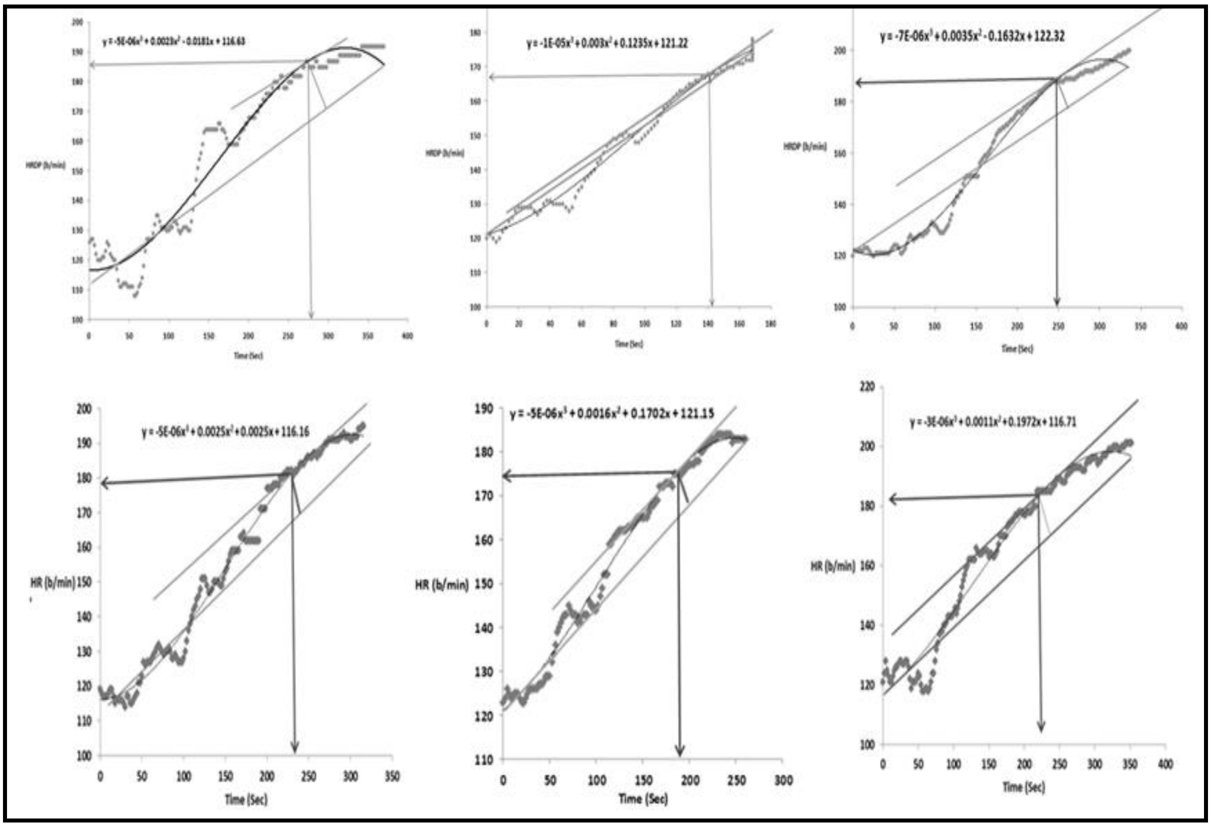

Figure2. Schematic illustration of HRDP determination by the fitness-dependent protocol in the six subjects

Results showed high agreement between heart rate deflection point (HRDP) and end-tidal carbon dioxide (PETCo2) during the fitness-dependent protocol (±1.96; 95% CI = -3.0 to +3.5 b/min; ICC=0.88; Figure three).

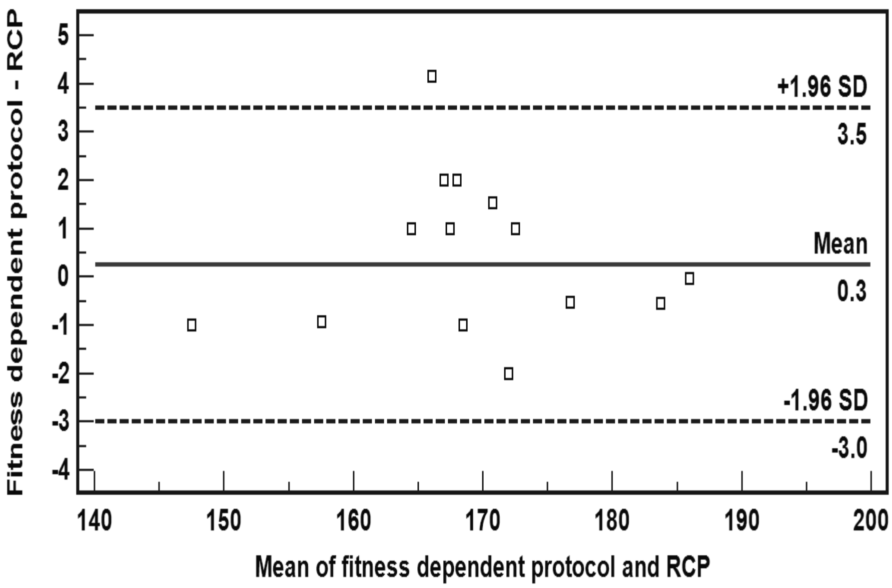

Figure3. Agreement between determined HRDP by the fitness-dependent protocol and PETCO2 methods

We showed synchronization between occurrences of the heart rate deflection point (HRDP) and an increased production of CO2 and a continuous rise in the CO2 fraction of the expired air

(PETCO2) in all of the subjects during the fitness-dependent protocol. Occurrence of HRDP and PETCO2 during the fitness-dependent protocol in one of the subjects illustrated in figure four.

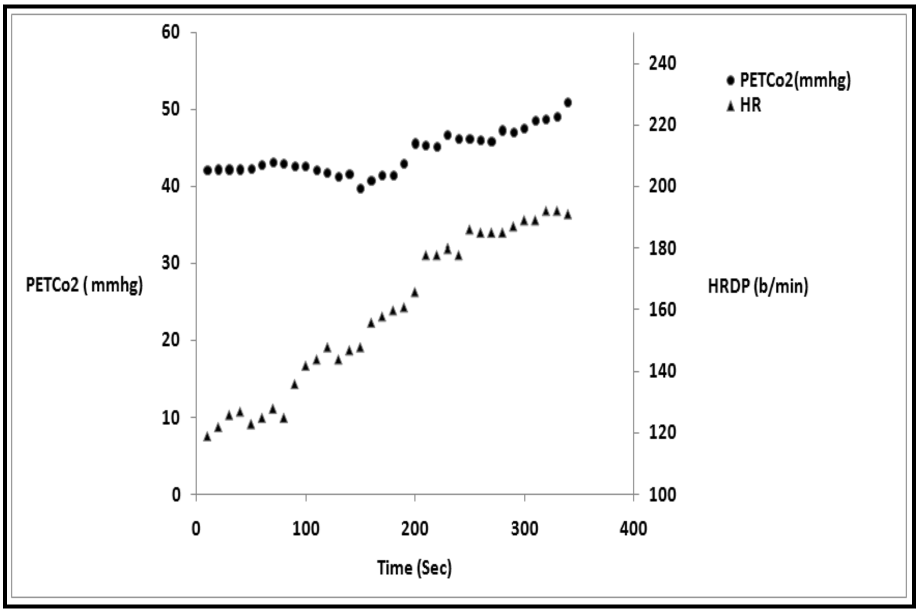

Figure 4. HRPC and PETCo2 in the fitness-dependent protocol in one of the subjects

Discussion

Our study results showed that fitness-dependent test protocol lead to HRDP in all of the subjects. In addition, we showed high agreement between HRDP and PETCo2 during the fitness-dependent test protocol.

Bodner & Rhodes indicated that the HRDP is a significant biological event and not an artifact of the protocol [40]. However, some researchers do not always find an HRDP during GXT tests[41]. For example, in the HRDP determined by the Conconi's method, one of the main features is that as the test proceeds, the time needed to complete each stage decreases. Therefore, this field protocol results in a shortening of stage durations and all the runners demonstrated an HRDP.

In fixed distance stage protocols with constant 60-s stages, only one-half of the runners showed a noticeable HRDP[42]. Findings reviled a strong, linear relationship between work intensity and heart rate at sub-maximal workloads. However, at near-maximal efforts, it was found that some individuals demonstrated a slight deviation from linearity as HR began to plateau [43]. In other studies, with the 45-60 Seconds time duration, HRDP occurs in 45-71% of subjects. Thus it would appear that only about one-half of all individuals show an HRDP with constant stage protocols, whereas practically all subjects show an HRDP with Conconi's test[44].

In 1996 Conconi et al. changed the test protocol so that HR measurements were based on fixed time intervals rather than on fixed distances. Every 30 s the runner increased his speed by a constant amount. Using mentioned protocol, they found that an HRDP occurred in almost all of their subjects. Therefore, they observed an HRDP occurrence in almost all subjects, even when the stage duration is held fairly constant. This conflict with Vachon et al. study results where they found a "constant-stage" protocol yielded a linear HR response in one-half of their subjects [22].

The shorter stages and rapid acceleration phase in Conconi new protocol allow subjects to attain higher maximal speeds than a test with constant 60-s stages. Therefore, the new protocol appears to increase the chance of observing HRDP [23]. Ozcelik and Kelestimur have been shown that modifications of the testing protocol lead to modifications in neurohumoral and gas exchange responses [25]. It seems that the loading pattern should be high enough to stimulate the anaerobic, not aerobic, pathway so that lactate turnover in the Cory cycle does not prevail. Therefore, according to the subjects' fitness level, our HRDP protocol starts with at Mod-Craig et al. method [12] and continued by two km/h speed increased per minute.

It should be noted that during such high load protocols, the starting point of HRDP protocol should be based on the subject's physiological and fitness level[15]. In this regard, Craig et al.[23] supposed modified version of Dmax method by the means of LTP1 and LTP2 concept which was validated by our recent works [12]. In fact, during the above mentioned approaches, ranges of HR data points were considered[45]. Primary HR data points, not only results in underestimation of HRDP, but also leads to prolongation of the protocol. That is why our fitness dependent HRDP protocol starts at HR concurrence with the Mod-Craig et al. method (Narita et al. equation).

Conclusion:

Generally, since the HRDPs of all the subjects were obtained by the new fitness dependent HRDP protocol, it can be concluded that the HRDP will occur if testing protocol initiates starts with at Mod-Craig et al. method according to the individual fitness level, the initial HR calculated by the Mod-Craig et al. model., and treadmill speed increased by two km/h every minute.

Acknowledgement

The authors would like to thanks all athletes for participation in this study and also thanks to the dep. of Physical Education and Sport Sciences supports, University of Mohaghegh Ardabil.

Conflict of interest: none

References

1. Erdogan, A., et al., Non-invasive indices for the estimation of the anaerobic threshold of oarsmen. *Journal of International Medical Research*, 2010. **38**(3): p. 901-915.
2. Fabre, N., et al., The modified Dmax method is reliable to predict the second ventilatory threshold in elite cross-country skiers. *The Journal of Strength & Conditioning Research*, 2010. **24**(6): p. 1546-1552.
3. Faude, O., W. Kindermann, and T. Meyer, Lactate threshold concepts. *Sports medicine*, 2009. **39**(6): p. 469-490.
4. Fell, J.W., The modified D-max is a valid lactate threshold measurement in veteran cyclists. *Journal of Science and Medicine in Sport*, 2008. **11**(5): p. 460-463.
5. Folke, M., Estimation of the lactate threshold using an electro acoustic sensor system analysing the respiratory air. *Medical & biological engineering & computing*, 2008. **46**(9): p. 939-942.
6. Stanula, A., et al., Calculating lactate anaerobic thresholds in sports involving different endurance preparation. *Journal of Exercise Science & Fitness*, 2013. **11**(1): p. 12-18.
7. Fabre, N., et al., A novel approach for lactate threshold assessment based on rating of perceived exertion. *International journal of sports physiology and performance*, 2013. **8**(3): p. 263-270.
8. Conde, J.H.S., et al., Identification of the lactate threshold and the heart rate deflection point by the perceived exertion curve. *J Exerc Physiol Online*, 2014. **17**(3): p. 32-38.
9. Hofmann, P. and R. Pokan, Value of the application of the heart rate performance curve in sports. *Int J Sports Physiol Perform*, 2010. **5**(4): p. 437-47.
10. Bodner, M.E. and E.C. Rhodes, A review of the concept of the heart rate deflection point. *Sports Medicine*, 2000. **30**(1): p. 31-46.

11. Cheng, B., et al., A new approach for the determination of ventilatory and lactate thresholds. *International journal of sports medicine*, 1992. **13**(07): p. 518-522.
12. Siahkouhian, M. and A. Meamarbashi, Advanced methodological approach in determination of the heart rate deflection point: S. Dmax versus L. Dmax methods. *The Journal of sports medicine and physical fitness*, 2013. **53**(1): p. 27-33.
13. Pinto, S.S., et al., Noninvasive determination of anaerobic threshold based on the heart rate deflection point in water cycling. *The Journal of Strength & Conditioning Research*, 2016. **30**(2): p. 518-524.
14. Delevatti, R.S., et al., Heart rate deflection point as an alternative method to identify the anaerobic threshold in patients with type 2 diabetes. *Apunts. Medicina de l'Esport*, 2015. **50**(188): p. 123-128.
15. Costa, R.R., et al., Heart rate deflection point as an alternative to determining the anaerobic threshold in dyslipidaemic patients. *Motriz: Revista de Educação Física*, 2019. **25**(1).
16. Leite, M.R., et al., Analysis of the heart rate deflection point as a tool for exercise prescription in subjects with COPD-a cross-sectional study. *Physiotherapy theory and practice*, 2019: p. 1-7.
17. Najera-Longoria, R.H., et al., Non spirographic or noninvasive methods to estimate anaerobic treshold. *Fizička kultura*, 2017. **71**(1): p. 55-62.
18. de Lima Costa, P., et al., Relationship between Heart Rate Deflection Point and Ventilatory Threshold in Elite Mountain Runners. *Journal of Exercise Physiology Online*, 2017. **20**(4): p. 184-192.
19. Stathus, G. and A. Sucec. The reliability of the hear rate deflection point (HRDP) and running speed at the HRDP for male distance runners. in *International journal of sports medicine*. 1987. Georg thieme verlag po box 30 11 20, D-70451 Stuttgart, Germany.
20. Conconi, F., et al., Determination of the anaerobic threshold by a noninvasive field test in runners. *Journal of applied physiology: respiratory, environmental and exercise physiology*, 1982. **52**: p. 869-873.
21. Jones, A.M. and J.H. Doust, The Conconi test is not valid for estimation of the lactate turnpoint in runners. *Journal of sports sciences*, 1997. **15**(4): p. 385-394.
22. Vachon, J.A., D.R. Bassett Jr, and S. Clarke, Validity of the heart rate deflection point as a predictor of lactate threshold during running. *Journal of applied physiology*, 1999. **87**(1): p. 452-459.
23. Craig, N., et al., Protocols for the physiological assessment of high-performance track, road and mountain cyclists. *Physiological tests for elite athletes/Australian Sports Commission. Champaign (IL): Human Kinetics*, 2000: p. 258-77.
24. Ghosh, A.K., Anaerobic threshold: Its concept and role in endurance sport. *The Malaysian journal of medical sciences: MJMS*, 2004. **11**(1): p. 24.
25. Ozcelik, O. and H. Kelestimur, Effects of acute hypoxia on the determination of anaerobic threshold using the heart rate-work rate relationships during incremental exercise tests. *Physiological research*, 2004. **53**(1): p. 45-52.
26. Baker, K.M., et al., Mathematical modeling and expression of heart rate deflection point using heart rate and oxygen consumption. *International journal of exercise science*, 2017. **10**(4): p. 592.
27. Siahkouhian, M., et al., A New Mathematical Method for the Estimation of Aerobic Threshold in Sports Physiology. *Journal of Advanced Sport Technology*, 2018. **1**(3): p. 28-34.
28. Siahkouhian, M. and D. Khodadadi, Narita target heart rate equation underestimates the predicted adequate exercise level in sedentary young boys. *Asian journal of sports medicine*, 2013. **4**(3): p. 175.
29. Narita, K., et al., [Development and evaluation of a new target heart rate formula for the adequate exercise training level in healthy subjects]. *Journal of cardiology*, 1999. **33**(5): p. 265-272.
30. Mikulic, P., V. Vucetic, and D. Sentija, Strong relationship between heart rate deflection point and ventilatory threshold in trained rowers. *The Journal of Strength & Conditioning Research*, 2011. **25**(2): p. 360-366.

31. De Wit, M., et al., Validity of peak oxygen uptake calculations from heart rate deflection points. *International journal of sports medicine*, 1997. **18**(03): p. 201-207.
32. Pereira, L.C., et al., The influence of body composition in the strength of elderly Brazilian men. *Revista Brasileira de Medicina do Esporte,* 2015. **21**(3): p. 196-199.
33. Kara, M., H. GÍ¶kbel, and C.S. Bediz, A combined method for estimating ventilatory threshold. *The Journal of sports medicine and physical fitness*, 1999. **39**(1): p. 16-19.
34. Jang, D.-G., et al. *A modified D-max method to estimate heart rate at a ventilatory threshold during an incremental exercise test*. in *2017 39th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*. 2017. IEEE.
35. Siahkohian, M., A new mathematical model for determination of heart rate deflection point. *International Journal of Fitness*, 2007. **3**(2).
36. Mainardi, F., et al., Predictive validity of VO2máx measurement and estimates in Mountain Bikers' performance. *Revista Brasileira de Medicina do Esporte*, 2015. **21**(1): p. 44-48.
37. Meamarbashi, A. and M. Siahkouhian, Designing Smart Treadmill for athletic endurance training. *Journal of Advanced Sport Technology*, 2017. **1**(2): p. 30-32.
38. Bland, J.M. and D.G. Altman, Measuring agreement in method comparison studies. *Statistical methods in medical research*, 1999. **8**(2): p. 135-160.
39. Portney, L. and M. Watkins, Foundations of clinical research: applications to practice. *Prentice Hall, Upper Saddle River,* 2008.
40. Bodner, M.E., et al., The relationship of the heart rate deflection point to the ventilatory threshold in trained cyclists. *The Journal of Strength & Conditioning Research*, 2002. **16**(4): p. 573-580.
41. Etxegarai, U., et al., Prediction of performance by heart rate-derived parameters in recreational runners. *Journal of sports sciences*, 2018. **36**(18): p. 2129-2137.
42. Guimarães, M.P., et al., Is There a Concordance between the Lactate Threshold and the Heart Rate Deflection Point during a Progressive Field Test in Moderately Trained Distance Runners? *Journal of Exercise Physiology Online*, 2017. **20**(5): p. 60-69.
43. Binder, R.K., et al., Methodological approach to the first and second lactate threshold in incremental cardiopulmonary exercise testing. *European journal of cardiovascular prevention & rehabilitation*, 2008. **15**(6): p. 726-734.
44. Conconi, F., et al., The Conconi test: methodology after 12 years of application. *International Journal of Sports Medicine*, 1996. **17**(07): p. 509-519.
45. Heber, S., et al., Exercise-based cardiac rehabilitation is associated with a normalization of the heart rate performance curve deflection. *Scandinavian journal of medicine & science in sports*, 2019.

***Corresponding Author**: Marefat Siahkouhian, Department of Sport Sciences, University of Mohaghegh Ardabili, Ardabil, Iran.

E-mail: m_siahkohian@uma.ac.ir, marefat_siahkuhian@yahoo.com, **Tel**: 00984515516815; **Fax**: 00984515516402

چکیده فارسی

پروتکل بیشینه جدید وابسته به سطح آمادگی بدنی برای تعیین نقطه انحراف ضربان قلب

معرفت سیاهکوهیان*[۱]، رضوان شمس[۲]، رقیه قلیزاده[۳]

۱-۳ گروه تربیت بدنی علوم ورزشی، دانشگاه محقق اردبیلی ، اردبیل ، ایران

چکیده:

نقطه شکست ضربان قلب (HRDP) یک تغییر رو به پایین یا رو به بالا از خط مستقیم در بررسی ارتباط بین بارکار و ضربان قلب می‌باشد که در طول بارکار فزاینده اتفاق می‌افتد. براساس مطالعات گذشته با آستانه بی هوازی (AT) همزمان است. هدف از مطالعه حاضر طراحی و معرفی پروتکل بیشینه جدید وابسته به سطح آمادگی جسمانی و با توجه به وضعیت بدنی افراد برای تعیین HRDP است. بدین منظور ۱۶ مرد جوان فعال (Vo2max mean ± SD =48.31±8,12ml·kg·min−1) پروتکل بیشینه وابسته به سطح آمادگی جسمانی فرد را به طور داوطلبانه تا سرحد واماندگی بر روی تردمیل در حالی انجام دادند که گازهای تنفسی به طور مداوم اندازه‌گیری می‌شد. آزمودنی‌ها به طور داوطلبانه پروتکل بیشینه HRDP وابسته به تناسب اندام را تا سرحد خستگی (GXT) با اندازه‌گیری مداوم تنفس گازهای تنفسی انجام دادند. برای ثبت منحنی عملکرد ضربان قلب (HRPC) در طول پروتکل از Polar Vantage Sport Tester XL استفاده شد. همچنین، از روش Mod-Dmax با توجه به مدل ریاضی شیب خط موازی(PSLS) برای تعیین HRDP و نمودار Bland و Altman و ضریب همبستگی درون گروهی (ICC) برای ارزیابی ارتباط بین HRDP و اندازه‌گیری گازهای تنفسی استفاده شد. براساس نتایج بدست آمده پروتکل تمرینی وابسته به سطح آمادگی جسمانی فرد منجر به وقوع HRDP در همه آزمودنی‌ها می‌شود. همچنین همبستگی بالایی بین HRDP و غلظت کربن دی اکسید پایان بازدمی (PETCo2)، (±1.96; 95% CI = -3.0 to +3.5 b/min; ICC=0.88) وجود دارد. بنابراین، براساس نتایج بدست آمده پروتکل وابسته به سطح آمادگی جسمانی فرد با زمان ثابت بر روی تردمیل، با استفاده از روش Mod-Dmax یک روش دقیق برای تعیین HRDP است.

کلمات کلیدی: منحنی عملکرد ضربان قلب (HRPC)، روش Dmax اصلاح شده، مدل ریاضی شیب خط موازی (PSLS).