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HEART RATE DEFLECTION POINT CORRESPONDS TO VENTILATORY THRESHOLD DURING WATER-BASED MAXIMAL TEST IN UNTRAINED WOMEN

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Background: The research problem addresses the investigation of the correlation and accuracy of the Heart Rate Deflection Point (HRDP) method compared to the Ventilatory Threshold (VT) method in predicting the Anaerobic Threshold (AT) during water-based stationary running maximal tests performed by untrained women.
Goals: This study compared heart rate (HR), oxygen uptake (VO_2), percentage of maximal heart rate ($\%HR_{max}$), percentage of maximal oxygen uptake ($\%VO_{2max}$), and cadence (CAD) related to the anaerobic threshold (AT) during a water-based stationary running maximal test performed by untrained women between HRDP and VT methods. In addition, the correlations between both methods were assessed for all variables.
Method: Fifty-six untrained women (40.2 ± 16.3 years) started the protocol at a cadence of 85 beats per minute ($b.min^{-1}$) for 3 min with subsequent increments of 15 $b.min^{-1}$ every 2 min until exhaustion.
Results: There was no difference in the HR, VO_2, $\%HR_{max}$, $\%VO_{2max}$, and CAD related to AT between the HRDP and the VT methods. Moreover, significant relationships were found between the methods to determine the AT (r=0.61-0.95).
Conclusions: In conclusion, the HRDP method may accurately predicting AT in untrained women performing the water-based stationary running maximal test.
Keywords: Aquatic exercise, anaerobic threshold, cardiorespiratory responses, exercise test, ventilatory threshold.

El punto de deflexión de la frecuencia cardíaca corresponde al umbral ventilatorio durante la prueba máxima basada en agua en mujeres no entrenadas.

Resumen
Antecedentes: El problema de investigación aborda la correlación y precisión del método del Punto de Deflexión de la Frecuencia Cardíaca (HRDP) comparado con el método del Umbral Ventilatorio (VT) en la predicción del Umbral Anaeróbico (AT) durante pruebas máximas de carrera estacionaria en agua realizadas por mujeres no entrenadas.
Objetivos: Este estudio comparó la frecuencia cardíaca (HR), el consumo de oxígeno ($\dot{V}O_2$), el porcentaje de la frecuencia cardíaca máxima ($\%HR_{max}$), el porcentaje del consumo máximo de oxígeno ($\%VO_{2max}$) y la cadencia (CAD) relacionados con el AT durante una prueba máxima de carrera estacionaria en agua por mujeres no entrenadas entre los métodos HRDP y VT. Además, se evaluaron las correlaciones entre ambos métodos para todas las variables.
Método: Cincuenta y seis mujeres no entrenadas (40,2 ± 16,3 años) iniciaron el protocolo con una cadencia de 85 latidos por minuto ($b.min^{-1}$) durante 3 min, con incrementos subsiguientes de 15 $b.min^{-1}$ cada 2 min hasta el agotamiento.
Resultados: No hubo diferencia en la HR, VO_2, $\%HR_{max}$, $\%VO_{2max}$ y CAD relacionados con el AT entre los métodos HRDP y VT. Además, se encontraron relaciones significativas entre los métodos para determinar el AT (r=0.61-0.95).
Conclusiones: El método HRDP puede ser un predictor preciso del AT en mujeres no entrenadas realizando la prueba máxima de carrera estacionaria en agua. Palabras clave: ejercicio acuático, umbral anaeróbico, respuestas cardiorrespiratorias.
Palabras clave: Terapia Acuática, Umbral Anaerobio, Capacidad Cardiovascular, Prueba de Esfuerzo, Umbral Ventilatorio.

O ponto de deflexão da frequência cardíaca corresponde ao limiar ventilatório durante o teste máximo baseado em água em mulheres não treinadas.

Resumo
Introdução: O problema de pesquisa aborda a investigação da correlação e precisão do método do Ponto de Deflexão da Frequência Cardíaca (HRDP) em comparação com o método do Limiar Ventilatório (VT) na predição do Limiar Anaeróbio (AT) durante testes máximos de corrida estacionária em água realizados por mulheres não treinadas.
Objetivos: Este estudo comparou a frequência cardíaca (HR), o consumo de oxigênio (VO_2), a porcentagem da frequência cardíaca máxima ($\%HR_{max}$), a porcentagem do consumo máximo de oxigênio ($\%VO_{2max}$) e a cadência (CAD) relacionados ao AT durante um teste máximo de corrida estacionária em água por mulheres não treinadas entre os métodos HRDP e VT. Além disso, as correlações entre ambos os métodos foram avaliadas para todas as variáveis.
Método: Cinquenta e seis mulheres não treinadas (40,2 ± 16,3 anos) iniciaram o protocolo com uma cadência de 85 batimentos por minuto ($b.min^{-1}$) por 3 min, com incrementos subsequentes de 15 $b.min^{-1}$ a cada 2 min até a exaustão.
Resultados: Não houve diferença na HR, $\dot{V}O2$, $\%HR_{max}$, $\%VO_{2max}$ e CAD relacionados ao AT entre os métodos HRDP e VT. Além disso, foram encontradas relações significativas entre os métodos para determinar o AT (r=0.61-0.95).
Conclusões: O método HRDP pode ser um preditor preciso do AT em mulheres não treinadas realizando o teste máximo de corrida estacionária em água.
Palavras chaves: Exercício aquático, limiar anaeróbio, aptidão cardiorrespiratória, teste de esforço, limiar ventilatório.

Introduction

Water-based aerobic exercises have been practiced by different populations, including healthy individuals (Colado et al., 2009; Pinto et al., 2014), older individuals (Pinto et al., 2015; Tsourlou et al., 2006), and people with special needs (Adsett et al., 2015). It is well documented in the literature that the lower maximal and submaximal physiological parameters (i.e., heart rate, oxygen uptake, lactate concentration) during aerobic exercise performed in the aquatic in comparison to dry land environment (Alberton et al., 2009; Alberton et al., 2014; Barbosa et al., 2007; Benelli et al., 2004; Kruel et al., 2013). Thus, it is important to acknowledge the pattern of cardiorespiratory parameters in water-based aerobic exercises to prescribe the intensity during water-based programs.

The anaerobic threshold (AT) has been used to prescribe the aerobic training intensity in different water-based activities performed by young and elderly populations (Kanitz et al., 2015; Pinto et al., 2014). The determination of the AT is important since the use of a pre-selected percentage of maximal heart rate or oxygen uptake may represent different intensities for the practitioners (i.e., aerobic vs. anaerobic intensity). However, the gold standard methods to determine the AT, spirometer, or lactate concentration are expensive and/or invasive. Thus, Conconi et al. (1982) established that the AT could be determined by a noninvasive test based on the relationship of incremental running speed with HR. The HR, corresponding to the breakpoint at which the linearity of the HR-speed relationship was broken, is defined as the heart rate deflection point (HRDP).

In the aquatic environment, there have been a few studies investigating the HRDP compared to gold standard methods (Alberton et al., 2013; Cellini et al., 1986; Kruel et al., 2013; Pinto et al., 2016). Kruel et al. (2013) reported similar HR and VO_2 corresponding to the AT between ventilatory (VT) (ventilation vs. intensity) and HRDP methods (HR vs. intensity) during maximal protocols in stationary running performed on land and in water by active young women. Analyzing three water-based aerobic exercises, Alberton et al. (2013) verified a significant relationship in the HR and VO_2 corresponding to the AT determined by the HRDP and VT methods during maximal protocols performed by active young women. However, the unique focus of our study on untrained women, who engage in water-based aerobic exercises across a wide age range and with varying physical fitness levels, is a novel and important contribution to the field, as it provides insights into the occurrence of the HRDP during water-based maximal tests in women with low aerobic conditioning, thereby aiding in the prescription of the adequate target training zone.

Therefore, this study was designed to assess the relationship between HRDP and the VT methods to determine the HR, VO_2, percentage of maximal HR ($\%HR_{max}$), percentage of maximal VO_2 ($\%VO_{2max}$), and cadence corresponding to the AT obtained during water-based stationary running maximal test performed by untrained women. It was hypothesized that cardiorespiratory variables related to AT would be similar between HRDP and VT methods. The data from the present study could be helpful for the prescription based on the AT in water-based setting training since there is limited information regarding the intensity during this activity in untrained women.

Methods

Participants

The inclusion criteria for the participants were 18–60 years old and not engaged in any regular and systematic training program in the previous six months. Exclusion criteria included any history of neuromuscular, hormonal, and cardiovascular diseases. Participants were not taking any medication that influenced on hormonal and neuromuscular metabolism. All participants were recruited from Porto Alegre, Brazil, by sending flyers, by e-mail, and through the local media (announcements in the daily newspaper). The announcement provided a contact (i.e., telephone number) for the study and the inclusion and exclusion criteria. Fifty-six healthy women (n=56, age: 40.2 ± 16.3 years; body mass: 67.2 ± 12.1 kg; height: 162.3 ± 6.4 cm; body fat: 34.0 ± 5.7%) contacted the research team and were recruited to the initial screening. Informed consent was also read and signed during the initial screening, and the participants were carefully informed about the study's design and the possible risks and discomforts related to the measurements. All recruited women met the inclusion and exclusion criteria and were included in this study. The sample size was calculated using the GPower version 3.1.9 program for T-tests. We adopted a power of 95%, an alpha level of 5%, and an effect size of d=0.51 based on data from Kruel et al. (2013). It resulted in a total sample size of 44 participants. Considering a dropout of 25%, a minimum of 55 participants would be necessary. The project was approved by the Local Research Ethics Committee, and all procedures were in accordance with the Helsinki Declaration of 1975 as revised in 1996.

Experimental procedure

To investigate the AT determined by the HRDP and VT methods, a maximal test was carried out in a shallow swimming pool with a depth between 0.95 and 1.30 m. For this purpose, volunteers participated in two different sessions. In the first session, the participants were familiarized with the protocol in the water environment. In the second session, they performed the water-based stationary running maximal test with the data collection of cardiorespiratory variables.

The sessions consisted of familiarization and experimental protocol. The first session occurred 48–72 hours before data collection during the experimental protocol. The following instructions were given to the participants before the test: fast for 3–4 hours before the test session, do not ingest stimulants, hydrate freely, and avoid intense exercise in the last 24 hours.

Familiarization session

In this session, body mass and height were measured using an analogic scale and a stadiometer (Asimed, Camarate, Portugal). Body composition was assessed using the skin fold technique. A 7-site skin fold equation was used to estimate body density (Jackson et al., 1980), and body fat was subsequently calculated using the Siri equation (Siri, 1993). Afterward, the participants performed the water-based stationary running exercise at different progressive cadences while wearing the gas collection mask. In addition, all the care details (e.g., hip and knee flexion maintainance at 90°), which would need to be taken when performing the exercise, were explained.

Experimental protocol session

A maximal test was applied in the aquatic environment to determine the HR, VO_2, $\%HR_{max}$, $\%VO_{2max,}$ and cadence corresponding to the AT,. The maximal test with stationary running was conducted with an initial cadence of 85 $b.min^{-1}$ for three minutes, with 15 $b.min^{-1}$ increases in cadence every two minutes until maximal effort was obtained. The participants were required to perform each phase of the exercise (i.e., hip flexion or extension) in one beat. A compact disc was used to reproduce the cadences employed during the test. The maximal test was stopped when the participants indicated their exhaustion using a hand signal. In addition, the assessment was considered valid when some of the following criteria were met at the end of the test: estimated maximal heart rate was reached (220 age), a respiratory exchange ratio (RER) greater than 1.15 was reached, and a maximal respiratory rate of at least 35 breaths per minute (Howley et al., 1995). Moreover, the average time to reach exhaustion ranged from 8 to 10 minutes, which is considered optimal for the validity of the maximal test performed. Similarly, the RER was also analyzed, and the result confirmed that the protocol is within the proper value needed to accept the test.

During the exercise, participants were connected to a mixing-box-type portable gas analyzer to evaluate the ventilatory data (VO2000, MedGraphics, Ann Arbor, USA). This equipment had been previously calibrated according to the manufacturer's specifications. The HR was measured using a Polar monitor (FS1, Shangai, China). The sampling rate of the collected HR and ventilatory data was one sample every 10 seconds, and the data were acquired using the Aerograph software. Throughout the experiment, the water temperature was maintained at 31.0 ± 0.1 °C, and the water depth for each subject was controlled between the xiphoid process and shoulders.

Data Treatment

Based on the cardiorespiratory data obtained during exercise, the AT was determined from the HRDP (HR-by-intensity) (Alberton et al., 2013; Kruel et al., 2013) and by the VT (V E-by-intensity), which was confirmed using CO_2 ventilatory equivalent (VE/VCO_2) (Wasserman et al., 1973). The breakpoint of the curves was visually inspected by two independent, blinded, experienced exercise physiologists. In the present study, determining the AT by the VT is considered the gold standard method.

Statistical Analysis

Data are presented as mean ± standard deviation. The normality of distribution was assessed by a Kolmogorov–Smirnov test. A paired two-tailed Student's t-test was used to compare all variables between the HRDP and the VT methods. The Pearson product-moment correlation coefficient was used to assess the relationship between the methods. The differences were plotted against the average value, as suggested by Bland and Altman (1995). Significance was accepted when $\alpha=0.05$, and the SPSS statistical software package (version 20.0) was used to analyze all data.

Results

All participants completed the test. No adverse effects or any safety concerns were found during the exercise protocol. The descriptive values regarding the maximal and AT variables obtained during the water-based stationary running maximal test are presented in Table 1.

Table 1. Descriptive statistics (mean ± SD) of maximal and submaximal variables during water-based stationary running maximal test.

	Mean	±SD
HR_{max} (bpm)	175	±15
VO_{2max} (ml.kg^{-1}.min^{-1})	23.09	±5.20
RER_{max}	1.38	±0.19
RER_{AT}	1.12	±0.13
TE (min)	9.91	±1.86

Note: HR_{max} - maximal heart rate; VO_{2max} - maximal oxygen uptake; RER_{max} - maximal respiratory exchange ratio; RER_{AT} - respiratory exchange ratio at anaerobic threshold; TE - time to exhaustion.

Heart rate deflection point was successfully determined in 51 of the 56 participants analyzed (91.07%). Thus, the results from five participants were excluded from the remaining analyses. There was no difference in the HR, VO_2, $\%HR_{max}$, $\%VO_{2max,}$ and cadence corresponding to AT between the HRDP and VT methods (Table 2). In addition, significant relationships were found between the methods to determine the AT for all variables analyzed. Figure 1 shows the relationship between HRDP and VT for HR, VO_2, $\%HR_{max}$, $\%VO_{2max,}$ and cadence. In addition, a Bland-Altman plot with estimated mean bias and 95% limits of agreement for differences in HR, $\%HR_{max}$ (%), $VO_{2,}$ and $\%VO_{2max}$ data between HRDP and VT, as plotted against the mean value, are presented in Figure 2.

Table 2. Comparison between VT and HRDP methods during water-based stationary running maximal test.

	VT		HRDP		
	Mean	±SD	Mean	±SD	p
HR (bpm)	152	±16	152	±15	0.095
VO_2 (ml.kg^{-1}.min^{-1})	17.46	±4.00	16.98	±3.81	0.073
$\%HR_{max}$ (%)	86.92	±5.09	86.27	±5.06	0.076
$\%VO_{2max}$ (%)	75.16	±10.69	74.10	±10.49	0.431
CAD (b.min^{-1})	120	±12	120	±13	0.766

Note: HR - heart rate; VO_2 - oxygen uptake; $\%HR_{max}$ - percentage of maximal HR; $\%VO_{2max}$ - percentage of maximal VO_2; CAD – cadence; VT - ventilatory threshold; HRDP - heart rate deflection point.

Figure 1. Relationship between HRDP and VT for HR, VO_2, $\%HR_{max}$, $\%VO_{2max}$ and cadence

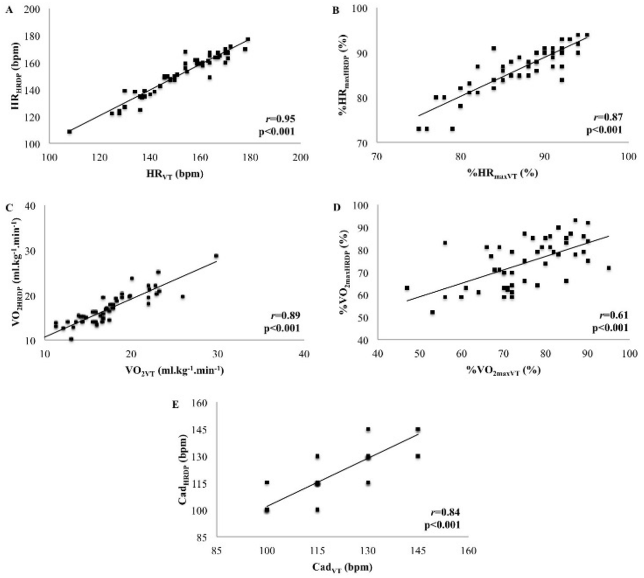
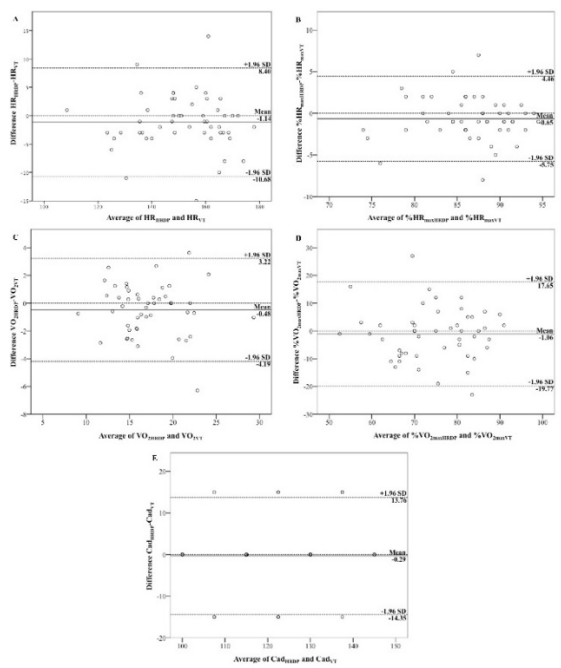


Figure 2. Evaluation of the agreement between HR, $\%HR_{max}$, VO_2, and $\%VO_{2max}$ Measurements Between HRDP and VT.



Discussion

The results of this study indicate a strong relationship between HRDP and VT methods for HR, VO_2, $\%HR_{max}$, $\%VO_{2max}$, and cadence (r=0.61-0.95; p<0.001). In addition, similar values were found between the methods for these variables. Thus, the HRDP method may be applied to determine the AT in untrained women during a maximal test performed with the widely used water-based stationary running exercise. By determining the AT through this noninvasive measurement, which is relatively simple to implement without costly materials, it is possible to precisely prescribe the intensity of this water-based exercise in untrained women in a wide age range.

Recent studies analyzed the relationship between HRDP and VT methods in water-based aerobic exercises. Kruel et al. (2013) investigated nine active women during a maximal test with stationary running performed in a water environment. They found similar HR (168 ± 13 bpm vs. 173 ± 8 bpm) and VO_2 (26.3 ± 4.7 ml.kg^{-1}.min^{-1} vs. 26.2 ± 6.0 ml.kg^{-1}.min^{-1}) values at AT between the two methods mentioned above. To investigate the relationship between HRDP and VT methods, Alberton et al. (2013) analyzed 20 young active women performing three water-based aerobic exercises (stationary running, frontal kick, and cross-country skiing) and reported no differences in HR (155-160 bpm vs. 155-159 bpm) and VO_2 (21-22 ml.kg^{-1}.min^{-1} vs. 21-23 ml.kg^{-1}.min^{-1}) responses between the methods. This study also verified the relationship between the methods on HR and VO_2 and observed significant correlations ranging from 0.67 to 0.97 for all evaluated exercises. In our study, the HR (152 ± 15 bpm vs. 152 ± 16 bpm) and VO_2 (16.98 ± 3.81 ml.kg^{-1}.min^{-1} vs. 17.46 ± 4 ml.kg^{-1}.min^{-1}) values at the AT were similar and showed significant correlations (HR: r=0.95; VO_2: r=0.89) between HRDP and VT methods in a large sample (n=51) comprised by untrained women.

Regarding the relative HR values corresponding to AT, in our study, the percentage achieved was 86 and 87% of the HRmax in HRDP and VT methods, respectively. This result agrees with the findings of other authors who verified a mean HR ranging from 88 to 94% of HR_{max} (Bodner et al., 2002; Bourgois and Vrijens, 1998; Hofmann et al., 2007; Mikulic et al., 2011). The relative VO_2 values corresponding to the AT determined by HRDP and VT methods were achieved at 74 and 75% of VO_{2max}, respectively. In the study developed by Fabre et al. (2008), the VO_2 values corresponding to the AT were achieved at 87% of $VO_{2\,max}$ in both HRDP and VT methods during continuous incremental field tests involving roller-skiing performed by well-trained cross-country skiers. Regarding the percentage of maximal cardiorespiratory variables corresponding to the AT (i.e., $\%HR_{max}$ and $\%VO_{2max}$), the studies in water and on dry land mentioned above did not present a relationship between the methods.

In the present study, the cadence corresponding to the AT during the water-based stationary running maximal test was similar between the HRDP (120 ± 13 b.min^{-1}) and VT (120 ± 12 b.min^{-1}) methods. In addition, we observed a significant correlation between them (r=0.84). Alberton et al. (2014) determined the cadence equivalent to AT by the gold standard VT method in the performance of the water-based stationary running maximal test and found a mean value of 134 ± 12 b.min^{-1} for a group of active young women (i.e., 24.0 ± 2.5 years). Investigating the relationship between HRDP and VT methods on running speed in trained runners, Petit et al. (1997) demonstrated similar and correlated (r=0.95) values between the methods (16.3 ± 2.1 km.h^{-1} vs. 16.4 ± 2.3 km.h^{-1}).

The HRDP was determined in most of the cases of untrained women (91%) in the present study. In addition, the Bland-Altman analysis suggests an acceptable concordance with the HRDP method for measuring the AT during water-based stationary running maximal tests performed by untrained women. The analysis of the Bland-Altman plots reveals that, in 95% of cases, HRHRDP may range from 10.7 bpm to less and from 8.4 bpm to greater than the original estimate, and VO_2HRDP may range from 4.2 ml.kg^{-1}.min^{-1} to less and from 3.2 ml.kg^{-1}.min^{-1} to greater than the original estimate, which can be considered a moderate difference. These results are following previous studies, which analyzed the agreement between HRDP and VT methods for these variables (Baiget et al., 2015; Mikulic et al., 2011). Moreover, the Bland-Altman plots were also investigated for the $\%HR_{max}$, $\%VO_{2max}$, and cadence. The results revealed that $\%HR_{max}$HRDP may range from 5.7% to less and from 4.5% to greater, the $\%VO_{2max}$HRDP may range from 19.8% to less and from 17.7% to greater, and the cadence may range from 14.3 b.min^{-1} to less and 13.8 b.min^{-1} to greater than the original estimate.

It is important to highlight that the HRDP method is simple, low-cost, and noninvasive. The time necessary to conduct the test is relatively short (approximately 10 minutes), which means it can be incorporated within or as part of a water-based training session. Additionally, attention is necessary when HRDP detection is based on visual analysis since experienced observers should perform this procedure. One possible limitation of our study is the sample size, which may have been small, and it could not detect modest but meaningful differences as statistically significant. Thus, future studies should explore the analysis of the HRDP method in a large sample that includes a wide age range.

Conclusions

The present study's findings showed that the HRDP and VT methods were strongly correlated for HR, VO_2, $\%HR_{max}$, $\%VO_{2max}$, and cadence. In addition, the agreement between methods was verified by the Bland-Altman plots for all analyzed variables. Thus, the HRDP method may accurately predict AT in untrained women performing the water-based stationary running maximal test.

Contribution and practical implications

This study significantly contributes to the existing literature by providing a comparative analysis of the HRDP and VT methods in assessing AT in untrained women during maximal aquatic tests. It deepens our understanding of physiological responses to aquatic exercise and offers a practical, less complex alternative for aerobic fitness assessment. The potential application of these methods by health and sports professionals for prescribing aquatic training further underscores the value of our research, expanding the tools available for physical assessment and developing effective interventions in the aquatic context.

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