

# Maximal and anaerobic threshold cardiorespiratory responses during deep-water running

## *Respostas cardiorrespiratórias máximas e no limiar anaeróbio da corrida em piscina funda*

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**Abstract** – Aquatic exercises provide numerous benefits to the health of their practitioners. To secure these benefits, it is essential to have proper prescriptions to the needs of each individual and, therefore, it is important to study the cardiorespiratory responses of different activities in this environment. Thus, the aim of this study was to compare the cardiorespiratory responses at the anaerobic threshold (AT) between maximal deep-water running (DWR) and maximal treadmill running (TMR). In addition, two methods of determining the AT (the heart rate deflection point [HRDP] and ventilatory method [VM]) are compared in the two evaluated protocols. Twelve young women performed the two maximal protocols. Two-factor ANOVA for repeated measures with a *post-hoc* Bonferroni test was used ( $\alpha < 0.05$ ). Significantly higher values of maximal heart rate (TMR:  $33.7 \pm 3.9$ ; DWR:  $22.5 \pm 4.1$  ml.kg<sup>-1</sup>.min<sup>-1</sup>) and maximal oxygen uptake (TMR:  $33.7 \pm 3.9$ ; DWR:  $22.5 \pm 4.1$  ml.kg<sup>-1</sup>.min<sup>-1</sup>) in TMR compared to the DWR were found. Furthermore, no significant differences were found between the methods for determining the AT (TMR: VM:  $28.1 \pm 5.3$ , HRDP:  $26.6 \pm 5.5$  ml.kg<sup>-1</sup>.min<sup>-1</sup>; DWR: VM:  $18.7 \pm 4.8$ , HRDP:  $17.8 \pm 4.8$  ml.kg<sup>-1</sup>.min<sup>-1</sup>). The results indicate that a specific maximal test for the trained modality should be conducted and the HRDP can be used as a simple and practical method of determining the AT, based on which the training intensity can be determined.

**Key words:** Heart rate; Oxygen uptake; Women.

**Resumo** – Os exercícios aquáticos proporcionam inúmeros benefícios à saúde de seus praticantes. Para assegurar esses benefícios, é indispensável uma prescrição adequada às necessidades de cada indivíduo e, para isso, faz-se importante estudar as diferentes respostas cardiorrespiratórias das atividades desenvolvidas nesse meio. Deste modo, o objetivo do estudo foi comparar as respostas cardiorrespiratórias no limiar anaeróbio (LAN) entre o teste máximo de corrida em piscina funda (CPF) e da corrida em esteira terrestre (CET). Além disso, comparar dois métodos de determinação do LAN (ponto de deflexão da frequência cardíaca [PDFC] e método ventilatório [MV]) entre os protocolos máximos. Doze mulheres jovens participaram do estudo. Foi utilizada ANOVA de dois fatores para medidas repetidas com *post-hoc* de Bonferroni ( $\alpha < 0,05$ ). Foram encontrados valores significativamente maiores de frequência cardíaca máxima (CET:  $190 \pm 5$ ; CPF:  $174 \pm 9$  bpm) e de consumo de oxigênio máximo (CET:  $33,7 \pm 3,9$ ; CPF:  $22,5 \pm 4,1$  ml.kg<sup>-1</sup>.min<sup>-1</sup>) na CET em comparação à CPF. Além disso, não foram encontradas diferenças significativas entre os métodos de determinação do LAN (CET: MT:  $28,1 \pm 5,3$ ; PDFC:  $26,6 \pm 5,5$  ml.kg<sup>-1</sup>.min<sup>-1</sup>; CPF: MV:  $18,7 \pm 4,8$ , PDFC:  $17,8 \pm 4,8$  ml.kg<sup>-1</sup>.min<sup>-1</sup>). Os resultados indicam a importância da realização de um teste máximo específico da modalidade treinada e o PDFC parece ser uma alternativa simples e prática para a determinação do LAN.

**Palavras-chave:** Consumo de oxigênio; Exercício; Frequência cardíaca; Mulheres.

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Received: 02 September 2014  
Accepted: 08 October 2014



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## INTRODUCTION

Physical activity is widely performed by individuals in order to improve physical capacity and maintain health. Water-based exercises are one option that, in addition to improving physical fitness<sup>1</sup>, offer advantages such as low joint impact<sup>2,3</sup> and less cardiovascular overload<sup>4</sup>. Within this context, water aerobic exercise and deep-water running (DWR) stand out because they provide several benefits for the cardiorespiratory system, as well as for the body composition and muscle strength of practitioners<sup>5</sup>. DWR is performed with the aid of a float vest that keeps the individual upright and does not allow the feet to rest on the bottom of the pool, thus eliminating any impact on the lower limbs<sup>6</sup>. Thus, it enables its practitioners to achieve high aerobic loads with less risk of damage to the lower limbs<sup>7</sup>.

To ensure that water-based training is properly prescribed, it is of paramount importance to determine the cardiorespiratory responses – such as volume of oxygen uptake ( $\text{VO}_2$ ), heart rate (HR) and the blood lactate response. Based on the blood lactate values found during an incremental maximal test, two breakpoints can be observed in its linearity, referred to as the first and second lactate thresholds, which represent different intensities and metabolic pathways<sup>8</sup>. However, determining the lactate threshold is considered invasive and costly. Furthermore, obtaining the thresholds from both the ventilatory equivalents for oxygen ( $\text{VE}/\text{VO}_2$ ) and carbon dioxide ( $\text{VE}/\text{VCO}_2$ ) requires the use of sophisticated equipment, such as a gas analyzer. To avoid such difficulties, an alternative method is to use the HR deflection point (HRDP) to determine the anaerobic threshold (AT). This method is based on the relationship between the HR and effort intensity. This relationship is partly linear and partly curved; the intensity of the effort at the point at which the break in linearity occurs (HRDP) is associated with the AT<sup>9</sup>.

A few studies published in the literature have comparatively analyzed the AT and HRDP. Debray and Dey<sup>10</sup> reported no significant differences between the mean HR and the respiratory exchange ratio (RER) obtained from the HRDP and the ventilatory method (VM) during a land-based treadmill protocol. Also on a treadmill, Sentija et al.<sup>11</sup> concluded that a ramp protocol can be used to determine the HRDP in trained runners. In incremental cycling, strong correlations were found between the AT, as determined by the HRDP, and the blood lactate response<sup>12</sup>. Mikulic et al.<sup>13</sup> compared physiological variables and performance on a rowing ergometer between two methods of determining the AT (HRDP and VM) and found a close relationship. By contrast, Bourgois et al.<sup>14</sup> concluded that the HRDP was not a valid method of measuring the lactate threshold in cycling. Finally, only two studies involving the aquatic environment proposed an adaptation of the HRDP for water exercises, one with water-cycling and the other with water aerobic exercises; both concluded that the minimum recommendations suggested by Conconi et al.<sup>9</sup> for identifying the point corresponding to the AT had been met<sup>15,16</sup>. However, to the best of our

knowledge, as yet no studies have been carried out to determine the AT by this method during DWR.

For the proper prescription of any exercise, it is necessary to use assessments consisting of valid and efficient protocols. A review of the literature reveals that there is a gap regarding methods of determining the AT in DWR and, moreover, there is a need to provide physical education professionals working in gyms and clubs with practical methods of doing so on an everyday basis. Therefore, the objective of this study was to compare the methods of determining the AT (HRDP and VM) in DWR and land-based treadmill running (LTR). In addition, the HR corresponding to the AT was correlated between the methods. It was hypothesized that no differences would be found in the cardiorespiratory responses between different methods of determining the AT. Furthermore, we speculated that high and significant correlations would be observed for the HR variable of the two methods in all protocols. Furthermore, we assumed that the maximal cardiorespiratory responses will be higher in LTR than DWR.

## METHODOLOGICAL PROCEDURES

### Subjects

The sample was composed of twelve young, physically active women (age:  $23.2 \pm 1.9$  years; body mass:  $57.9 \pm 7.1$  kg; height:  $161.4 \pm 5.6$  cm; body mass index:  $20.9 \pm 5.1$ ; maximal oxygen consumption [ $VO_{2max}$ ]:  $33.7 \pm 3.9$  ml.kg<sup>-1</sup>.min<sup>-1</sup>). The sample was selected through verbal invitation to scholarship holders within a community project coordinated by the School of Physical Education at the Federal University of Rio Grande do Sul. For inclusion in the sample, candidates had to be free from physical problems, not using medication and be non-smokers. The sample size was calculated using the software PEPI (version 4.0), in which a significance level of 0.05 and a power of 90% were adopted. All participants read and signed the informed consent form, approved, along with the research project, by the Ethics Committee of the Federal University of Rio Grande do Sul (No.: 2008/192).

### Procedures

First, the sample members attended a session in which they signed the informed consent form, filled out a personal data form and had their weight and height recorded. In addition, the date and time of the familiarization session was arranged as were the two maximal tests sessions the order of which was randomized. For these latter sessions, the participants were asked not to eat in the three hours prior to the test and not to consume stimulants. In addition, they were asked to not practice heavy physical exercise 12 hours prior to tests<sup>17</sup>.

In the same session, LTR familiarization was held in the research laboratory and after this all the subjects went to the swimming center to perform DWR familiarization. The DWR familiarization session was conducted in a deep indoor pool measuring 16 m in width, 25 m in length and 2 m in depth.

During the familiarization session, the correct DWR technique using the float vest was demonstrated and the sample members were shown how to wear the neoprene mask used for gas collection. The DWR technique involved maintaining a near vertical position with the head above water. The arms were flexed at the elbow at an angle of approximately 90°. Leg movements were also standardized and made to simulate land running.

After the subjects were familiar with the exercises, two sessions of maximal tests were performed: one DWR and the other LTR. Each subject was tested individually and each test was conducted on different days, with at least 48 hours between the two tests. Furthermore, the sessions were always held in the afternoon, between 4:00 and 7:00 p.m. Before each protocol, the subject remained at rest in the supine position for 30 minutes to assess the at-rest  $\text{VO}_2$  and HR. This situation was performed to check if the subjects started the exercises with the same metabolic situation in the two maximal sessions. Immediately after, the exercise protocol was performed.

Laboratory conditions remained constant for the maximal LTR tests (IMBRAMED, model 10200 ATL). Temperature was maintained between 22 and 24 °C. The maximal LTR test was performed at an initial speed of 6  $\text{km}\cdot\text{h}^{-1}$  for three minutes, with increments of 1  $\text{km}\cdot\text{h}^{-1}$  every two minutes and with a fixed inclination of 1% until the patient reached the maximum effort.

The maximal DWR tests were conducted with water temperature at 30 °C. The subjects performed the test in the stationary position and were submerged to shoulder level (T1). The test was performed with one end of a cable attached to the subject through the floatation vest and the other end fixed at the edge of the pool. The subjects were asked to maintain stride amplitude during the entire test and were assisted through visual feedback from the researcher. The protocol test began at a rate of 85  $\text{beats}\cdot\text{min}^{-1}$  for three minutes, with increments of 15  $\text{beats}\cdot\text{min}^{-1}$  every two minutes until the subject reached the maximum effort. The intensity of each maximal incremental test was controlled using a metronome (model MA-30, KORG, Tokyo, Japan). This protocol was based on a pilot study conducted by our research group. The following criteria were considered in the validation of the test: keeping the pace marked by the metronome; achieving a RER greater than 1.15; and indicating a rating of perceived exertion (RPE) of at least 18 on Borg's 6–20 RPE Scale.

HR,  $\text{VO}_2$  and ventilation (VE) were collected every 10 seconds during the two maximal tests and in the rest situation. For this, a HR monitor (Polar, model FS1) was used to measure HR. A portable gas analyzer (INBRAMED, model VO2000) was used to check the  $\text{VO}_2$  and VE. The equipment was calibrated according to the manufacturer's instructions prior to each collection.

For each test, the AT was determined using the ventilator method and was also determined using the HRDP. The ventilator method was obtained by determining the second inflection point in the VE curve and it was confirmed by means of the  $\text{CO}_2$  ventilatory equivalent ( $\text{VE}/\text{VCO}_2$ )<sup>18,19</sup>. In

addition, the AT was also determined based on the HRDP observed on the HR-by-intensity graph (HRDP)<sup>9</sup>. The curves were analyzed by three blinded, independent, experienced exercise physiologists. The point was considered valid when two of the three analyzers indicated the same value. When the three values were different, the average of the three values was used. In the case of the variables  $VO_{2max}$  and maximum HR ( $HR_{max}$ ), the highest values obtained during the tests were considered.

## Statistical analysis

Descriptive statistics were used with the data presented as means  $\pm$  standard deviations. To compare the maximal cardiorespiratory responses between the two protocols (maximal DWR test and maximal LTR test) and the at-rest cardiorespiratory responses between the two maximal test collection days, a paired t-test was performed. To compare the cardiorespiratory variables of the AT between the methods of determination and between the protocols, a two-factor ANOVA test for repeated measures was used with a *post-hoc* Bonferroni test. The intra-class correlation coefficient test (ICC) was used to correlate the HR corresponding to the AT between the two methods in each protocol. The level of significance was set at  $\alpha = 0.05$  and the SPSS (version 20.0) statistical program was used. The statistical powers observed from the effects of the protocol were 64% for  $HR_{AT}$ ; 97% for relative  $VO_{2AT}$ ; and 90% for absolute  $VO_{2AT}$ .

## RESULTS

The at-rest HR and  $VO_2$  values measured prior to the maximal tests are shown in Table 1. According to the results, there were no statistically significant differences between the pre-exercise variables from the two days. The results showed that the individuals started the exercises with the same metabolic situation, i.e., they had similar cardiorespiratory responses on the two data collection days. These results indicate that the magnitudes of the responses found in the exercise situations can be attributed to the effort required to complete them.

A comparison of the mean  $HR_{max}$  and  $VO_{2max}$  values obtained in the maximal tests performed for LTR and DWR is presented in Table 1. All cardiorespiratory variables showed higher values during maximal LTR compared to maximal DWR.

Table 2 shows a comparison of the HR at the AT ( $HR_{AT}$ ) and  $VO_2$  at the AT ( $VO_{2AT}$ ) between the protocols and the methods of determining the AT: the HRDP and the VM. We found significantly higher values for  $HR_{AT}$  and  $VO_{2AT}$  during maximal LTR when compared to maximal DWR. In contrast, there was no significant difference between the methods of determining the AT. Furthermore, no significant interactions were observed between the tests and methods, showing that regardless of the protocol used and the method of determining the AT the behavior of the variables was similar.

**Table 1.** Means  $\pm$ SD for the rest and maximal cardiorespiratory variables for the maximal deep-water running and maximal land-based treadmill running.

Variable	LTR		DWR		p
	Mean	$\pm$ SD	Mean	$\pm$ SD	
HR <sub>rest</sub> (bpm)	71	8	74	11	0.163
VO <sub>2rest</sub> (l.min <sup>-1</sup> )	0.21	0.03	0.17	0.07	0.075
HR <sub>max</sub> (bpm)	190	5	174	9	0.002*
VO <sub>2max</sub> (l.min <sup>-1</sup> )	2.1	0.3	1.4	0.4	<0.001*
VO <sub>2max</sub> (ml.kg <sup>-1</sup> .min <sup>-1</sup> )	33.7	3.9	22.5	4.1	<0.001*

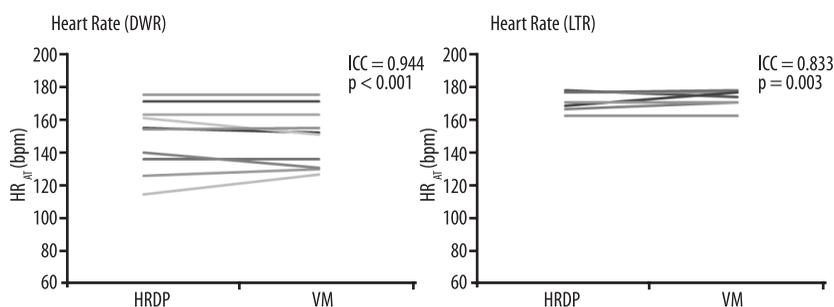
\* Indicates significant difference ( $p < 0.05$ ). HR<sub>rest</sub>: heart rate at rest. VO<sub>2rest</sub>: oxygen uptake at rest. HR<sub>max</sub>: maximal heart rate. VO<sub>2max</sub>: maximal oxygen uptake. DWR: deep-water running. LTR: land-based treadmill running

**Table 2.** Means  $\pm$ SD in the comparison between the protocols, methods and interaction for the cardiorespiratory variables.

Variables	Protocol	Methods						
		HRDP		VM		PRO	MET	PRO*MET
		Mean	$\pm$ SD	Mean	$\pm$ SD	p	p	p
HR <sub>AT</sub> (bpm)	DWR	153	17	152	18	0.031*	0.844	0.410
	LTR	171	6	172	6			
VO <sub>2AT</sub> (ml.kg <sup>-1</sup> .min <sup>-1</sup> )	DWR	17.8	4.8	18.7	4.8	0.001*	0.077	0.743
	LTR	26.6	5.5	28.1	5.3			
VO <sub>2AT</sub> (l.min <sup>-1</sup> )	DWR	1.0	0.3	1.0	0.3	<0.001*	0.113	0.547
	LTR	1.5	0.3	1.6	0.3			

\*Indicates significant difference ( $p < 0.05$ ). PRO: protocol. MET: methods. PRO\*MET: interaction protocol\*method. HR<sub>AT</sub>: heart rate in anaerobic threshold. VO<sub>2AT</sub>: oxygen uptake in anaerobic threshold. DWR: deep-water running. LTR: land-based treadmill running. HRDP: heart rate deflection point. VM: ventilatory method.

In Figure 1 the behavior of the HR<sub>AT</sub> between the two methods of determining the AT and the two tested protocols can be observed. The results showed that the variable analyzed in the maximal tests in water and on land presented high and significant ICC values between the two methods of determining the AT<sup>20</sup>.

**Figure 1.** Intraclass correlation coefficients (ICC) and significance level (p) for the heart rate (HR) in maximal deep-water running (DWR) and maximal land-based treadmill running (LTR) protocols based on the determination of the anaerobic threshold (AT) by HR deflection point (HRDP) and ventilatory method (VM).

## DISCUSSION

The aim of the present study was to compare the maximal cardiorespiratory responses and the AT during maximal LTR and DWR tests. In addition,

two methods of determining the AT (HRDP and VM) were compared during the two evaluated exercise protocols. The results show that the  $HR_{max}$ ,  $VO_{2max}$ ,  $HR_{AT}$  and  $VO_{2AT}$  were significantly higher during the LTR test than during the DWR test. Furthermore, no difference was found between the methods of determining the AT. These results are important because they show that a prescribed intensity of water exercises cannot be made based on physiological parameters obtained on land, and also that the HRDP is an efficient method of determining the AT.

The distinct behavior of the variables analyzed during the two tests can be attributed to the different physical characteristics existing between the water and land environments that have been well reported in the literature. Among them, there is the hydrostatic pressure of the water acting on the body and different thermal conductivity of this environment relative to land. Both these characteristics act by increasing the volume of blood in the central region of the body, thus reducing the HR<sup>21</sup>. However,  $VO_2$  may present a distinct behavior because the reduced hydrostatic weight in the aquatic environment means less muscle recruitment is required to maintain posture and execute the exercise<sup>22,23</sup>. Equally, it may be due to the different characteristics of DWR and LTR. Because of these differences between the mean HR and  $VO_2$  responses, we suggest that when a maximal test is required in order to prescribe training it should be conducted in the environment in which the modality is to be performed, according to the principle of specificity<sup>24</sup>.

While some studies do not prescribe training based on a specific test for the training modality, it is also common for training to be prescribed based on percentages related to maximum cardiorespiratory responses and their extrapolation to different individuals<sup>7,25</sup>. However, such a strategy involves the risk of overestimating or underestimating the training load due to the different intensity at which each individual reaches the AT<sup>8</sup>. This means that the same percentage relative to the maximum can represent, for example, anaerobic work for one individual and aerobic work for another. This undermines the training periodization, since control over the predominant metabolic pathway that the practitioner is training is lost. This type of error can be avoided by using percentages relative to the point corresponding to the AT that allows for greater control of the training zone.

Several studies in the literature have demonstrated the application of the HRDP to determine the AT in different land-based exercise modalities<sup>10-12,15,25-27</sup>. However, in the aquatic environment there are, currently, few studies available. Cellini et al.<sup>28</sup> identified the HRDP in swimmers. As a result the authors found a correlation of  $r = 0.84$  between the AT determined using the HRDP and that determined using the blood lactate response. Furthermore, Martins et al.<sup>15</sup> observed the HRDP in 85% of subjects analyzed in a progressive water-cycling test. This study evaluated 15 women and 12 men in a test which consisted of an initial load of 50 rpm with increments of 3 rpm every minute until exhaustion. Recently, Alberton et al.<sup>16</sup> also found no differences in cardiorespiratory responses between the

methods of determining the AT (HRDP and VM) in three different water aerobics exercises (stationary running, frontal kick and cross-country skiing); the ICC values of HR determined by the two methods were high and significant (ICC: 0.966; 0.895; 0.943 [ $p < 0.001$ ], respectively). Within this context, the results of the present study also demonstrated no significant differences between the methods of determining the AT (HRDP and VM) either in DWR or LTR. Furthermore, high and significant ICC values were found between the two methods of determining the AT for  $HR_{AT}$  (DWR ICC: 0.944,  $p < 0.001$ ; LTR ICC: 0.833,  $p = 0.003$ ). These results demonstrate that determining the AT by the HRDP appears to be an efficient method. Moreover, the mean of the total time of each protocol was 10 minutes, 59 seconds for the water-based protocol and 10 minutes, 33 seconds for the land-based protocol, time considered ideal to validate a maximal test (8–15 minutes)<sup>29</sup>.

## CONCLUSIONS

The values corresponding to the maximum and AT of the HR and  $VO_2$  were significantly lower in the aquatic environment. This suggests that when choosing to use a maximal test for a training prescription, it should be specific to both the exercise and environment in which it is practiced. Moreover, determining the AT and using percentages relative to it makes training prescription more efficient, since by this means it is possible to achieve control of the metabolic pathway that is being emphasized. Finally, according to the literature reviewed, the present study appears to be the first to investigate the determination of the AT by means of the HRDP in DWR, while comparing and correlating these values with those obtained using the VM. This demonstrates that the point corresponding to the AT can be determined by both VE-by-time and HR-by-intensity graphs. However, the HRDP can be used as a simple and practical alternative means of determining the AT during DWR and LTR tests. Given these findings, using the HR-by-intensity graph one can determine the point of deflection, and from this point it is possible to determine the percentages of the HR corresponding to the desired training zone.

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