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Physiological transition threshold in mountain runners: a systematic review

Limiares de transição fisiológica em corredores de montanhas: uma revisão sistemática

Poliana de Lima Costa[1]
Pâmela de Souza dos Santos[1]
Luana Loss Cabral[1]
Raul Osiecki[1]

Abstract – The identification of physiological transition thresholds (TT) is commonly used for prescribing and evaluating the performance of endurance athletes; however, the methods need further investigation in mountain runner athletes. The aim of the present review was to analyze the different methods used to determine TT in mountain runners. After analyzing 1,176 articles found in different databases, 4 articles that presented a relationship with the theme were selected. Varied proposals were observed, in which the surveys searched for physical and/or cardiorespiratory performance, as well as the effect of acclimatization and training at different altitudes in mountain runners. All studies used spirometry to identify the anaerobic threshold through visual methods and a relative mean intensity in thresholds occurred at 80 – 90% of VO_2max. The results of studies analyzed evidenced the limited use of methodologies in the identification of exercises for training evaluation and prescription, as well as the use of effective and low-cost alternative methods to determine these thresholds in mountain runners.

Key words: Anaerobic threshold; Athletic performance, Running.

Resumo – *A identificação dos limiares de transição fisiológica (LT) é comumente utilizada para prescrição e avaliação do desempenho de atletas de endurance, no entanto, os métodos precisam de maiores investigações em atletas corredores de montanhas. O objetivo da presente revisão foi analisar os diferentes métodos utilizados para a determinação dos LT em corredores de montanhas. Após a análise de 1176 artigos encontrados em diferentes bases de dados, foram selecionados 4 artigos que apresentaram relação com o tema. Pode-se observar propostas variadas, nas quais as pesquisas buscaram investigar o desempenho físico e/ou cardiorrespiratório, bem como o efeito da aclimatização e treinamento em diferentes altitudes nos corredores de montanhas. Todos os artigos utilizaram a espirometria para a identificação do limiar anaeróbio, através de métodos visuais e a intensidade média relativa nos limiares ocorreu próxima a valores de 80 – 90% VO_2máx. Os resultados dos estudos analisados evidenciam o uso limitado de metodologias na identificação dos LT para a avaliação e prescrição de treinamento, bem como a utilização de métodos alternativos eficazes e de baixo custo para a determinação destes limares em atletas corredores de montanhas.*

Palavras-chave: *Corrida; Desempenho atlético; Limiar anaeróbio.*

1 Federal University of Paraná. Curitiba, PR. Brazil.

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INTRODUCTION

Currently, mountain races have gained many enthusiasts, and because it is a sport in which athletes are exposed to diverse environmental, temperature and altitude variations[1,2], physiological adaptations are necessary to maintain high performance in the modality. The successful performance of athletes in long-distance events depends on numerous factors, such as maximal oxygen uptake (VO_2max), VO_2max fraction sustained during a race and energy cost[3]. In addition, other prerequisites such as physical and cardiopulmonary fitness[4] and training strategies[5] are fundamental for the safety and injury prevention of these athletes. Thus, oxygen uptake at the physiological transition threshold (VO_2LT) is considered an important factor for the determination of performance in endurance races and the ability to maintain it at higher levels with aging can be observed in mountain running athletes when compared to their untrained peers[4].

Physiological transition thresholds (TT) comprise the moment when there is an imbalance between energy use and the removal of the metabolites resulting from the activity of muscles during exercise[6]. In literature, several terminologies are used to represent TT and are observed by oxygen uptake, such as ventilatory threshold (VT), ventilatory anaerobic threshold or VO_2max, by blood lactate, also called lactate threshold (LT), where there is onset of lactate accumulation in the blood and, also, maximal lactate steady state[7]. Other terminologies are used to define TT such as second physiological threshold or anaerobic threshold. However, these variations can be justified by the means and methods used to identify TT, and in studies addressed in the present review, the terms anaerobic threshold and VO_2max are easily identified. Therefore, the identification of TT by LT or VT are commonly used to prescribe and evaluate the performance of endurance athletes[8-10] and its importance is justified by the association of these thresholds with performance[9,10].

However, little is known about the use of methods most used for such identification in mountain runner athletes, whose popularity of the modality has been increasing in recent years[2,12,13]. Therefore, the methods for determining the thresholds need to be further investigated for this modality, whose events exposes the athlete's body to numerous environmental conditions, such as variations in terrain, temperatures and altitudes[2], which may be responsible for highly exhaustive factors that alter physiological and psychological processes [14] and, thus, the intensity of occurrence of these thresholds.

The interest in research in this scientific area is still precarious and the great majority of studies have focused on objectives involving hydration status[15], nutrition[16-18], anthropometry[5,16,19] or injuries[20]. The VO_2LT values and the test time are associated to the results of athletes, determining their performance in mountain racing events[4]. These variables were associated in a hyperbolic way in 869 final runners of international mountain events, where athletes with lower VO_2LT obtained time up to seven times greater

compared to athletes who presented higher VO_2LT. These results suggested that longer test times may increase the fatigue rate and, likewise, increase the chances of muscle injuries[21]. For this reason, the aim of the present review was to analyze the different methods used for the determination of TT in mountain runners.

METHODOLOGICAL PROCEDURES

The present study followed the guidelines proposed in literature (PRISMA, 22 Preferred Reporting Items for Systematic Reviews and Meta-Analyses)[22], performed in pairs[23]. Initially, the search was performed in English and Portuguese in Medline/Pubmed, Science Direct, Scopus, BVS (Bireme) and Sport Discus electronic databases. The descriptors used were the most found in this area of study (mountain runners and threshold) and the logical operator "AND" was used. The search was carried out in October 2016 and there was no limited date for the selection of articles, and only original articles were included.

Firstly, the search and selection of articles in databases was carried out by two independent researchers and 1176 articles were found. Repeated titles were deleted and soon after, the remaining titles were analyzed and selected for the next step. After analysis, the abstracts were read and subsequently articles were selected. In the last step, articles were read in full and finally, 4 articles were selected to be included in this review.

Reviews, thesis or dissertation, letter to editors, articles that had no relation with the subject, articles with non-runner populations, and, finally, articles that did not approach physiological transition thresholds were excluded. Original articles related to mountain runners and articles that presented analyses of physiological thresholds in the methodology were included. The procedures adopted for each of the steps are shown in Figure 1.

Articles were analyzed for methodological quality according to a protocol for the present study, based on scales pre-elaborated in literature[23]. The quality of articles was verified according to the following criteria: (1) articles should present the general sample characteristics; (2) articles should present methodology compatible with the study objectives; (3) articles should present a description of the method used to determine the threshold; (4) articles should use spirometry or lactometer to measure the threshold; (5) articles should present the statistical analysis used; (6) articles should present conclusion that corresponds to the study objective (Table 1). Finally, after the selection of potential articles, a descriptive table was constructed in alphabetical order of authors, including the author, year of publication, scientific journal, study objective, sample description and methodology (Table 2).

Table 1. Methodological quality of selected articles

Articles	(1)	(2)	(3)	(4)	(5)	(6)	Total
Comparison of Level and Graded Treadmill Tests to Evaluate Endurance Mountain Runners[1]*	X	X	X	x	x	x	6
Superior Endurance Performance in Aging Mountain Runners[4]	X	X	X	x	x	-	5
Race performance and exercise intensity of male amateur mountain runners during a multistage mountain marathon competition are not dependent on muscle strength loss or cardiorespiratory fitness[24] *	X	X	X	x	x	x	6
"Living high-training low": effect of moderate-altitude acclimatization with low-altitude training on performance[25]	-	X	X	x	x	x	5

* articles that obtained maximum score (six points) in relation to quality criteria: (1) articles should present the general sample characteristics; (2) articles should present methodology compatible with the study objectives; (3) articles should present a description of the method used to determine the threshold; (4) articles should use spirometry or lactometer to measure the threshold; (5) articles should present the statistical analysis used; (6) articles should present conclusion that corresponds to the study objective

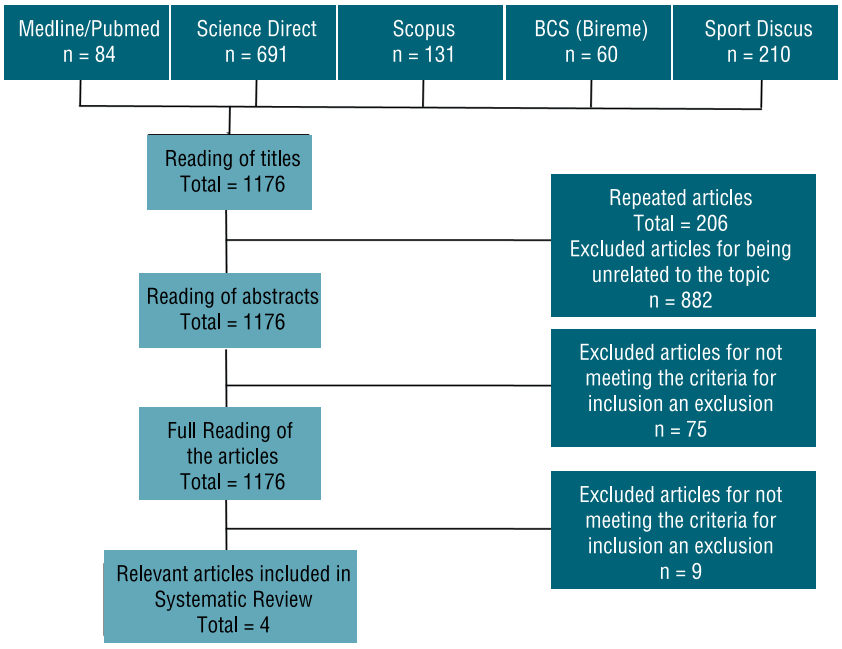

Figure 1. Flowchart of the systematic review steps

RESULTS

Sample characteristics

Most of the analyzed articles used high-performance professional mountain runners[4,1,25] and only one used amateur athletes[24]. From the total analyzed articles, two studies evaluated male runners[1,24], totalizing in a sample of ten and sixteen individuals, respectively, while two other studies analyzed both sexes, with a total of ten (7 males and 3 females)[4] and thirty-nine individuals (27 males and 12 females)[25].

The studies by Balducci et al.[1], Burtscher et al.[4] and Gatterer et al.[24] reported the mean age and standard deviation of runners (38.5 ± 6.4 years, 45.9 ± 8.5 years, 41 ± 8 years, respectively). The study by Levine and Stray-Gundersen[25] only reported the age range for sample selection (18-31 years). Based on these data, 100% of studies included young and middle-aged adults (19-60 years), according to the age rating proposed by Havighurst and Levine[26].

Table 2. Objectives and methodologies of selected articles.

Author	Journal	Study objective	Sample description	Methodology used to determine threshold
Balducci et al.[1]	Journal of Sports Science and Medicine	Determine whether uphill running performance can be predicted based on treadmill tests or whether an uphill test is required to predict performance in a homogeneous group of high-level mountain training resistance runners.	10 high-level male runners participated in the study (age 38.5 ± 6.4 years, height 1.77 ± 0.08 m, and body mass 69.8 ± 8.6 kg, VO2 63.3 ± 3.9 ml / min / kg).	VT was determined by the visual method of Wasserman et al [23].
Burtscher et al.[4]	International Journal of Experimental, Clinical, Behavioral and Technological Gerontology	Investigate the relationship between individual VO_2values at the anaerobic threshold and run times in mountain runners.	10 mountain runners (7 males and 3 females) participated in the study (age 45.9 ± 8.5 years, height 176.5 ± 7.5 cm, body mass 64.5 ± 7.9 kg, VO_2 4.06 ± 0.41 l / min).	The anaerobic threshold was defined as the time when the respiratory exchange rate values stabilized above 1.0 and did not return to levels below this value.
Gatterer et al.[24]	Journal of Strength and Conditioning Research	To quantify the cardiorespiratory fitness level, indicative of exercise intensity of amateur mountain runners, and characterize the association of cardiorespiratory fitness and muscle function (potency of lower limbs during competition).	16 male amateur mountain runners participated in the study (age 41 ± 8 years, height 178 ± 4 cm, body mass 73 ± 5.3 kg, VO2 67.8 ± 6.9 ml / min / kg).	VT was determined by non-linear increase in ventilation (VE) in combination with an increase in the respiratory equivalent of VO_2 (VE / VO_2) and expired O_2 pressure ($PETO_2$), without a concomitant increase in the respiratory equivalent of VCO_2 (VE / VCO_2). The respiratory compensation point was determined by the increase in VE / VO_2 and VE / VCO_2 and concomitant decrease in the expired CO_2 pressure ($PETCO_2$).
Levine e Stray-Gundersen[25]	Journal Applied Physiology	To test the hypothesis that moderate altitude acclimatization (2,500m), added to low altitude training (1,250m), "live high- train low" improves sea-level performance in well-trained runners more than altitude at sea level or an altitude control group.	39 distance runners (27 men and 12 women) completed all training and testing sessions (age 18-31 years).	VT (or maximum steady state) for all tests was determined by the criterion cited by Anderson and Rhodes [26], reporting a simultaneous analysis of multiple VO_2 vs. VE, VO_2 vs.VE/VO_2, VO_2 vs. VCO_2 and VO_2 vs. VE/VCO_2 plots

Proposed Objectives

Regarding the objectives analyzed in studies, varied proposals could be observed, which sought to investigate the physical and / or cardiorespiratory performance in laboratory tests associated with competition[4,24] or to tests that approximate the reality lived in the modality[1], as well as the effect of acclimatization and training at different altitudes on runners' performance[25].

The study by Balducci et al.[1] sought to investigate whether VO_2max and energy cost measured in uphill and flat running events are associated and, if indeed, non-inclination tests are able to predict performance in runs characterized by uphill stretches. Burtscher et al.[4] investigated the possible relationship between individual VO_2 values at the anaerobic threshold and the running times during a competition. Gatterer et al.[24] chose to verify if the running performance and intensity are influenced by HR, loss of muscular strength (evaluated by the counter-movement jump) and / or cardiorespiratory fitness (evaluated through VO_2max and anaerobic threshold). Levine and Stray-Gundersen[25] tested the hypothesis that living at moderate altitude and training at low altitude improves sea-level

performance in well-trained runners.

Methods for identifying thresholds

It could be observed that all studies used spirometry for the identification of the anaerobic threshold, i.e. VT. Gatterer et al.[24] were the only ones to identify the two physiological transition thresholds, VT being equivalent to the first threshold and the respiratory compensation point corresponding to the second threshold.

Segmentation of curves of different ventilatory parameters is performed to identify ventilatory thresholds and the visual method is commonly used. Balducci et al.[1] and Gatterer et al.[24] used the method proposed by Wasserman et al.[27] and Wasserman et al.[28], respectively. This method consists of a nonlinear increase in ventilation (VE), in combination with an increase in the respiratory equivalent of VO_2 (VE / VO_2) and expired O_2 pressure ($PETO_2$), without concomitant increase in the respiratory equivalent of VCO_2 (VE / VCO_2) for the determination of the first threshold. The respiratory compensation point, which represents the second threshold, corresponds to the increase in VE / VO_2 and VE / VCO_2 and a concomitant decrease in expired CO_2 pressure ($PETCO_2$).

Burtscher et al.[4] applied the method proposed by Solberg et al.[29], which corresponds to the moment when the values of the respiratory exchange rate stabilize above 1.0 and do not return to levels below this value, while Levine and Stray-Gundersen [25] refer to the threshold as the maximal steady state and applied the threshold determination criteria proposed by Anderson and Rhodes[30], reporting the simultaneous analysis of multiple VO_2 vs. VE, VO_2 vs.VE/VO_2, VO_2 vs. VCO_2 and VO_2 vs. VE/VCO_2 plots.

Intensity of thresholds

The intensity of VT occurrence is expressed as VO_2max percentages (% VO_2max). For all studies, the relative mean intensity occurred near values of 80-90% VO_2max. The study by Balducci et al.[1] found mean values of 90.4 ± 2.4% VO_2max; Burtscher et al.[4] found values close to 82% VO_2max (73-90%); Gatterer et al.[24] identified threshold at intensities close to 90% VO_2max; while Levine and Stray-Gundersen[25] reported values close to 80% VO_2max.

Methodological quality results

In relation to the presentation of the sample characteristics (criterion 1), three studies[1,4,24] contemplated this criterion, since they present characteristics of age, height and body mass of individuals of their samples. All studies considered the criteria for methodology presentation compatible with the study objectives (2); description of the method used for the threshold determination (3); presentation of the use of spirometry or lactometer for threshold measurement (4) and presentation of the statistics used (5). The presentation of conclusion that met the study objective (criterion 6) was observed in three studies[1,24,25].

DISCUSSION

The results of the studies analyzed evidenced the limited use of methods in the TT identification, with predominance of approaches involving VT, possibly because this is an effective, validated and widely used measure in current literature. This method allows measuring ventilatory parameters that are fundamental for the evaluation and prescription of training in mountain runners[31,32].

In the reviewed articles, there was a predominance of high-performance athletes (75%) and in competition situations, whose exposure involves highly exhaustive environmental processes that require great physiological and / or psychological demand from the athlete[14,33]. The majority of studies approached athletes with ages close to 40 years, possibly because it is the predominant age classification for this modality, as reported in previous studies[12,34,35].

The predominance of male subjects was also verified. All studies have addressed this gender and, although Burtscher et al. [4] and Levine and Stray-Gundersen[25] have selected mixed samples, it is noticed that women represent a small part of participants. The fact may be justified by the far lower number of female in relation to male mountain runners, which recently has become the focus of research on the sports scene[36]. However, this number is increasing[37] and women have represented about 20% of participants in recent years[12,35].

Although the objectives of studies were to verify factors that possibly influence performance and its evaluation, a gap is observed in investigations that involve a specific line of research. As already mentioned, TT is important for the evaluation and prescription of training[8-10], and its association with performance in endurance athletes has already been proven in previous studies[4,10,11] and, for this reason, should be addressed in study methods. Burtscher et al.[4] were the only ones to use VO_2LT as the main object of the research and affirm that this variable determines almost completely the performance of mountain runners.

The use of the ventilatory method by visual inspection for the TT identification was mentioned in 100% of studies analyzed. However, lack of standardization for the methodology is perceived, which makes the comparison of results difficult. The visual methods proposed by Wasserman et al.[27] and Wasserman et al.[28] were mentioned in the studies by Balducci et al.[1] and Gatterer et al.[24], respectively, while other methods[19,20] were chosen by Burtscher et al.[4] and Levine and Stray-Gundersen[25], respectively.

Other methods of TT identification can also be approached as an alternative and may be quite effective for this modality. For example, Gatterer et al.[24] point out that cardiorespiratory fitness parameters evaluated in laboratory tests (e.g., VO_2max., VT) are not sufficient to define performance in mountain marathons, suggesting that psychological factors, such as previous experience in dealing with increased pain perception and effort regulation, as well as in controlling exercise intensity, can substantially influence performance[24,33]. Future investigations involving alterna-

tive approaches for threshold identification with effective, less costly and noninvasive measurements that also address psychophysical factors, e.g., physiological and psychological factors that are fundamental in mountain runner athletes should be conducted.

Finally, the following are limitations of reviewed articles: (a) the small number of participants who composed the research sample[1,4,24] (b) the almost exclusive use of male participants; (c) lack of research involving a specific line of research; (d) absence of other TT identification parameters (e.g., lactate, heart rate); and (e) standardization and clarity of the mentioned protocols for such function.

The limitation on the use of new approaches for TT determination and the lack of research for this specific topic were the main limitations that made the comparison of results difficult. These alternative approaches require further investigation regarding the relationship between metabolic and perceptual thresholds in mountain runners, whose competitions exposes the athlete's body to numerous environmental conditions, such as variations in terrain, temperatures and altitudes[2], which may be responsible for highly exhaustive factors that alter physiological and psychological processes in the athlete's body[14] and, thus, the intensity of occurrence of TT and effort regulation. In this sense, it is clear the need to broaden the research with TT in mountain runners, as well as clear measures and alternative approaches that clarify all the procedures used, as well as their effectiveness for this specific group of athletes.

CONCLUSIONS

There is a gap in studies addressing TT identification for training evaluation and prescription, as well as the use of alternative, effective, simple and low-cost operational methods, such as the Dmax method, applied to the subjective perception of effort and to the point of heart rate deflection for the determination of these thresholds in mountain runners. The importance of using transitional thresholds for the evaluation of endurance athletes is justified by their association with performance. The mountain racing modality exposes the athlete's body to several environmental conditions and physiological stress, capable of altering the intensity of occurrence of transition thresholds, and further investigation is necessary for a precise and safe training prescription.

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CORRESPONDING AUTHOR

Poliana de Lima Costa
Department of Physical Education
Coração de Maria Street, 92,
Federal University of Paraná,
Curitiba, Paraná, Brazil
CEP: 80210-132
E-mail: poli.edf@hotmail.com