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ORIGINAL RESEARCH ARTICLE

Validation of the Shortened Dmax Method for Non-Invasive Estimation of Anaerobic Threshold: Implications for Health and Performance in Elite Wrestlers

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Abstract

Background Optimizing training intensity through the accurate determination of the anaerobic threshold is essential for elite athletes, particularly wrestlers. This study aimed to evaluate the validity of the Shortened Dmax method as a non-invasive approach for identifying the heart rate deflection point (HRDP) and estimating the anaerobic threshold in young Iranian national team wrestlers.

Methods In a semi-experimental design, seventeen elite male junior wrestlers completed an incremental treadmill test using the Bruce protocol. Heart rate was continuously monitored, and blood lactate concentrations were measured before and after exercise. The HRDP was identified using the Shortened Dmax mathematical model. Regression analyses and graphical outputs were generated using Microsoft Excel.

Results The Shortened Dmax method successfully identified a clear HRDP in all participants. Blood lactate levels increased significantly following exercise, supporting the method's consistency with established physiological indicators of anaerobic metabolism.

Conclusion The Shortened Dmax method appears to be a valid, practical, and non-invasive alternative for estimating the anaerobic threshold in wrestlers. Its application may enhance training-intensity prescription in combat sports; however, further validation using sport-specific testing protocols is recommended. This method can help prevent overtraining and support cardiovascular health monitoring in elite athletes.

Keywords Anaerobic threshold, Exercise test, Heart rate, Lactate, Physical exertion, Wrestling

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1 Introduction

Optimizing training intensity is fundamental to achieving peak athletic performance and enhancing physiological capacities.[1,2] Within this context, cardiovascular endurance is a key component of physical fitness and plays a decisive role in athletic success, particularly in high-intensity and sustained-duration sports.[3,4] A persistent challenge for coaches and exercise physiologists is determining the exercise intensity that effectively induces physiological overload while preventing premature fatigue and overtraining.[5,6] Traditionally, general indices such as maximum heart rate or maximal oxygen uptake (VO_2max) were used to guide training prescription. However, contemporary approaches increasingly emphasize identifying individualized physiological thresholds, particularly the anaerobic threshold.[7,8]

One widely used non-invasive technique is the determination of the Heart Rate Deflection Point (HRDP).[9,10] The HRDP represents the point during an incremental exercise protocol at which the linear relationship between heart rate and workload deviates, producing a distinct deflection or "break" in the heart rate curve.[11,12] This deflection is commonly assumed to coincide with the anaerobic threshold.[10,13,14] Among the methods proposed for identifying the HRDP, the Dmax method introduced by Cheng et al. has demonstrated high accuracy and reliability.[15] This method involves drawing a straight line between the first and last data points of the heart rate curve and identifying the point on the curve with the greatest perpendicular distance from this line.[10,16] Modified versions, such as the Shortened Dmax method, have been developed to improve efficiency and reduce testing duration.[17,18]

Despite encouraging findings regarding the accuracy of the Dmax method in various athletic populations, its application, particularly the shortened version, has been insufficiently investigated among elite wrestlers.[19,20] Wrestlers require the simultaneous development of aerobic and anaerobic capacities at the highest competitive level.[21] Training prescription based on generalized methods risks insufficient physiological stimulus or, conversely, overtraining.[22] Although non-invasive methods such as the HRDP are widely used in endurance sports, limited research has validated their applicability in combat sports such as wrestling.[23] In Iran, where wrestling holds a prominent international standing, a clear gap exists in studies examining practical and accurate methods for determining the anaerobic threshold in elite wrestlers.[24,25]

Accurate identification of anaerobic threshold not only enhances performance but also contributes to safer and more health-conscious training practices. Given these considerations, the present study aimed to validate a model based on the heart rate curve using the Shortened Dmax method to determine the HRDP and estimate the anaerobic threshold in young Iranian national team wrestlers. This research seeks to determine whether the shortened method can serve as a valid and practical alternative to invasive and costly approaches for this specific athletic population.

2 Methods

Study Design

This semi-experimental study examined the effectiveness of the Shortened Dmax method for determining the HRDP in young Iranian wrestlers. Twenty-one members of the national junior wrestling team were initially recruited, and after applying the exclusion criteria, 17 athletes were included in the final analysis. All participants provided written informed consent prior to testing. The study protocol was approved by the Ethics Committee of Mohaghegh Ardabili University (IR.ARUMS REC.1397.301). and all procedures were conducted in accordance with the ethical standards of the 1964 Helsinki Declaration and its later amendments.

Participants

Eligible participants were male wrestlers aged 16–18 years who had accumulated at least three years of competitive experience at the national level. Additional inclusion requirements were the absence of cardiovascular, pulmonary, or metabolic disorders; no adherence to special diets during the study period; no use of prohibited substances or performance-enhancing drugs; and a Body Mass Index (BMI) between 19 and 26 kg/m^2. Participants also needed to be physically capable of completing the Bruce treadmill protocol without limitations.

Athletes were excluded if they had any musculoskeletal injury or illness that could affect performance, if they were taking medications that might influence heart rate or metabolic responses, or if their BMI fell outside the predefined range. Individuals who failed to comply with pre-test requirements, such as abstaining from strenuous exercise or caffeine intake for 48 hours before testing, were also excluded.

Experimental Protocol

All testing procedures were conducted in the Exercise Physiology Laboratory under controlled environmental conditions. Participants performed an incremental treadmill test (Bruce protocol) on a motorized treadmill (h/p/cosmos, Germany). Heart rate was continuously monitored throughout the test, and blood lactate concentrations were measured at rest and immediately after exercise. Additional physiological variables, including VO_2max, BMI, and body fat percentage, were also assessed.

Data Analysis

Data analysis was conducted using Microsoft Excel (version 2016; Microsoft Corp., Redmond, WA, USA). Regression plots and graphical analyses were generated in Excel to determine the HRDP.

3 Results

Table 1 presents the mean and standard deviation of the physical and physiological characteristics of the wrestlers. Participants had a mean age of 18.85 ± 0.79 years, with heights ranging from 163 to 189 cm and body masses between 57 and 128.7 kg. The athletes demonstrated relatively low body fat percentages (mean: 14.1 ± 4.7%) and a mean BMI of 25.06 ± 3.9 kg/m². Resting lactate values ranged from 1.40 to 3.00 mmol/L, with a mean of 1.90 ± 0.42 mmol/L. The average VO_2max of the athletes was 56.84 ± 5.4 ml/kg/min.

Table 1 Physical and physiological characteristics of the participants (Mean ± SD)

Variable	Mean ± SD	Max	Min	N
Age (years)	18.85 ± 0.79	20	17	17
Weight (kg)	78.65 ± 19.11	128.70	57	17
Height (cm)	176.09 ± 8.23	189	163	17
Body fat percentage (%)	14.1 ± 4.7	22.1	3	17
BMI (kg/m²)	25.06 ± 3.9	36	19	17
Waist-to-hip ratio (WHR)	0.73 ± 0.05	0.82	0.64	17
Resting lactate (mmol/L)	1.90 ± 0.42	3.0	1.40	17
VO_2max (ml/kg/min)	56.84 ± 5.4	62	43	17

VO_2max: Maximum heart rate or maximal oxygen uptake, BMI: Body Mass Index

Details of the seven-stage Bruce treadmill protocol used for cardiorespiratory evaluation are presented in Table 2.

Table 2 Bruce treadmill test protocol for cardiorespiratory evaluation

Stage	Duration (min)	Speed (km/h)	Grade (%)
1	3	1.7	10
2	3	2.5	12
3	3	3.4	14
4	3	4.2	16
5	3	5.0	18
6	3	5.5	20
7	3	6.0	22

Based on Table 3 and Figure 1, the mean secondary lactate concentration measured immediately after the test was 10.53 ± 2.42 mmol/L, with individual values ranging from 4.20 to 14.30 mmol/L. Lactate values exhibited a clear and expected physiological rise, increasing from a minimum pre-test value of 1.40 mmol/L to 4.20 mmol/L post-test, and from a maximum pre-test value of 3.00 mmol/L to 14.30 mmol/L post-test. Overall, mean lactate concentration increased significantly from 1.90 ± 0.42 mmol/L to 10.53 ± 2.42 mmol/L following the graded exercise protocol.

Table 3 Post-exercise blood lactate levels of the participants (mmol/L)

Variable	Mean ± SD (mmol/L)	Max (mmol/L)	Min (mmol/L)	N
Secondary lactate	10.53 ± 2.42	14.30	4.20	17

The heart rate deflection point determined using the shortened Dmax method is summarized in Table 4 and illustrated in Figure 1. The mean HRDP among participants was 167.5 ± 7.7 beats per minute (bpm), with recorded values ranging from 152 to 176 bpm. The HRDP values were derived from heart rate curves obtained immediately after completion of the incremental exercise test and subsequently analyzed in Excel. These findings reflect the physiological breakpoint at which heart rate departs from linearity, corresponding to the onset of increased anaerobic contribution.

Table 4 Heart Rate Deflection Point (HRDP) values determined by the Shortened Dmax method (bpm)

Variable	Mean ± SD	Maximum	Minimum	N
Heart Rate Deflection Point (HRDP)	167.5 ± 7.7	176	152	17

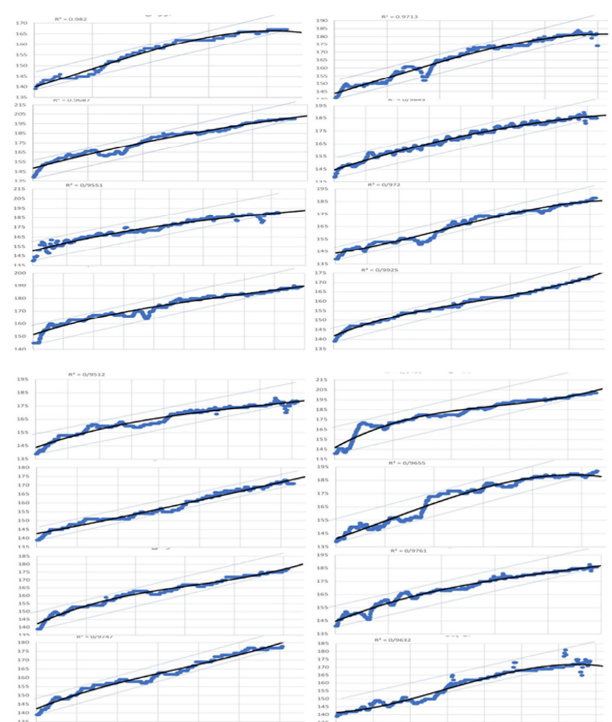

Figure 1 Heart rate deflection point of the study participants

4 Discussion

This study aimed to determine the HRDP using the Shortened Dmax method and examine its relationship with the anaerobic threshold in elite Iranian junior wrestlers. The findings indicate that the Shortened Dmax method successfully identified a distinct HRDP in this athletic population, with a mean value of 167.5 ± 7.7 bpm. The substantial rise in blood lactate concentration from resting levels (1.90 ± 0.42 mmol/L) to post-exercise values (10.53 ± 2.42 mmol/L) further confirms that the incremental Bruce protocol effectively induced an anaerobic metabolic response.

These results are consistent with previous research across other intermittent and high-intensity sports. Jamnick et al. (2018) reported strong agreement among several lactate-threshold identification techniques, including the Dmax method, in cyclists, supporting the validity of non-invasive approaches for defining exercise-intensity domains.[26] Similarly, the classic work of Hofmann et al. (1997) demonstrated a significant association between HRDP (via the Conconi test) and the anaerobic threshold in elite runners, contributing to the widespread adoption of HRDP-based assessment in sport science.[27]

However, the reliability of heart rate–derived thresholds remain debated. Caminal et al. (2018), in a comprehensive review, noted that although HRDP and heart rate variability indices show potential, they are influenced by protocol design, exercise modality, and individual physiological variation, which can lead to inconsistent results across studies.[28] In team-sport athletes, Chalmers et al. (2015) found the Dmax method to be reliable but not always interchangeable with the gold-standard Maximal Lactate Steady State (MLSS), suggesting that HRDP may be more appropriate for intra-individual monitoring rather than for prescribing absolute training intensities.[29] These contrasting findings underscore the importance of population-specific validation, particularly in a sport as physiologically unique as wrestling.

The underlying physiological rationale for HRDP is that it reflects a cardiovascular marker of the anaerobic threshold.[10] During incremental exercise, heart rate typically increases linearly with workload.[30,31] Once exercise intensity surpasses the anaerobic threshold, lactate accumulates rapidly, leading to metabolic acidosis.[32,33] These triggers heightened chemoreceptor activation and a surge in sympathetic nervous system activity and catecholamine release. The resulting non-linear acceleration in heart rate manifests as the deflection point detected through HR-workload analysis.[34,35]

From a health monitoring perspective, the Shortened Dmax method provides a valuable non-invasive tool for preventing overtraining and optimizing athlete well-bein[23,24] By enabling regular assessment of the anaerobic threshold, this approach allows for early detection of excessive cardiovascular strain and accumulated fatigue.[27] This facilitates timely adjustments to training loads, reducing injury risks while promoting long-term athletic health.[22] The method's practicality makes it suitable for routine implementation in wrestling training programs, serving as an effective bridge between performance enhancement and health preservation.[36]

Despite meaningful findings, this study has several limitations. The small and homogenous sample size limits generalizability, and the use of a standard treadmill-based protocol does not fully replicate the intermittent, grappling-based demands of wrestling. Consequently, sport-specific metabolic and mechanical characteristics may not be fully captured. Future research should validate the Shortened Dmax method against the MLSS in wrestlers to confirm its precision and applicability. Additionally, protocols incorporating wrestling-specific movements may enhance ecological validity when determining HRDP. Longitudinal studies are also warranted to evaluate whether training intensities prescribed via HRDP lead to measurable improvements in wrestling performance, thereby determining the method's practical utility for coaches and strength-conditioning professionals.

5 Conclusion

The Shortened Dmax method effectively identified the heart rate deflection point and provided a valid, non-invasive estimate of the anaerobic threshold in elite wrestlers. This approach offers a practical alternative to invasive physiological testing, facilitating individualized training prescription. The Shortened Dmax method provides a non-invasive, safe, and efficient approach for assessing anaerobic threshold, supporting athlete health and training optimization.

Declarations

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Artificial Intelligence Disclosure

The authors utilized an AI-powered language model (ChatGPT, OpenAI) exclusively for assistance with linguistic refinement and formatting of the pre-print version of this manuscript. All scientific content, data analysis, interpretation of results, and intellectual contributions remain entirely the responsibility of the human authors. The AI system was used as a tool to improve readability and was not involved in the design, execution, or scientific decision-making of the study.

Authors' Contributions
Amir Hossein Hormati Oughoulbaig: Conceptualization, Methodology, Investigation, Data Curation, Writing – Original Draft Preparation, Project Administration. Reza Farzizadeh: Methodology, Formal Analysis, Investigation, Resources, Writing – Review & Editing. Roghayyeh Afroundeh: Validation, Formal Analysis, Writing – Review & Editing, Supervision. Marefat Siahkouhian: Conceptualization, Resources, Writing – Review & Editing, Supervision.

Availability of Data and Materials
The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

Conflict of Interest
The authors declare that they have no conflict of interest related to this study.

Consent for Publication
Not applicable.

Ethical Considerations
All procedures involving human participants were conducted in accordance with the ethical standards of the institutional and national research committee, and with the 1964 Helsinki Declaration and its later amendments. The study was approved by the Ethics Committee of Mohaghegh Ardabili University (IR. ARUMS REC.1397.301).

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