Application of heart rate monitoring for assessing the intensity of training loads in speed–strength sports: a case study of combat sports

https://doi.org/10.65149/eajss.2026.v6i6.a001

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Abstract

Objective. The purpose of this study was to critically evaluate the effectiveness of heart rate (HR) monitoring as a method for assessing the intensity of sport-specific training loads employed in combat sports.

Materials and Methods. The study involved highly qualified members of the Russian National Karate Team (WKF Kumite). The participants completed three standardized blocks of sport-specific exercises:

(1) repeated high-intensity speed-oriented alactic anaerobic exercises consisting of five maximal-effort bouts separated by one-minute recovery intervals;

(2) a simulated competitive bout with standardized attacking sequences (2 min for female athletes and 3 min for male athletes);

(3) official sparring bouts conducted under WKF competition rules. Peak heart rate was recorded using Polar heart rate monitors, while blood lactate concentration was determined from capillary blood samples. Correlation analysis revealed no statistically significant relationship between post-exercise heart rate and blood lactate concentration ($r = 0.22$).

Results. The findings demonstrated that maximal or post-exercise heart rate values do not adequately reflect either the actual intensity or the metabolic cost of high-intensity sport-specific exercises performed in combat sports. The weak correlation between heart rate and blood lactate concentration confirms the limited applicability of conventional heart rate–based training zones for monitoring predominantly anaerobic exercise.

Conclusions. A linear relationship between heart rate and exercise intensity exists only within a relatively narrow range of predominantly aerobic exercise intensities up to approximately 0.75 of the maximal metabolic rate, (MMR), representing less than 5% of the total spectrum of training loads encountered in combat sports. For the quantification of speed–strength training loads, the cumulative heart rate cost of exercise (including both exercise and recovery periods) is proposed as a more informative physiological indicator, owing to its close association with oxygen demand and the overall energetic cost of exercise.

Keywords: combat sports; heart rate; blood lactate; cumulative heart rate cost of exercise; anaerobic threshold; training load quantification.

Introduction

Heart rate (HR) monitoring systems, particularly wearable devices manufactured by Polar, have become an integral component of contemporary athletic training across a wide range of sports. The concept of heart rate training zones, based on the assumption of a linear relationship between heart rate and exercise intensity, has been extensively adopted for monitoring and prescribing aerobic exercise. This approach has proven highly effective in endurance disciplines such as long-distance running, swimming, road cycling, and cross-country skiing. However, its direct application to speed–strength sports, and especially to combat sports, remains highly controversial from the perspectives of exercise bioenergetics and sports physiology [1,2,3,5,7].

The aim of the present study was to critically evaluate the validity of heart rate monitoring as a method for assessing the intensity of sport-specific training loads performed in combat sports.

It is well established that muscular activity is supported by three major metabolic energy systems that are recruited sequentially as exercise intensity increases: the alactic anaerobic (phosphagen) system, the anaerobic glycolytic system, and the aerobic oxidative system [3–8]. Each energy system is characterized by its own maximal rate of ATP production (power output) and total energy capacity.

If resting metabolic rate is taken as the reference level, the metabolic power available to highly trained athletes extends from resting conditions to approximately 10 times the maximal metabolic rate (MMR) associated with maximal oxygen uptake (VO_{2max}) [3,5,7,8]. Consequently, the mechanical power generated during a maximal sprint or a rapid series of striking actions may exceed the energy production capacity of the aerobic system by an order of magnitude.

The linear relationship between heart rate and oxygen consumption (VO_2) is maintained only within the predominantly aerobic range of exercise, extending from approximately 110 beats·min^{-1} to the anaerobic threshold (AT). Beyond this point, heart rate reaches a plateau or increases at a substantially lower rate than exercise power output [4,5,7]. Classical submaximal exercise tests, including the PWC_{170}

test and the Harvard Step Test, were developed specifically within this linear physiological range, where a heart rate of approximately 170 beats·min^{-1} corresponds to exercise intensity close to the individual's critical power.

However, once exercise intensity exceeds approximately 0.75 MMR, which roughly corresponds to the anaerobic threshold, the linear relationship between heart rate and mechanical power deteriorates. During explosive movements lasting no more than 10–15 seconds, heart rate kinetics are too slow to accurately reflect either the actual power output or the metabolic cost of the exercise [4,6].

Accordingly, the range within which heart rate can be interpreted as a valid indicator of exercise intensity represents no more than approximately 5% of the entire spectrum of training intensities employed in the preparation of elite athletes. In combat sports, where training predominantly consists of repeated short-duration, high-intensity efforts, heart rate monitoring therefore provides only limited information regarding the true physiological demands of exercise.

To experimentally verify this theoretical assumption, a pilot study was conducted during a centralized training camp involving members of the Russian National Karate Team (WKF Kumite). Highly qualified male and female athletes specializing in kumite participated in the investigation.

Methods

To experimentally verify the proposed theoretical assumptions, a pilot study was conducted during a centralized training camp involving members of the Russian National Karate Team (WKF Kumite). The study included highly qualified male and female athletes specializing in kumite.

The participants completed three standardized blocks of sport-specific training tasks that differed in their predominant metabolic characteristics.

1. Speed-Oriented Sport-Specific Exercise Block (Predominantly Alactic Anaerobic)

Athletes performed five sets of maximal-intensity attacking actions, each lasting 10 s, with 1-min passive recovery intervals between consecutive sets. This exercise protocol simulated repeated explosive actions typically observed during competitive kumite bouts.

2. Simulated Competitive Bout (Mixed Anaerobic–Aerobic Metabolic Profile)

The athletes completed a sequence of standardized technical tasks with a total duration corresponding to official WKF competition rules (2 min for female athletes and 3 min for male athletes). The protocol incorporated regulated pauses consistent with official competition procedures.

The exercise sequence consisted of:

continuous footwork with a single-hand attack performed every 10 s;

continuous footwork followed by a two-technique combination (hand–leg) every 15 s;

continuous footwork followed by a three-technique combination (hand–leg–hand) every 15 s.

This protocol reproduced the intermittent metabolic demands characteristic of an actual karate bout while ensuring identical external workloads for all participants.

3. Official Competitive Sparring

Each athlete completed two full-contact kumite bouts conducted according to the official World Karate Federation (WKF) competition rules. This protocol was designed to evaluate physiological responses under conditions that closely resembled actual competitive performance.

Immediately after completion of each exercise block, the following variables were recorded:

peak heart rate (HR) using Polar heart rate monitoring systems;

capillary blood lactate concentration, measured with a portable Lactate Pro analyzer.

Blood lactate concentration served as the principal biochemical indicator of anaerobic glycolytic metabolism, reflecting the degree of activation of the glycolytic energy system during exercise.

The relationship between heart rate and post-exercise blood lactate concentration was evaluated using correlation analysis. The results of the correlation analysis are presented in Fig. 1.

The strength of the association between these independent physiological variables was assessed using the correlation coefficient (r), with statistical significance determined according to conventional criteria.

Discussion

The findings of the present study can be readily explained from the perspective of contemporary exercise bioenergetics and cardiovascular physiology.

During short-duration explosive exercise, represented by the first experimental protocol, adenosine triphosphate (ATP) resynthesis is supplied predominantly by the phosphagen (alactic anaerobic) energy system. This metabolic pathway operates independently of oxygen delivery and therefore does not require an immediate increase in cardiac output or heart rate. Consequently, heart rate kinetics lag behind the actual metabolic power output, while blood lactate accumulation remains minimal because anaerobic glycolysis contributes only marginally to energy production during efforts of such short duration.

In the simulated competitive bout, exercise intensity fluctuated continuously as high-intensity attacking actions alternated with periods of lower activity and brief recovery. Under these conditions, cardiovascular responses represent an integrated physiological reaction rather than an instantaneous reflection of external workload. Moreover, post-exercise blood lactate concentration depends primarily on the cumulative duration of glycolytic metabolism, which varies substantially among athletes according to their technical style, tactical decisions, and individual physiological characteristics.

During official competitive bouts, interpretation of heart rate becomes even more problematic. In addition to exercise intensity, heart rate is strongly influenced by psychological stress, anticipatory sympathetic activation, hyperventilation, and prolonged isometric muscle contractions associated with maintaining combat posture. These factors substantially increase cardiovascular activity without producing a proportional increase in metabolic energy expenditure. Consequently, elevated heart rate values during competition cannot be interpreted as a direct measure of exercise intensity.

Collectively, these physiological mechanisms explain the weak correlation observed between post-exercise heart rate and blood lactate concentration in the present study. The findings demonstrate that the predictive value of heart rate monitoring, which has been well established for continuous aerobic exercise, decreases markedly during intermittent, high-intensity activities that rely predominantly on anaerobic energy metabolism. Therefore, conventional heart rate–based training zones should not be considered an appropriate method for quantifying sport-specific training loads in combat sports or other speed–strength disciplines.

A more physiologically valid alternative is provided by the concept of the cumulative heart rate cost of exercise, which integrates cardiovascular activity throughout both the exercise period and the subsequent recovery phase.

According to this concept, the heart rate cost of exercise represents the total number of heartbeats accumulated during exercise (exercise heart rate cost) together with those recorded during recovery until heart rate returns to a predetermined reference level (recovery heart rate cost). Their sum constitutes the cumulative heart rate cost of exercise, an integral physiological index that has been shown to correlate closely with oxygen demand and the total energetic cost of physical work.

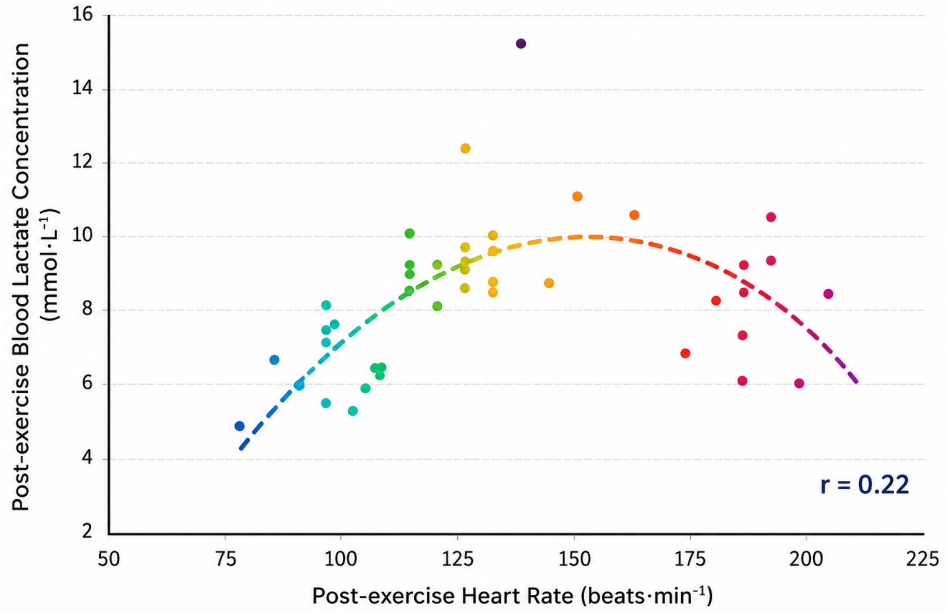
The physiological rationale for this approach is based on the well-established relationship between cumulative cardiac output and whole-body oxygen consumption. Although heart rate may underestimate the metabolic demands of brief maximal exercise, the excess post-exercise oxygen consumption (EPOC) that follows anaerobic work requires sustained cardiovascular activity during recovery. Consequently, inclusion of the recovery period enables a substantially more accurate estimation of the overall metabolic cost of exercise than heart rate measured during exercise alone.

Previous investigations in competitive swimming and other sports have demonstrated that the cumulative heart rate cost reproduces the fundamental physiological relationships observed for oxygen demand, increasing systematically with both exercise intensity and maximal exercise duration. This evidence supports its application as a universal quantitative indicator of training load across exercises with different metabolic characteristics.

Recognition of the limited validity of instantaneous heart rate measurements for monitoring anaerobic exercise has important practical implications. Training control in combat sports, team sports, sprint events, and weightlifting should shift from exclusive reliance on conventional heart rate zones toward an integrated monitoring strategy that combines cumulative heart rate cost with selected biochemical markers of metabolic stress.

Such an approach provides a substantially more accurate assessment of the physiological demands imposed by sport-specific exercise and allows coaches to optimize training load prescription while reducing the risk of

Fig 1. .Correlation between post-exercise heart rate and blood lactate concentration as immediate indicators of the intensity of sport-specific exercise in highly qualified athletes (r = 0.22).



both excessive fatigue and insufficient training stimulus.

Conclusion

The present study demonstrates that the use of peak or instantaneous heart rate (HR) as the primary indicator for assessing the intensity of sport-specific training loads in combat sports is methodologically inadequate. The weak correlation observed between post-exercise HR and blood lactate concentration (r = 0.22) indicates that heart rate reflects only a limited proportion of the actual metabolic demands imposed by high-intensity intermittent exercise.

The findings confirm that the well-established linear relationship between HR and exercise intensity is restricted to predominantly aerobic exercise performed below the anaerobic threshold. Once exercise intensity exceeds approximately 75% of the maximal metabolic rate (MMR), cardiovascular responses no longer accurately reflect either mechanical power output or the energetic cost of exercise. Consequently, conventional heart rate–based training zones cannot be considered an appropriate tool for monitoring anaerobic and speed–strength training loads.

The concept of the cumulative heart rate cost of exercise, which incorporates cardiovascular responses during both exercise and recovery, provides a more physiologically valid approach to training load quantification. Because this integral indicator closely reflects oxygen demand and total energy expenditure, it represents a more reliable criterion for evaluating the physiological impact of sport-specific exercise across a broad range of metabolic conditions.

The proposed approach may contribute to improving training load monitoring and optimizing the management of athlete adaptation during the preparation of highly qualified competitors in combat sports.

Practical Implications. The findings of the present study have several practical implications for coaches and sport scientists involved in the preparation of athletes participating in combat sports and other speed–strength disciplines.

First, relatively low heart rate values recorded immediately after repeated explosive efforts should not be interpreted as evidence of insufficient exercise intensity. Although cardiovascular responses may appear moderate, the metabolic cost of such exercise can be substantial and becomes more evident during the recovery period. Consequently, exclusive reliance on conventional heart rate training zones may result in inaccurate evaluation of training load.

Second, modern heart rate monitoring systems enable automatic calculation of the cumulative number of heartbeats over any selected time interval. It is therefore recommended to record the heart rate cost both during exercise and throughout recovery, for example until heart rate decreases to approximately 120 beats·min^{-1}. Monitoring the cumulative heart rate cost over

successive microcycles and mesocycles provides a more objective assessment of athlete adaptation than instantaneous heart rate measurements alone.

Third, during the most demanding phases of the annual training cycle, training load monitoring should be based on an integrated assessment combining cardiovascular indices with selected biochemical markers, including blood lactate concentration, urea, and creatine kinase activity. Such a multidimensional monitoring strategy allows more accurate evaluation of both the physiological and metabolic consequences of training.

Finally, assessment of the acute effects of sport-specific exercise should distinguish clearly between predominantly aerobic and predominantly anaerobic training tasks. Different physiological mechanisms govern cardiovascular responses under these conditions, and therefore different monitoring approaches are required to ensure valid evaluation of exercise intensity.

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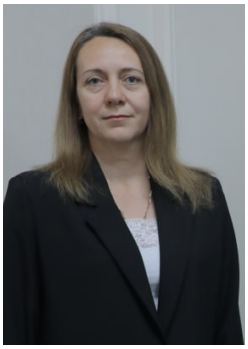
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