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Application of Wearable Devices in Swimming Training Monitoring from the Perspective of Training Load Quantification

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Abstract

This study explores the application of wearable devices in training monitoring based on the current need for training load quantification in swimming. Through a literature review, relevant studies were collected and analyzed, examining the role of different metrics in training load quantification. The results indicate that wearable devices in swimming can quantify load indicators such as heart rate, muscle oxygen, and speed, assisting coaches and athletes in better understanding training effects and fatigue levels. It concludes that the use of wearable devices provides more precise monitoring for swimming training, aiding in the optimization of training plans and enhancement of athletic performance.

Keywords: load quantification, swimming training, wearable devices, training monitoring

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1. Introduction

1.1 Research Background

With the continuous advancement of sports science and technology, athletes' demand for precise quantification and management of training loads has been steadily increasing. Traditional training methods primarily rely on the coach's experience and subjective judgment, making it difficult to accurately assess training effectiveness or predict potential risks. This is especially true in competitive sports, where athletes often face high-intensity and high-frequency training. Effectively preventing overtraining syndrome and improving training efficiency have become key issues.

With the rapid development of wearable devices, technologies such as heart rate monitors, GPS devices, accelerometers, and biosensors have been widely applied in sports training monitoring. These devices can monitor various physiological indicators in real time, such as heart rate, blood oxygen levels, body temperature, and biomechanical parameters like gait. Additionally, they consider external environmental factors (such as temperature, humidity, etc.), providing comprehensive data support for training load. The introduction of intelligent algorithms has made it more efficient and accurate to extract key information from large data sets, thus providing technical support for training load quantification.

The core goal of training load quantification is to reasonably arrange training plans using scientific methods, ensuring that athletes maintain a high level of competitive performance while reducing the risk of injury. By managing training loads, training plans can be optimized to improve recovery efficiency and promote long-term development. Research has shown that load management helps prevent functional decline due to overtraining and supports athletes in maintaining peak performance. Additionally, research on training load quantification contributes to the deeper exploration of the relationship between training and performance in the field of sports science, effectively translating theoretical research into practical applications.

1.2 Methodology

This study employs a literature review method. Relevant studies published in the past decade were collected from databases such as PubMed, Web of Science, and China National Knowledge Infrastructure (CNKI) using keywords like "swimming wearable devices," "training load quantification," "quantified training load," "wearable technology," "athletic training," and "physiological monitoring." The screening criteria included publication date, relevance to the research topic, and whether the study subjects were high-level swimmers. The literature evaluation was based on scientific rigor, data completeness, and applicability of the results. After screening, 20 relevant papers were selected for review.

2. Classification and Evaluation Methods of Training Load and Applications in Sports

2.1 Types of Training Load and Their Evaluation Methods

This section summarizes different types of training loads and their corresponding evaluation methods (Table 1). It categorizes training loads into internal load, external load, and a combination of both. Internal load evaluation methods include, but are not limited to, subjective rating of perceived exertion (RPE), heart rate (HR), blood lactate concentration, and oxygen consumption (VO2). External load is mainly assessed using data from Global Positioning System (GPS) tracking, such as covered distance, speed variations, and acceleration, as well as considering power output and data recorded by accelerometers. The combined approach aims to integrate subjective experience with objective data, allowing for real-time monitoring of athlete performance and facilitating long-term trend analysis, thereby supporting precise adjustments to training plans.

Table 1. Types of Training load and method

Types of load	Method	Role
Internal Load	Rating of Perceived Exertion (RPE)	Assesses training intensity through the athlete's subjective experience, adjusting training plans based on physiological data (Perrey Stephane, 2022; Collette Robertet al., 2018; Anna E. Saw et al., 2015; Saw Anna E et al., 2016).
	Heart Rate (HR)	Monitors the heart's response to training stimuli, serving as an indicator of training intensity (Perrey Stephane, 2022; Saw Anna E et al., 2016).
	Blood Lactate	Measures lactate concentration in the blood to assess the athlete's metabolic state (Collette Robertet al., 2018; Anna E. Saw et al., 2015).
	Oxygen Consumption (VO2)	Assesses aerobic capacity, reflecting the athlete's oxygen utilization at different training intensities (Perrey Stephane, 2022; Fullagar Hugh H K et al., 2015).
External Load	GPS Data (e.g., distance, speed, acceleration)	Provides precise quantification of the athlete's performance during training or competition, such as running distance and acceleration, helping to understand the athlete's load (Collette Robertet al., 2018; Anna E. Saw et al., 2015).

	Power Output	Commonly used in cycling, rowing, and other sports, measures the power produced by the athlete within a specific time period (Perrey Stephane, 2022; Fullagar Hugh H K et al., 2015).
	Acceleration	Uses an accelerometer to monitor speed and movement patterns to estimate the training load (Fullagar Hugh H K et al., 2015).
Combined Internal + External	Load, RPE and Training Distance	Combines subjective perception with actual movement distance, offering a more comprehensive evaluation of training load (Perrey Stephane, 2022; Collette Robertet al., 2018; Anna E. Saw et al., 2015; Saw Anna E et al., 2016).

2.2 Evaluation Indicators for Different Sports

Through a review of the literature, key indicators used to assess training load in specific sports are listed (Table 2). In swimming, the focus is on measuring muscle oxygen saturation, heart rate, and blood lactate concentration. In basketball, the key indicators include the athlete's acceleration, speed, heart rate, and Rating of Perceived Exertion (RPE). These sport-specific indicators integrate both internal and external load measurements, forming a comprehensive system that enables coaches to effectively assess the intensity and condition of an athlete's training.

Table 2. Evaluation Indicators for Different Sports

Sport	Evaluation Indicators	Method (Internal/External/Internal + External)
Swimming	Muscle oxygen saturation, heart rate, lactate level	Internal + External (Perrey Stephane, 2022)
Basketball	Acceleration, speed, heart rate, RPE	External + Internal (Perrey Stephane, 2022)
Canoeing	Muscle oxygen saturation, heart rate	Internal + External (Perrey Stephane, 2022)
Football	Running distance, speed, heart rate	External + Internal (Perrey Stephane, 2022)
Athletics	Power output, heart rate, oxygen consumption	Internal + External (Perrey Stephane, 2022)
Long-distance Running	RPE, heart rate, distance	Internal + External (Perrey Stephane, 2022)

2.3 Training Load Evaluation

The literature review provides insights into the classification of training loads and their evaluation methods, covering internal load, external load, and their combination (Table 3). Internal load evaluation methods include both qualitative and quantitative approaches, such as heart rate, RPE, and blood lactate concentration. External load evaluation focuses mainly on quantitative data, such as acceleration, running distance, and power output. The combined internal and external load evaluation also uses a quantitative approach. By distinguishing these categories, coaches and researchers can better understand how to use multiple methods to quantify and control training load, ultimately optimizing training results.

Table 3. Training Load Evaluation

Load Type	Intervention Duration	Quantitative/Qualitative
Internal Load	Short-term/Long-term	Qualitative + Quantitative (heart rate, RPE, lactate, etc.)
External Load	Short-term/Long-term	Quantitative (acceleration, running distance, power, etc.)
Internal + External Load	Short-term/Long-term	Quantitative

3. Research Results

Based on the collected literature, wearable devices have quantified training load in several aspects: Swimming wearable devices have been used to monitor muscle oxygenation, internal load, sleep quality, recovery, and the importance of subjective self-report measures. Specifically, near-infrared spectroscopy (NIRS) has been found to assist in measuring changes in oxygenated hemoglobin (O2Hb) and deoxygenated hemoglobin (HHb) in the muscles, providing more accurate monitoring of muscle oxygenation levels (Perrey Stephane, 2022).

The subjective rating of perceived exertion (SRPE) can help track the athlete's adaptive response to different training stimuli (Collette Robertet al., 2018), thus offering a better understanding of internal load monitoring.

Subjective self-reports are a form of subjective feedback that can provide insights into the athlete's experiences. While objective physiological data offers critical information, several studies show that subjective self-reports (such as feelings of fatigue and mood) may more accurately reflect the athlete's actual experiences (Anna E. Saw et al., 2015). Self-report measures can better assist in helping athletes.

Good sleep quality is crucial for maintaining high-level athletic performance. Sleep deprivation can impair immune function, affect cognitive performance, and even simulate symptoms of overtraining syndrome (Fullagar Hugh H K et al., 2015). Sleep monitoring tools can help us understand the relationship between sleep quality and recovery.

Regarding the relationship between muscle oxygenation levels and training intensity, scholars like Grassi et al. believe that NIRS measurement represents a simple, safe, reliable, and rapid method for determining the training intensity range based on the metabolic state transition of the working muscles (Perrey Stephane, 2022).

For the relationship between internal training load and recovery-stress state, Collette et al. showed that using both SRPE and the Recovery-Stress State Scale (ARSS) can effectively reveal the connection between these factors (Collette Robertet al., 2018).

In summary, understanding the relationship between muscle oxygenation levels and training intensity requires a focus on the primary muscle groups involved in specific tasks. For the relationship between internal training load and recovery-stress state, we believe that in addition to physiological indicators, psychological factors should be considered, as emotional balance and other factors can also influence the athlete's overall recovery status. Moreover, considering individual athlete differences, personalized training plans are crucial.

4. Research Conclusion

Quantifying training load allows for more effective analysis of athletes' fatigue and training status. Quantified data on heart rate, muscle oxygenation, speed, and other indicators provide precise training feedback, which can optimize training plans and reduce the risk of injury (Perrey Stephane, 2022; Anna E. Saw et al., 2015).

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