

## Strategy for determining physical key performance indicators (KPIs) in rowing to optimize athlete performance

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World Journal of Advanced Research and Reviews, 2026, 29(03), 609-614

Publication history: Received on 27 January 2026; revised on 09 March 2026; accepted on 10 March 2026

Article DOI: <https://doi.org/10.30574/wjarr.2026.29.3.0578>

### Abstract

Rowing is a sport that demands high physical abilities, especially aerobic capacity, muscle strength, and optimal body composition to produce maximum performance. Determining the right physical indicators as Key Performance Indicators (KPIs) is crucial to support the evaluation process and development of athlete training programs. However, information regarding the relationship between physical indicators and body composition with rowing performance in young athletes is still limited. Therefore, this study aims to analyze the relationship between several physical indicators and body composition with rowing performance to determine key performance indicators that can be used to improve rowing athlete performance. This study used a quantitative research design with a cross-sectional study approach. The study subjects consisted of rowing athletes who underwent a series of measurements including anthropometric characteristics, aerobic capacity ( $VO_2\max$ ), muscle strength, muscle explosiveness, flexibility, fat mass, muscle mass, and rowing performance as measured by the time taken in a rowing test. The data obtained were analyzed using a correlation test to determine the relationship between physical indicators and body composition variables with rowing performance. The results showed that  $VO_2\max$ , muscle strength, muscle explosiveness, flexibility, and muscle mass had a significant negative correlation with rowing performance time, indicating that improvements in these variables are associated with improved athlete performance. Conversely, fat mass showed a significant positive correlation with rowing time, indicating that increased fat mass can decrease athlete performance. Overall, these physical and body composition indicators can be used as a basis for determining KPIs to optimize rowing athlete performance through a more targeted training program.

**Keywords:** Rowing Performance;  $VO_2\max$ ; Muscle Strength; Body Composition; Key Performance Indicators

### 1. Introduction

Rowing is a sport that demands an optimal combination of muscular strength, cardiovascular endurance, technical precision, and integrated team strategy [1]. As a sport that relies on physical capacity and collective coordination, rowing requires a scientific approach in the process of evaluating and improving athlete performance [2]. In the context of performance development, determining physical Key Performance Indicators (KPIs) is a crucial component because it functions as an objective parameter to assess athlete readiness, monitor training progress, and identify physical aspects that need improvement [3].

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Rowing is a unique sport because it integrates strength, endurance, and coordination into one complex movement pattern. The speed of a boat in competition depends heavily on the athlete's ability to generate force efficiently with each stroke [4-5]. Therefore, physical KPIs serve as strategic measurement tools to help coaches and athletes focus training on the components that most impact performance.

Some common physical KPIs used in rowing include muscular strength, cardiovascular endurance (VO2 max), flexibility, muscular explosiveness, and body composition [6-7]. Muscle strength particularly in the back, shoulders, and legs is often measured through one-repetition maximum (1RM) tests and has been shown to correlate positively with boat speed [1, 8-9]. Cardiovascular endurance, measured through VO2 max tests or alternatives such as the beep test, is a key determinant of performance in middle- to long-distance events [10-11].

Furthermore, flexibility, as measured by the sit and reach test, contributes to movement efficiency and reduces the risk of injury. Muscular power, as assessed by the vertical jump test, plays a crucial role in the initial phase of the stroke, particularly in generating maximum power in a short period of time. Body composition including fat percentage and muscle mass also influences the strength-to-weight ratio, which directly impacts an athlete's performance.

Although these indicators have been widely used, there is still variation in the practice of determining and measuring them at various levels of competition [12-13]. This condition indicates the need for a comprehensive evaluation to determine the most relevant, valid, and applicable physical KPIs. Therefore, this study aims to evaluate and determine the most effective physical KPIs for rowing athletes based on a synthesis of the latest scientific evidence to support the standardization of coaching systems and the continuous optimization of athlete performance.

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## **2. Material and methods**

### **2.1. Study Design**

This study used a quantitative design with a descriptive-correlational approach to identify and define the physical Key Performance Indicators (KPIs) most relevant to rowing athlete performance. This approach aimed to analyze the relationship between physical condition components and actual athlete performance indicators.

### **2.2. Participants**

Participants in this study were national-level competitive rowing athletes who actively participated in a structured training program organized by the KONI East Java (Indonesia). Inclusion criteria included: (1) athletes aged 15–19 years, (2) having at least 2 years of training experience, and (3) being in good health and injury-free during the data collection period. All participants provided written informed consent before the study was conducted.

### **2.3. Data Collection Procedures**

Data collection was conducted during the competition preparation phase under controlled conditions. Prior to the test, all participants underwent a standard warm-up procedure for 10–15 minutes to minimize the risk of injury and ensure physical readiness. Physical variables measured in this study included muscle strength, cardiovascular endurance, muscular explosive power, flexibility, and body composition. Muscle strength was measured using a one-repetition maximum (1RM) test on the bench pull movement. Cardiovascular endurance was measured using a VO2 max test using a rowing ergometer with a graded exercise test protocol. Muscle explosive power was measured using a vertical jump test, flexibility was assessed using a sit and reach test, and body composition was analyzed using the bioelectrical impedance analysis (BIA) method to obtain body fat percentage and muscle mass. Rowing performance, as the dependent variable, was measured through a simulated 2000-meter run time using a standard competition ergometer.

### **2.4. Statistical Analysis**

Data were analyzed using statistical software (SPSS version 21). Descriptive statistical tests were used to describe participant characteristics. Pearson's correlation test was used to determine the relationship between physical variables and rowing performance. Furthermore, multiple linear regression analysis was performed to identify the most significant physical variables in predicting performance. The significance level was set at  $p < 0.05$ .

### 3. Results and discussion

**Table 1** Descriptive Statistics of Anthropometric and Physical Performance Variables of Rowing Athletes

Parameters	Minimum	Maximum	Mean	Std. Deviation
Age (yrs)	15.00	19.00	17.20	1.47
Weight (kg)	63.00	81.00	70.91	6.86
Hight (m)	1.57	1.80	1.68	0.05
Body Mass Index (kg/m <sup>2</sup> )	21.55	27.66	24.92	1.84
Rowing Performance (min)	6.43	8.55	7.62	0.72
VO <sub>2</sub> max (mL/kg/min)	24.22	71.15	48.74	13.54
Muscle Strength (kg)	35.00	90.00	58.33	19.24
Muscle Explosive Power (cm)	39.00	63.00	49.33	8.61
Flexibility (cm)	10.00	28.00	17.60	6.01
Fat Mass (kg)	6.16	31.83	17.86	7.89
Muscle Mass (kg)	20.91	33.63	26.01	4.18

Based on the results of the descriptive analysis of the characteristics of rowing athletes, a general overview of the physical profile and performance capacity of the athletes who were the subjects of the study was obtained (Table 1). The age of the athletes was in the range of 15–19 years with an average value of  $17.20 \pm 1.47$  years. The weight of the athletes ranged from 63–81 kg with an average of  $70.91 \pm 6.86$  kg. Meanwhile, the height of the athletes was in the range of 1.57–1.80 m with an average value of  $1.68 \pm 0.05$  m. The Body Mass Index (BMI) of the athletes showed an average value of  $24.92 \pm 1.84$  kg/m<sup>2</sup> with a range of 21.55–27.66 kg/m<sup>2</sup>, which indicates a relatively proportional body composition condition for rowing sports activities.

From the physical performance aspect, the rowing performance test results showed that the travel time ranged from 6.43 to 8.55 minutes with an average value of  $7.62 \pm 0.72$  minutes. Aerobic capacity measured through VO<sub>2</sub>max showed a fairly wide range of values, namely 24.22–71.15 mL/kg/minute with an average of  $48.74 \pm 13.54$  mL/kg/minute, which reflects the variation in cardiovascular endurance levels among athletes.

The components of muscle strength and explosive power also showed significant variation. Muscle strength had a minimum value of 35.00 kg and a maximum of 90.00 kg with an average of  $58.33 \pm 19.24$  kg. Meanwhile, muscle explosive power ranged from 39–63 cm with an average value of  $49.33 \pm 8.61$  cm. Athletes' flexibility ranged from 10–28 cm with an average of  $17.60 \pm 6.01$  cm.

In terms of body composition, the athletes' fat mass ranged from 6.16 to 31.83 kg with an average value of  $17.86 \pm 7.89$  kg, while muscle mass ranged from 20.91 to 33.63 kg with an average of  $26.01 \pm 4.18$  kg. Overall, the results of this descriptive analysis indicate that athletes have varying physical and physiological characteristics, which are an important basis in determining physical Key Performance Indicators (KPIs) in rowing to optimize athlete performance. The correlation test between variables is presented in Table 2.

**Table 2** Correlation Between Physical Indicators and Body Composition Variables with Rowing Performance

Parameters	Rowing Performance (min)	
	<i>r</i>	<i>p-value</i>
VO <sub>2</sub> max (mL/kg/min)	-0.961**	0.001
Muscle Strength (kg)	-0.886**	0.001
Muscle Explosive Power (cm)	-0.698**	0.001
Flexibility (cm)	-0.782**	0.001
Fat Mass (kg)	0.722**	0.001
Muscle Mass (kg)	-0.946**	0.001

The results of the study showed that  $VO_2\text{max}$  had a very strong negative correlation with rowing performance ( $r = -0.961$ ;  $p = 0.001$ ). This indicates that the higher the athlete's aerobic capacity, the faster the time produced in the rowing test.  $VO_2\text{max}$  capacity is a primary indicator of the ability of the cardiovascular and respiratory systems to deliver oxygen to the muscles during high-intensity activity. In rowing, which is dominated by the aerobic energy system,  $VO_2\text{max}$  capacity is a major determinant in maintaining energy production during the race. Research on rowing athletes shows that  $VO_2\text{max}$  is one of the most important physiological parameters in determining performance in ergometer tests and rowing competitions because it is directly related to the ability to produce aerobic energy during sustained activity [14]. In addition, longitudinal research on elite rowing athletes also shows that increases in physiological parameters such as aerobic capacity and power output during long-term training are associated with improved performance in the 2000 m and 6000 m rowing tests [15]. This strengthens the findings of this study that high aerobic capacity is very important in increasing muscle work efficiency during rowing activities.

Muscle strength showed a strong negative correlation with rowing performance ( $r = -0.886$ ;  $p = 0.001$ ). This result indicates that athletes with higher muscle strength tend to produce faster rowing times. In rowing, muscle strength, especially in the lower extremities, back, and arms, is crucial for generating propulsive force during each stroke phase. Muscle strength enables athletes to generate greater power with each stroke, thereby increasing movement efficiency and boat speed. Furthermore, muscle explosive power also showed a significant negative correlation with rowing performance ( $r = -0.698$ ;  $p = 0.001$ ). This suggests that the ability to generate force quickly plays a role in increasing initial acceleration and movement efficiency during the stroke. In rowing, the combination of strength and speed of muscle contraction is crucial for producing optimal power output during the drive phase of the rowing cycle. Similarly, flexibility showed a significant negative correlation with rowing performance ( $r = -0.782$ ;  $p = 0.001$ ). Good flexibility allows athletes to achieve a more optimal range of motion throughout the stroke cycle, particularly during the catch and finish phases. Optimal range of motion can increase stroke length and biomechanical efficiency, contributing to improved performance.

On the other hand, fat mass showed a positive correlation with rowing time ( $r = 0.722$ ;  $p = 0.001$ ), which means that the higher an athlete's fat mass, the lower their rowing performance tends to be. Body composition is an important factor in rowing because excess fat mass can increase body weight without contributing to power production. Recent research has shown that body composition, such as body fat percentage, is related to aerobic capacity and physical performance of athletes, where increased body fat can reduce physiological efficiency during sports activities [16]. Conversely, muscle mass showed a very strong negative correlation with rowing performance ( $r = -0.946$ ;  $p = 0.001$ ). This indicates that the greater the muscle mass an athlete has, the better the resulting performance. Muscle mass directly contributes to the ability to produce strength and power during rowing activities. Research on adolescent rowers also shows that fat-free mass (lean body mass) is an important predictor of  $VO_2\text{max}$  values and performance capacity of rowers [17].

Overall, the results of this study indicate that physiological factors and body composition, such as  $VO_2\text{max}$ , muscle strength, muscle explosiveness, flexibility, fat mass, and muscle mass, are significantly related to rowing performance. These findings suggest that these indicators can be used as Key Performance Indicators (KPIs) in the evaluation and development of training programs for rowing athletes to optimize athlete performance.

This study has several limitations that should be considered when interpreting the results. The relatively limited sample size and its limited age group may limit the generalizability of the results to a broader population of rowing athletes. Furthermore, the cross-sectional study design only describes the relationships between variables at a single measurement point and therefore cannot directly explain cause-and-effect relationships. This study also focused only on a few physical indicators, while other factors potentially influencing rowing performance, such as biomechanics, rowing technique, psychological factors, and athlete training programs, have not been comprehensively analyzed. Therefore, future research is recommended to involve larger samples, use longitudinal or experimental designs, and consider additional variables to gain a more comprehensive understanding of the factors influencing rowing performance.

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#### 4. Conclusion

This study shows that several physical indicators have a significant relationship with rowing performance, namely  $VO_2\text{max}$ , muscular strength, muscular explosiveness, flexibility, fat mass, and muscle mass.  $VO_2\text{max}$ , muscular strength, muscular explosiveness, flexibility, and muscle mass showed a negative correlation with rowing performance time, which means that an increase in these variables contributes to improved athlete performance. Conversely, fat mass showed a positive correlation with rowing time, which indicates that an increase in fat mass tends to decrease performance. These findings suggest that these physical indicators can be used as a basis for determining Key Performance Indicators (KPIs) to optimize rowing athlete performance. Future research is recommended to involve a

larger sample size, use a longitudinal or experimental research design, and integrate other variables such as biomechanical factors, rowing technique, and other physiological aspects to obtain a more comprehensive understanding of the factors that influence rowing athlete performance.

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## Compliance with ethical standards

### *Acknowledgments*

The author would like to express his gratitude to the Faculty of Sport and Health Sciences (FIKK), State University of Surabaya (UNESA) for the funding support for this research through the 2025 Faculty Assignment scheme.

### *Disclosure of conflict of interest*

The authors declare no competing interests in this study.

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