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Investigating the Relationship Between Body Composition, Aerobic Capacity, and Cardiac Responses in Athletes

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Abstract

Body composition is a key determinant of athletic performance, influencing both aerobic and anaerobic energy systems. Understanding the relationship between body composition variables and physiological indicators such as aerobic capacity and heart rate responses is essential for optimizing training programs and improving athletic efficiency.
Objective: This study aimed to investigate the relationship between body composition components—including body fat percentage (FATP), fat mass (FATM), fat-free mass (FFM), total body water (TBW), and predicted muscle mass (PPM)—and both aerobic capacity and heart rate responses in a sample of athletes.
Methods: A descriptive-analytical research design was adopted. The purposive sample consisted of 10 male athletes aged 19–24 years, regularly engaged in physical activity. Anthropometric measurements were performed using a Body Composition Analyzer (TANITA), while aerobic capacity was assessed via the Sharkey test on a treadmill. Heart rate responses during exercise were monitored using a Polar H10 device. Pearson's correlation coefficient was applied to determine the relationships between body composition variables, aerobic capacity, and heart rate, with statistical significance set at $p \leq 0.05$.
Results: The results revealed very strong and statistically significant positive correlations between FFM ($r = 0.990$, $p = 0.001$), TBW ($r = 0.991$, $p = 0.001$), and PPM ($r = 0.988$, $p = 0.002$) with aerobic capacity. However, FATP and FATM showed positive but non-significant correlations. No significant relationships were found between any body composition variables and heart rate responses during exercise.
Conclusions: Fat-free mass, muscle mass, and hydration status are critical predictors of aerobic performance in athletes. Training programs should prioritize improving these components to enhance oxygen utilization and endurance capacity.

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Introduction

Sports training is considered a multidimensional process aimed at developing physical and psychological capacities by inducing targeted physiological adaptations. With the evolution of performance concepts in modern sports, the focus is no longer limited to increasing training intensity or volume. It has become essential to integrate individual body composition and functional characteristics into training plans to achieve optimal adaptation [1.[

Body composition, including body fat percentage, muscle mass, and total body water, is among the key factors influencing the efficiency of energy systems, particularly the aerobic system. Studies have shown that athletes with lower body fat percentages and appropriate muscle mass achieve better results in aerobic endurance tests, such as VO_2max and the Cooper test [2][3]. For instance, one study [4] reported that a 5% reduction in body fat was associated with a 7–10% increase in VO_2max among long-distance runners.

On the other hand, while increased muscle mass contributes to enhancing anaerobic performance, it may negatively affect aerobic efficiency if there is an imbalance between cardiac strength and active muscle mass. This was highlighted in a study [5] analyzing the performance of bodybuilders during endurance activities. Total body water, meanwhile, plays a vital role in oxygen transport, thermoregulation, and biochemical reactions during physical exertion. Research has indicated that even a 2% decrease in total body water can reduce aerobic performance by up to 10% [6.[

Given these considerations, it is crucial to investigate the relationship between body composition and both aerobic capacity and functional cardiac indicators, such as heart rate during exercise, recovery, and at rest. Body composition represents more than superficial measurements; it is a direct reflection of metabolic status, cardiovascular and respiratory efficiency, and the muscular system's ability to sustain effort. Understanding this relationship can pave the way for the development of highly tailored training programs that account for individual physiological differences, moving beyond generic approaches that may not suit all athletes.

Furthermore, a comprehensive analysis of this relationship contributes to optimizing sports nutrition and prioritizing goals during different phases of athletic preparation. For example, an athlete experiencing an imbalance between muscle mass and body fat may require nutritional or training interventions to restore this balance, thereby improving VO_2max or reducing excessive cardiac responses to exercise stress. Therefore, this study is significant in providing a scientific model that coaches and performance specialists can use to design more effective training plans, reduce injury risks, and enhance long-term athletic performance [1][7].

2. Methodology

This study employed a descriptive-analytical approach, which was deemed appropriate for the nature of the research aiming to analyze the relationship between selected physiological and physical variables among athletes. Specifically, the study focused on examining the association between body composition (body fat percentage, muscle mass, and total body water), aerobic capacity, and cardiac indicators during exercise.

Study Sample

A purposive sampling technique was used to select the study sample from athletes within the original population. The sample consisted of 10 participants aged between 19 and 24 years, all of whom were in good health and had at least two years of experience in regular physical activity. Care was taken to ensure homogeneity among participants with respect to key variables such as age, sex, and body composition, in order to minimize variability that might affect the outcomes of the correlation analysis.

Homogeneity of the Study Sample

The homogeneity of the sample was verified across the key variables (age, height, weight, and BMI) using the skewness coefficient. Table (1) presents the results:

Table (1) Means, Standard Deviations, and Skewness Coefficients for the Study Sample.

Variable	Mean	Standard Deviation	Skewness Coefficient
Age (years)	23.40	1.34164	-0.166
Height (cm)	170.20	2.77489	0.009
Weight (kg)	67.82	5.91244	0.080
BMI (kg/m^2)	23.40	1.30958	-0.001

As shown in Table (1), the study sample demonstrated homogeneity across the variables of age, height, weight, and BMI. The skewness coefficients ranged between -0.166 and 0.080, which fall within the acceptable range (-3 to +3), indicating no substantial deviations or extreme values in the data. This confirms the normal distribution and suitability of the sample for subsequent statistical analyses.

Ethical Considerations

All ethical aspects related to conducting the study were carefully observed. The research objectives and procedures were clearly explained to all participants prior to data collection, and written informed consent was obtained to confirm their voluntary participation and willingness to be involved. Confidentiality of personal information was strictly maintained, ensuring that data were used solely for scientific purposes without disclosing participants' identities. Additionally, participants were given full freedom to withdraw from the study at any point without any repercussions. All steps were carried out in accordance with internationally recognized ethical standards for human studies and the principles of the Declaration of Helsinki.

Instruments and Data Collection Tools

This study utilized a range of instruments and tools to ensure accurate and objective data collection. Initially, a content analysis was performed by reviewing previous literature and studies addressing the relationship between body composition and both aerobic and anaerobic capacities, thereby strengthening the theoretical framework of the research. Field tests were then conducted to assess aerobic capacity using the Sharkey test, which measures cardiorespiratory endurance in participants.

In addition, body composition assessments were carried out using a Body Composition Analyzer, which provided precise measurements of fat percentage, muscle mass, and total body water. A medical-grade scale (TANITA) was used to measure participants' body weight and height with high accuracy. A measuring tape was employed to determine distances for the field tests, and a motorized treadmill equipped with a heart rate sensor (Polar H10) was utilized to monitor heart rate during exercise. Finally, an electronic stopwatch was used to manage test timing and ensure procedural accuracy.

Specifications of Measurements and Tests

The study employed both body composition measurements and physical performance tests following rigorous scientific standards. For anthropometric assessments, participants' weight and height were measured using a TANITA scale, with each participant standing barefoot on the device while wearing lightweight sportswear to ensure accuracy. Measurements were recorded automatically by the device. Subsequently, the Body Composition Analyzer was used to analyze the proportions of body fat, muscle mass, and water content, providing the researchers with detailed data to create an accurate profile of each participant's body composition.

Regarding performance testing, the Sharkey test was implemented to evaluate aerobic capacity and monitor heart rate during exertion. This test is widely recognized as a reliable method for assessing cardiorespiratory fitness under continuous workload conditions. The procedure was conducted as described below, with heart rate data recorded using precise monitoring devices throughout the stages of the test.

Sharkey Test for Assessing Aerobic Capacity

The Sharkey Test was adopted to evaluate the aerobic capacity of the study participants. This test is considered a highly precise physiological assessment used to determine the efficiency of the cardiorespiratory system during a progressively increasing workload. The test is based on incrementally increasing physical demands by adjusting both the treadmill's incline and running speed.

The test consists of two consecutive stages. In the first stage, the treadmill speed is fixed at 12.8 km/h, while the incline is increased by 1% every minute, starting from 4% and reaching 10% by the seventh minute. In the second stage, the incline is fixed at 11%, and the speed is increased by 1.6 km/h every minute, reaching the treadmill's maximum speed of 22.4 km/h at the fourteenth minute. If the participant does not reach voluntary exhaustion at this point, the incline is increased by an additional 1% per minute until the treadmill reaches its maximum incline of 15%, and the participant continues running until maximal exhaustion is achieved [8].

A motorized treadmill equipped with adjustable speed and incline settings was used for this test. Heart rate responses were monitored continuously using a Polar H10 device to record cardiac responses during the different stages of the test.

The table below illustrates the workload progression in the Sharkey Test:

Table (2): Workload Stages in the Sharkey Test [8]

Stage	Incline (%)	Speed (km/h)	Minute	Stage	Incline (%)	Speed (km/h)	Minute
First	4	12.8	1	Second	11	14.4	8
	5	12.8	2		11	16.0	9
	6	12.8	3		11	17.6	10
	7	12.8	4		11	19.2	11
	8	12.8	5		11	20.8	12
	9	12.8	6		11	22.4	13

Pilot Study

A pilot study was conducted on April 13, 2025, involving a group of athletes from the target population. The purpose of this pilot was to ensure the feasibility and reliability of the instruments and field procedures before implementing the main study. Specifically, the pilot aimed to evaluate the applicability of the Sharkey Test for assessing aerobic capacity among participants and to test the accuracy and usability of the Body Composition Analyzer for measuring fat percentage, muscle mass, and total body water. The pilot was carried out under the same conditions and resources allocated for the main study. Participants involved in the pilot were excluded from the primary sample to maintain the accuracy and validity of the main study procedures.

Field Procedures

The field procedures followed a structured sequence of steps, beginning with sample selection, continuing through anthropometric and performance assessments, and concluding with data analysis.

Initially, the primary sample of 10 athletes was selected purposively from students in the Department of Physical Education and Sports Sciences, based on specific inclusion criteria. These included regular engagement in physical activity and having a moderate body composition in terms of fat percentage, muscle mass, and total body water, to ensure suitability for investigating the relationships between the targeted variables.

On April 20, 2025, initial anthropometric measurements were conducted using a Body Composition Analyzer to determine fat percentage, muscle mass, and total body water, in addition to measuring height and body weight. Participants were instructed to fast for at least ten hours prior to testing to eliminate potential dietary or hydration effects on the results, particularly regarding subcutaneous water levels, which could directly influence the accuracy of the measurements [9].

On April 24, 2025, the Sharkey Test was administered to all participants to evaluate aerobic capacity and record heart rate responses during exercise. The procedures followed those detailed in Appendix 1, utilizing a motorized treadmill and a Polar H10 heart rate monitor for precise data collection.

In the final stage of the fieldwork, statistical analyses were performed using SPSS software. Pearson's correlation coefficient (Pearson's r) was calculated to examine the relationships between body composition variables (fat, muscle, water) and the dependent variables: aerobic capacity and heart rate. A significance level of $P \leq 0.05$ was adopted as the threshold for accepting or rejecting the study hypotheses.

Statistical Methods

A set of statistical methods was employed to analyze and interpret the data accurately and scientifically. The mean and standard deviation were calculated to describe the characteristics of the sample and assess the variability around the central tendency. The skewness coefficient was determined to verify the normality of data distribution and ensure its suitability for parametric analyses. Finally, Pearson's correlation coefficient was used to assess the relationships between body composition variables (fat, muscle, and water) and both aerobic capacity and heart rate.

Results

Table (3) presents the means and standard deviations for the Sharkey test, heart rate, and body composition variables. It also shows the Pearson correlation coefficients and the significance levels for the study sample.

Variable	**auditions**		**Body Components**		**R**	**Sig**
	$\bar{x}$	St.D	$\bar{x}$	St.D		
Fat percentage) (percentage)						
Achievement in a Participant Test (min)	6.8760	0.84243	17.0400	4.30790	0.723	0.167
Heart rate (beat/minute)	194.2000	7.19027			0.328	0.590
Fat Weight (kg)						

Achievement in a Participant Test (min)	6.8760	0.84243	11.7400	3.92912	0.768	0.130
Heart rate (beat/minute)	194.2000	7.19027			0.277	0.652
Grease-free weight (ffm) (kg)						
Achievement in a Participant Test (min)	6.8760	0.84243	56.0800	2.29281	0.990**	*0.001
Heart rate (beat/minute)	194.2000	7.19027			-0.148	0.812
Water Weight (Tbw) (kg)						
Achievement in a Participant Test (min)	6.8760	0.84243	41.0600	1.66373	0.991**	*0.001
Heart rate (beat/minute)	194.2000	7.19027			-0.143	0.818
Muscle weight (ppm) (kg)						
Achievement in a Participant Test (min)	6.8760	0.84243	53.5600	2.07918	0.988**	*0.002
Heart rate (beat/minute)	194.2000	7.19027			-0.133	0.831

Note: $p \leq 0.05$ indicates statistical significance.

The data in Table (3) reveal significant correlations between the Sharkey test results, as an indicator of aerobic capacity, and certain body composition variables, specifically Fat-Free Mass (FFM), Total Body Water (TBW), and Predicted Muscle Mass (PPM). The significance levels for these variables were below 0.05, indicating statistically significant relationships that highlight the influence of these components on aerobic performance efficiency.

In contrast, body fat percentage (FATP) and fat mass (FATM) did not demonstrate significant correlations with the Sharkey test results, as their p-values exceeded 0.05. This suggests the absence of strong statistical relationships between these fat-related indicators and aerobic endurance performance.

Regarding heart rate responses during exercise, no significant correlations were observed with any of the body composition variables studied, including FATP, FATM, FFM, TBW, and PPM. All p-values exceeded the threshold of 0.05, indicating that cardiac responses during exercise were not directly associated with body composition within this athlete sample.

Overall, Table (3) provides insights into the potential relationships between body composition metrics (e.g., body fat percentage, fat mass, fat-free mass, muscle mass, and total body water) and performance indicators (Sharkey test and heart rate). These relationships will be further analyzed and discussed in detail in the following section to interpret their physiological implications.

Relationships Between Body Composition Variables and Aerobic Performance

1. **Relationship Between Body Fat Percentage (FATP) and Aerobic Performance**

The statistical analysis revealed a positive correlation between body fat percentage and Sharkey test results ($r = 0.723$); however, this relationship was not statistically significant ($p = 0.167 > 0.05$). This suggests a lack of statistical evidence supporting a meaningful association, despite the positive trend observed. Similarly, a weak correlation was found between body fat percentage and heart rate during exercise ($r = 0.328$), which was also not statistically significant ($p = 0.590 > 0.05$). These findings indicate that body fat percentage may not be a reliable predictor of aerobic performance or cardiac responses to exercise within this sample, potentially due to the small sample size or homogeneity of values among participants.

2. **Relationship Between Fat Mass (FATM) and Aerobic Performance**

The results showed a positive correlation between fat mass and Sharkey test performance ($r = 0.768$); however, this correlation was not statistically significant ($p = 0.130 > 0.05$). Likewise, the correlation between fat mass and heart rate during exercise was weak and not significant ($r = 0.277$, $p = 0.652$). These findings suggest that minor variations in fat mass within the healthy range for athletes did not negatively affect aerobic performance or cardiac responses and may not have been sufficient to establish a strong relationship, likely due to limited variability in the sample.

3. **Relationship Between Fat-Free Mass (FFM) and Aerobic Performance**

A very strong and statistically significant correlation was observed between fat-free mass and Sharkey test results ($r = 0.990$, $p = 0.001$), indicating that higher fat-free mass—including muscles, bones, and water—is strongly associated with improved aerobic capacity. In contrast, no significant relationship was found between FFM and heart rate during exercise ($r = -0.148$, $p = 0.812$). These results suggest that fat-free mass effectively contributes to enhanced oxygen utilization efficiency but does not necessarily influence immediate cardiac responses during physical exertion.

4. **Relationship Between Total Body Water (TBW) and Aerobic Performance**

Total body water exhibited a very strong positive correlation with Sharkey test performance ($r = 0.991$, $p = 0.001$), highlighting the crucial role of proper hydration in optimizing aerobic performance by maintaining blood volume and metabolic balance during exercise. Conversely, no significant relationship was observed between TBW and heart rate ($r = -0.143$, $p = 0.818$), indicating that body water content does not directly influence heart rate during exertion, although it plays a clear role in sustaining overall endurance.

5. Relationship Between Predicted Muscle Mass (PPM) and Aerobic Performance

Predicted muscle mass showed a very strong positive correlation with Sharkey test results ($r = 0.988$, $p = 0.002$), supporting the role of muscle mass in enhancing aerobic capacity and energy production efficiency during continuous exercise. In contrast, no significant correlation was observed between muscle mass and heart rate during exercise ($r = -0.133$, $p = 0.831$). These findings indicate that muscle mass is one of the strongest body composition factors influencing aerobic performance, though it does not directly affect immediate cardiac responses under physical stress.

Discussion

The statistical analysis revealed a very strong and statistically significant correlation between predicted muscle mass (PPM) and aerobic performance, as assessed by the Sharkey test ($r = 0.988$, $p = 0.002$). This represents one of the highest correlation values observed in the study. This finding suggests that increased muscle mass serves as a highly valuable physiological indicator for enhancing aerobic performance in athletes through multiple mechanisms that integrate muscular architecture, mitochondrial capacity, and oxygen utilization efficiency at the cellular level.

From a physiological perspective, muscle mass plays a pivotal role in increasing the body's ability to consume oxygen (VO_2max), as skeletal muscles are the primary consumers of oxygen during physical activity. The greater the structural efficiency of these muscles (in terms of size, fiber type, and capillarization), the greater the body's capacity to generate aerobic energy [10,11]. The literature highlights that athletes with higher muscle mass, particularly those with a predominance of type I (slow-twitch) fibers, demonstrate superior abilities to extract oxygen from circulating blood and utilize it for energy production through the Krebs cycle, which directly translates into improved aerobic performance [12].

Additionally, regular endurance training enhances capillary density surrounding muscle fibers and increases the activity of oxidative enzymes such as citrate synthase and succinate dehydrogenase, thereby improving the oxidative capacity of muscles. This adaptation is particularly critical in sports requiring sustained effort, such as marathon running, rowing, and swimming [13]. Consequently, athletes with active and well-balanced muscle mass are better equipped to sustain high levels of performance for extended periods before fatigue sets in.

On the other hand, the study found no significant correlation between predicted muscle mass and heart rate during exercise (r = -0.133, p = 0.831). This suggests that cardiac responses during physical exertion are not directly dependent on muscle mass but are influenced more by regulatory factors such as stroke volume, autonomic nervous system balance (sympathetic and parasympathetic activity), cardiac efficiency, and psychological influences [14]. In other words, individuals with higher muscle mass may still maintain a moderate heart rate during exercise due to efficient circulatory adaptations, which explains the absence of a direct positive relationship between these variables in the current study.

Comparative studies indicate that athletes in endurance sports, such as long-distance running and cycling, display a clear balance between muscle mass and respiratory system efficiency. Aerobic performance depends on achieving an optimal threshold of muscle mass without developing hypertrophy that could compromise oxygen economy [15]. This balance is essential, as excessive increases in muscle mass may lead to elevated oxygen demands without a proportional improvement in aerobic capacity, a phenomenon referred to as the “Unnecessary Mass Hypothesis” [16].

Therefore, predicted muscle mass can be considered a central indicator for determining aerobic performance levels. It should be incorporated into athlete assessments and training load planning, with an emphasis on recognizing that efficiency depends not only on muscle size but also on fiber type distribution, oxidative capacity, and integration with cardiovascular and respiratory systems. These findings underscore the importance of including precise body composition assessments in training programs and periodic evaluations, particularly for athletes aiming to improve aerobic capacity without compromising movement economy.

Conclusions

- The statistical analysis revealed a very strong and statistically significant positive correlation between fat-free mass (FFM) and aerobic performance, as measured by the Sharkey test. This finding underscores the critical role of both active muscle mass and internal hydration levels in supporting oxygen consumption processes and enhancing the efficiency of continuous aerobic activities.
- Although positive correlations were observed between body fat percentage (FATP) and fat mass (FATM) on the one hand, and aerobic performance on the other, these relationships were not statistically significant. This suggests that fat levels within the healthy range for athletes do not pose a barrier to aerobic performance and may even be neutral or supportive in certain cases, provided they remain within physiologically acceptable limits.
- The study found no significant relationships between body composition variables (fat, muscle, and water) and heart rate responses during exercise, indicating that cardiac responses to physical exertion are more influenced by regulatory factors such as cardiorespiratory fitness, neuromuscular adaptations, and general training status, rather than body composition alone.

Recommendations

- Training programs should be specifically designed to target the enhancement of body composition components that significantly impact aerobic performance, particularly muscle mass and total body water, tailored to the demands of each sport and the athlete’s performance level.
- Incorporate resistance training regularly into aerobic endurance programs, as it effectively increases muscle mass and improves the body’s ability to utilize oxygen efficiently during prolonged activities.
- Emphasize the importance of monitoring hydration status, especially before and during physical activity, particularly in endurance sports and long-duration aerobic events. Maintaining optimal hydration is essential for supporting performance, reducing fatigue, and facilitating effective recovery.
- Advise male athletes to maintain a body fat percentage between 10–20%, a range considered physiologically ideal for supporting physical performance without compromising endurance or imposing excessive functional load on the body.

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