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The Impact of Cardiorespiratory and Metabolic Parameters on Match Running Performance (MRP) in National-Level Football Players: A Multiple Regression Analysis

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Abstract: The aim of the study was to examine the association between cardiorespiratory and metabolic parameters and match running performance (MRP) in highly trained football players. The sample of participants consisted of 41 national-level football players (aged 23.20 ± 3.40 years, body height 182.00 ± 5.15 cm, and body mass 76.86 ± 6.06 kg) from the Serbian Super league. For the purposes of this research, the following measurements were applied. A maximal multistage progressive treadmill test, with a direct measurement of maximal oxygen consumption (VO_2max) (using Fitmate MED, Cosmed, Rome, Italy) was conducted, alongside continuous heart rate monitoring. Capillary blood samples were taken from the hyperemic area using specific test strips, and, after sample collection, lactate concentration was immediately determined using a lactate analyzer. MRP variables were analyzed according to the BioIRC model of motion structure analysis, based on existing standards for profiling movement intensity. The results of multiple regression analysis indicated an association between cardiac parameters and total distance (R2 = 54.3%, p = 0.000), high-speed running (R2 = 46.4%, p = 0.000), and jogging (R2 = 33.6%, p = 0.004). Regression analysis revealed an association between cardiorespiratory parameters and total distance (R2 = 24.8%, p = 0.014), and high-speed running (R2 = 20%, p = 0.039). Meanwhile, no association was found between lactate concentration and running performance. The explanation for these regression analysis results is based on the observation that functional abilities represent significant potential for expressing movement performance, a crucial condition for success in football.

Keywords: physical performance; cardiovascular endurance; lactate concentration; maximal heart rate; professional soccer players; running performance analysis; VO_2max

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1. Introduction

In recent years, the demands of modern football have changed, increasing significantly, and this trend certainly continues day after day [1]. Football, as a characteristic intermittent sport, requires players to execute multiple activities that require agility, strength, speed, balance, stability, flexibility, and endurance, implying that the physical conditioning of players is an extremely complex procedure [2]. In terms of training application, modern football and growing demands impose the need for the highest quality professional and scientific approach [3]. In competitive conditions of top-level football play, it is necessary to have high levels of functional abilities to adequately respond to the physical and technical/tactical demands of the game, including the ability to perform a large number of high-intensity movements, delay the onset of fatigue, and mitigate its impact on efficiency in the game [4,5].

Measurements in football show that both the aerobic and anaerobic pathways of metabolism make significant contributions to match performance [6]. During a football game, the aerobic energy system provides approximately 90% of the energy. In this regard, elite football players must have high aerobic endurance fitness to play for 90 min and recover between high-intensity sprints [7]. One of the best measures of cardiorespiratory fitness and endurance capacity performance is the maximal aerobic power, denoted by VO_2max [8]. Generally speaking, maximal oxygen consumption (VO_2max) represents the maximum work rate at which the body can absorb and use oxygen when engaging in maximal exercise. Given the demands of team sports, such as the ability to change direction during high-intensity running, the primary focus for players should be on endurance and metabolic conditioning [9].

Working muscle oxygen deficiency is thought to be a controlling factor in the metabolic alterations that lead to the depletion of muscle glycogen stores and the suppression of glycolytic enzyme activity. This is thought to be one of the main causes of the decline in efficiency and, consequently, the emergence of indicators of muscular tiredness [10]. The VO_2max of elite soccer players is typically between 50 and 75 mL/kg/min, but different values higher than 70 mL/kg/min have been identified [11].

During competitive matches, professional players typically operate at approximately 80–90% of their maximum heart rate, which corresponds to approximately 75–80% of the VO_2max [12]. Increasing VO_2max is believed to enhance players' tactical and technical performance by 7%. Additionally, this implies more efficient ball contacts and a greater number of longer sprints during a game, which increases the likelihood of scoring a goal [13]. It has been confirmed that leading football teams in the league have higher VO_2max values compared to weaker teams [14]. Therefore, the efficiency of the cardiorespiratory system is considered one of the most crucial components of the physical readiness of football players [5].

The match running performance (MRP) of football players has been the focus of researchers in recent years [15,16]. It has been established that, in professional football, players can cover total distances ranging from 9 to 14 km during matches, of which 5–15% are covered by high-intensity running [17]. Two important energy components determine energy expenditure in the game: the way players move and the way they control the ball. The energy expenditure of forward running is lower than that of backward and lateral running [18,19]. A football match's progression is typically associated with a gradual decline in the speed of runs, a fall in the number of sprints, and a shortening of the distance covered at maximum speed, especially in the later part of the game [20]. The culprit of this decrease in speed and in the frequency of sprints has been identified as a sharp decrease in glycogen in the working muscles of the players as the match moves forward. This viewpoint is supported by an increase in the blood lactate of players in the latter stages of matches [21]. More rapid elimination of lactate from the blood as the game progresses is a significant concern because it determines, at least in part, how quickly an athlete will become fatigued [22]. Working muscle oxygen deficiency is thought to be a regulatory factor in the metabolic changes that cause the depletion of muscle glycogen resources and the inhibition of glycolytic enzyme activity. A greater lactate threshold indicates that a player can maintain greater average intensity in a task without lactate accumulation [21].

Anaerobic threshold (AT) and VO_2max measurements are frequently used to assess aerobic fitness. It is important to note that players with higher values of VO_2max during high-intensity activities achieve lower blood lactate concentrations compared to players with lower VO_2max values [23]. The majority of the published studies on the relationship between lactate threshold and endurance have shown a strong correlation, indicating that training-induced improvements in cardiorespiratory endurance are significantly associated with improvements in lactate threshold [24,25]. While outdoor tests can be used to indirectly evaluate both VO_2max and AT, laboratory treadmill testing provides the most reliable measurement [26]. A previous study [26] has analyzed the correlation of cardiorespiratory fitness and team performance, player position, and physical characteristics. The mentioned study shows that cardiorespiratory fitness does not differentiate between age, weight, height, team performance, and player position, but VO_2max varies with age, weight, height, and BMI [26]. The study also found a strong correlation between the physical requirements of player positions throughout a match and the aerobic capacity of players playing those positions, which should be considered in soccer training [13]. In addition, Doncaster et al. [27] reported that measures of ventilatory equivalent, a determinant of running economy, at all sub-maximal exercise intensities were inversely related to the volume and percentage of very-high-intensity activities.

Today, it is known that coaches and sports scientists can tailor training plans based on well-defined physiological parameters such as VO_2max, maximum heart rate, and blood lactate concentration [28]. Although recent studies have revealed an association between cardiorespiratory parameters and running performances, such as high-intensity running [29,30] and total distance covered [31], it should be emphasized that conflicting results have been obtained in the study by Metaxas et al. [32], where no association between VO_2max and MRP was found. Therefore, these findings need to be verified. Regarding the association between lactate and MRP, only one study has shown an association between lactate levels and the total distance covered [33]. However, it is important to note that this study focused on young footballers. Additionally, a commonality among all mentioned studies is the limited number of observed parameters. Furthermore, there is a lack of studies that comprehensively assess the physiological parameters of players in a single sample. Therefore, there is a need for a study that will more thoroughly investigate this area. To the authors' knowledge, this is the first study to report the effect of a wide set of variables, cardiorespiratory and metabolic parameters, on match running performance. More importantly, this study is the only one with a national-level sample of football players in the territory of Serbia. Hence, the purpose of this study was to determine the association between cardiorespiratory and metabolic parameters and running performance in highly trained football players. In this regard, hypotheses have been formulated indicating that (i) there is an association between cardiovascular and running performance; (ii) there is an association between cardiorespiratory parameters and running performance; and (iii) there is an association between metabolic parameters and running performance. This study will contribute to understanding the relationship between cardiorespiratory and metabolic parameters and running performance among highly trained football players in Serbia, and will determine which cardiovascular and metabolic parameters are associated with specific running speeds.

2. Materials and Methods

2.1. Participants

The sample of participants in this cross-sectional study consisted of 41 elite football players (aged 23.20 $\pm$ 3.40 years, with a body height of 182.00 $\pm$ 5.15 cm, and a body mass of 76.86 $\pm$ 6.06 kg; Table 1). All players were members of the Serbian Super League, which is the top-tier national football competition. That is, according to categorization, they are highly trained/national level athletes [34]. The criteria for inclusion in the study were players aged $\geq$ 18 to $\leq$35 years, with a training age of $\geq$6 years, without a recent injury (>12 months) or any illness at that moment. Randomly, 4 teams out of 16 were selected from the league. Then, every other player was chosen through randomization. In the end, we selected 44 players to participate. Out of those, we gathered all the data for 41 players. All participants voluntarily participated and were informed about the purpose, benefits, and risks of the study, and they all provided written consent to participate in the study. Additionally, all data have been anonymized to ensure the confidentiality of the players and teams. Therefore, all procedures conducted in the study involving human participants were in accordance with the Helsinki Declaration and were approved by the Ethics Committee of the Faculty of Medical Sciences, University of Kragujevac (decision number: 01-15731; date 29 December 2021).

Table 1. Sample description.

	Mean	SD	Min	Max
Age	23.20	3.40	18.00	32.00
Body height (cm)	182.00	5.15	172.00	192.00
Body mass (kg)	76.86	6.06	63.00	88.00

2.2. Procedures

The testing of football players was conducted in March 2022. Laboratory tests were performed in a room where the temperature was 20–23 °C and the air humidity was 55–60% so that the microclimatic conditions corresponded to the recommended ones. All measurements were performed in the morning, at approximately the same time (11 a.m.). On the day of testing, participants did not train in the morning as they needed to be rested, and, afterwards, they resumed their daily obligations. A multistage progressive treadmill test was conducted. After warming up, they performed 3 min of running on a treadmill at a speed of 5 km/h; the speed and incline were determined to increase at precise time intervals. The criteria for stopping the test were the fulfillment of 2 out of 4 conditions: VO_2max plateau reached (2 mL/kg/min); HR max reached; respiratory exchange coefficient (RER) > 1.2; the appearance of subjective complaints. The performance data of players' running performance were collected using performance analysis software during official football matches. It should be emphasized that during the research, the participants did not have a break in training but rather continued with their daily routines.

2.3. Anthropometric Characteristics

Anthropometric assessments were conducted following the guidelines of the International Biological Program [35]. A Tefal 6010 scale (Rumilly, Haute-Savoie, France) was used to measure body mass, and the result was read from the scale's display with an accuracy of 0.1 kg. Body height was measured using an anthropometer (GPM, Zurich, Switzerland), and the measurement result was read with an accuracy of 0.1 cm.

2.4. Cardiorespiratory Parameters

For the purposes of this research, a maximum multistage progressive treadmill test was applied (Technogym Run Exciting 9000, Fairfield, NJ, USA). After positioning the subjects, a mask (Hans Rudolph, Kansas City, MO, USA) was secured with elastic straps to prevent air leakage, and the VO_2max value was directly measured (Cosmed's FitMate Med, Rome, Italy). After securing the mask, a heart rate monitor (Polar Pro Team System, Kempele, Finland) was placed with the strap positioned around the chest, just below the nipples, and fastened. The heart rate monitor was placed directly on bare skin to enable successful measurement with constant heart rate monitoring. Cardiovascular and respiratory parameter values were automatically recorded every 15 s. The subject walked and ran during the test at different intensities and on varying inclines. A standardized stepwise continuous test protocol was employed [36,37].

2.5. Lactate Concentration

To define lactate thresholds, capillary blood lactate levels (measured in mmol/L) were used at the end of each phase of the step-continuing test. Capillary blood samples were obtained from a hyperemic lobe using special test strips. After acquiring a sample, the lactate concentration was determined immediately using a lactate analyzer (Lactate Scout, EKF SensLab, Leipzig, Germany). The sensitivity and accuracy of lactate concentration measurement using the Lactate Scout analyzer (EKF SensLab, Leipzig, Germany) were scientifically validated [38]. Based on the obtained results, the metabolic efficiency index was calculated, which represents the ratio of blood lactate concentration at the 4th and 10th minutes of recovery.

2.6. Match Running Performance (MRP)

For recording matches using the BioIRC Tracking Motion system (BioIRC, Kragujevac, Serbia), two identical Sony NEX-VG10 video cameras (Sony, Tokyo, Japan) were used, both in full-HD resolution, along with one high-speed control camera. The algorithmic part of the video-processing software for tracking the running performance (RP) of players was based on determining the similarity measure of the statistical color distribution of objects [39]. The software for analysis tracked player RP across the entire field, alternately analyzing video footage of each half of the field, depending on the current player's activities. The analysis speed on the computer (with Intel(R) Core2Duo E6750@2.66 GHz, 2 GB RAM, Win7 32-bit; Intel, Santa Clara, CA, USA) was approximately 4 frames per second. Match videos were processed in multiple stages. For video file analysis purposes, the videos were compressed using the XVID codec in MOV format, with a frame rate of 30 frames per second.

2.7. Cardiovascular and Metabolic Variables

The independent variables in this study can be categorized into three groups: cardiac parameters, parameters related to cardiovascular system efficiency, and lactate-related parameters. A total of eight cardiovascular variables were divided into two groups of four each. The first group included heart parameters such as maximum heart rate (HRmax), heart rate at the anaerobic threshold (HR AT), heart rate at the first minute of recovery (HR 1′), and heart rate at the second minute of recovery (HR 2′). The second group consisted of parameters associated with cardiovascular system efficiency, including maximum oxygen uptake (VO_2max), running efficiency (VO_2max/v), and cardiorespiratory efficiency (VO_2max/HR). Lactate metabolism variables comprised lactate at 4 min (LA 4′), lactate at 10 min (LA 10′), metabolic recovery index (Index LA), and metabolic efficiency index (Index ME); Table 2.

Table 2. Cardiovascular and metabolic variables.

No.	Variable	Abbreviation
1.	Maximum heart rate	HRmax
2.	Heart rate at the anaerobic threshold	HR AT
3.	Heart rate at the first minute of recovery	HR 1′
4.	Heart rate at the second minute of recovery	HR 2′
5.	Maximum oxygen uptake	VO_2max
6.	Running efficiency	VO_2max/v
7.	Cardiorespiratory efficiency	VO_2max/HR
8.	Lactate at 4 min	LA 4′
9.	Lactate at 10 min	LA 10′
10.	Metabolic recovery index	Index LA
11.	Metabolic efficiency index	Index ME

2.8. MRP Variables

The determination of MRP variables was conducted according to the BioIRC motion structure analysis model, based on existing standards for profiling movement intensities with respect to basic physical (movement speed) and physiological (physiological and biochemical changes at given speeds) parameters. Based on this model, five categories of movement intensity for players during the match were defined, and a sixth variable representing total player movement was calculated based on the measured variables [40–42].

The dependent variables were MRP variables including sums of movement (in meters) within specific speed ranges: walking (<8 km/h), jogging (8–15 km/h), running (15.1–19 km/h), high-speed running (19.1–23 km/h), sprinting (>23 km/h), and the total distance (total; Table 3).

Table 3. MRP variables.

No.	Variable	Abbreviation
1.	Walking (from 0 to 8 km/h)	<8 km/h
2.	Jogging (from 8 to 15 km/h)	8–15 km/h
3.	Running (from 15.1 to 19 km/h)	15.1–19 km/h
4.	High-speed running (from 19.1 to 23 km/h)	19.1–23 km/h
5.	Sprinting (over 23 km/h)	>23 km/h
6.	Total distance	Total

2.9. Statistics

For all data obtained through testing, basic central and distributional parameters were calculated, including the mean, standard deviation, minimum, maximum, and range. To assess the normality of the distribution of results, skewness and kurtosis were used. Pearson's correlation analysis was employed to explore the univariate association between physiological parameters and MRP. The classification of correlation coefficients followed the suggested guidelines: an r value of $\leq$0.35 denoted a low or weak correlation, an r value ranging from 0.36 to 0.67 indicated a modest or moderate correlation, an r value from 0.68 to 1.0 represented a strong or high correlation, and an r value greater than 0.90 signified a very high correlation [43]. The residual statistics diagram was used to assess the independence of residuals. Multivariate relationships among the predictors and criteria were evaluated using multiple regression analysis. Based on the formula n = 20 + 5k (where k represents the number of predictors), which was proposed by the authors [44] as optimal, considering the principle based on the rate of change in reliability criteria relative to the number of participants, this study calculated that it is optimal to use 4 predictor variables. The coefficients R, R^2, and p were calculated for linear multiple regression. Evaluation of the model was assessed through R2, which indicates the proportion of variance in the dependent variable explained by the model. Meanwhile, the statistical significance of the model was evaluated in the ANOVA test section. The assessment of each independent variable in the model was calculated based on standardized coefficients (Beta) to determine the contribution of each variable to the final equation [45]. Statistical significance was set at $p < 0.05$. Data analysis was performed using IBM SPSS Statistics software, version 26 (Statistical Package for Social Sciences, v26.0, SPSS Inc., Chicago, IL, USA).

3. Results

3.1. Descriptive Cardio-Respiratory, Metabolic, and Running Performance Parameters

The results in Table 4 for 41 national-level football players showed that the values of skewness within the normal distribution range from −1 to 1, with kurtosis ranging from −2.75 to 2.75 for all variables, except for the variable Index La.

Table 2 presents descriptive parameters for the top football players, and it was noticeable that the average value of HRmax was 192.90 ± 7.95 bpm, with a significant range, where the minimum value of Hrmax was 174.00, and the maximum was 207.00 bpm. The average value of VO_2max was 61.15 ± 3.89 mL/kg/min, with a noticeable range between the minimum and maximum values (ranging from 53.40 to 69.20 mL/kg/min). Lactate value at 4 min of rest averaged 9.42 ± 1.73 mmol/L. Concerning the total distances covered by the players, they averaged 10,799.79 ± 1143.70 m, with the smallest recorded total distance during the game being 8429.52 m, and the largest reached being 12,602.25 m. The participants covered an average distance of 4522.56 m by walking, as well as 4193.87 m while jogging. When they ran (15.1–19 km/h), they covered a distance of 983.55 m. Then, at higher speeds (high-speed running and sprinting), they covered 611.45 m and 488.38 m, respectively.

Table 4. Cardio-respiratory, metabolic, and match running performance parameters of national-level football players.

	Mean	SD	Min	Max	Range	Skew	Kurt
HRmax (bpm)	192.90	7.95	174.00	207.00	33.00	−0.30	−0.68
HR AT (bpm)	167.20	8.02	152.00	180.00	28.00	−0.07	−0.92
HR 1′ (bpm)	170.05	12.67	140.00	193.00	53.00	−0.48	−0.06
HR 2′ (bpm)	129.44	17.52	103.00	174.00	71.00	0.70	−0.01
VO_2max (ml/kg/min)	61.15	3.89	53.40	69.20	15.80	0.16	−0.27
VO_2max/v (mL·kg·min^1/km/h)	2.93	0.21	2.59	3.38	0.79	0.48	−0.32
VO_2max/HR	0.32	0.02	0.27	0.36	0.09	0.15	−0.60
La 4′ (mmol/L)	9.42	1.73	6.50	14.10	7.60	0.36	−0.25
La 10′ (mmol/L)	6.94	1.37	3.80	11.70	7.90	0.67	2.74
Index LA	39.01	31.77	−2.35	165.79	168.14	1.79	5.01
Index ME	2.29	0.45	1.56	3.33	1.77	0.52	−0.43
<8 km/h (m)	4522.56	450.43	3301.36	5243.99	1942.63	−0.58	0.34
8.1–15 km/h (m)	4193.87	831.19	2580.46	5850.53	3270.07	0.08	−0.57
15.1–19 km/h (m)	983.55	247.63	502.00	1393.53	891.53	−0.22	−1.27
19.1–23 km/h (m)	611.45	154.36	319.33	885.60	566.27	0.22	−0.75
>23 km/h (m)	488.38	144.99	261.26	893.85	632.59	0.76	0.36
Total (m)	10,799.79	1143.70	8429.52	12,602.25	4172.73	−0.11	−0.71

Legend: Mean—arithmetic mean; SD—standard deviation; Min—minimal value; Max—maximal value; Skew—skewness, measure of asymmetry; Kurt—kurtosis, measure of flattening.

3.2. Correlation Analysis

Based on Table 5, it is noticeable that cardiorespiratory parameters moderately correlate with speeds of movement at 8.1–15 km/h, 19.1–23 km/h, and total distance (−0.28–−0.045). Additionally, heart rate correlates with total distance (0.29–0.50) and heart rate at 2 min with speeds of movement of 8.1–15 km/h and 19.1–23 km/h, and the total distance. On the other hand, lactate does not significantly correlate with maximal running speeds in general.

Table 5. Pearson's correlation coefficients between MRP and predictor variables.

	<8 km/h	8.1–15 km/h	15.1–19 km/h	19.1–23 km/h	>23 km/h	Total
HR max	0.27 *	0.18	0.10	0.26	0.01	0.30 *
HR AT	0.09	−0.21	−0.20	−0.16	−0.14	−020
HR 1′	0.25	0.18	0.07	0.23	0.11	0.29 *
HR 2′	−0.16	−0.42 **	−0.22	−0.50 **	−0.10	−0.50 **
VO_2max	0.00	−0.21	−0.17	−0.28 *	−0.04	−0.23
VO_2max/v	−0.22	−0.35 *	−0.13	−0.39 **	−0.18	−0.45 **
VO_2max/HR	−0.16	−0.28 *	−0.20	−0.39 **	−0.05	−0.37 **
LA 4′	0.08	0.21	0.07	0.07	−0.06	0.07
LA 10′	0.16	0.17	0.10	0.10	−0.06	0.20
Index LA	−0.10	0.01	−0.01	−0.01	0.11	−0.09
Index ME	0.01	−0.21	−0.03	−0.03	0.13	0.05

Note ** $p < 0.01$, * $p < 0.05$.

3.3. Residual Statistics

A scatter plot matrix was used to assess the independence of residuals. The scatter plots depict the dispersion of points with respect to the dependent variable across various movement speeds, and that is for HR parameters (Figure 1,), VO_2max parameters (Figure 2), and lactate parameters (Figure 3).

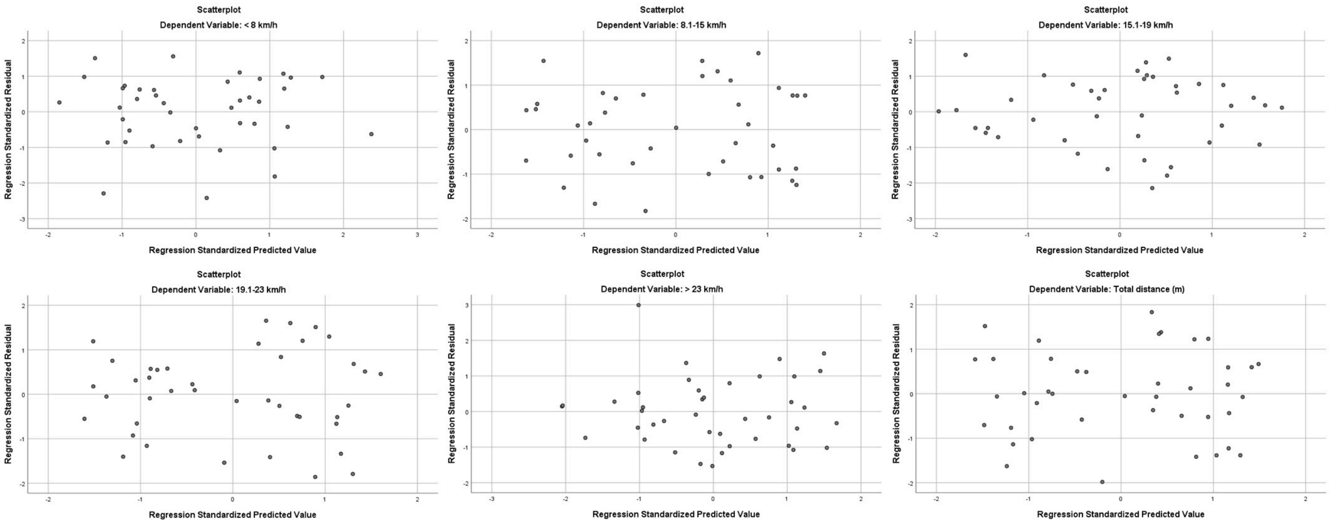

Figure 1. Scatter plot of standardized residuals; HR parameters for dependent MRP variables.

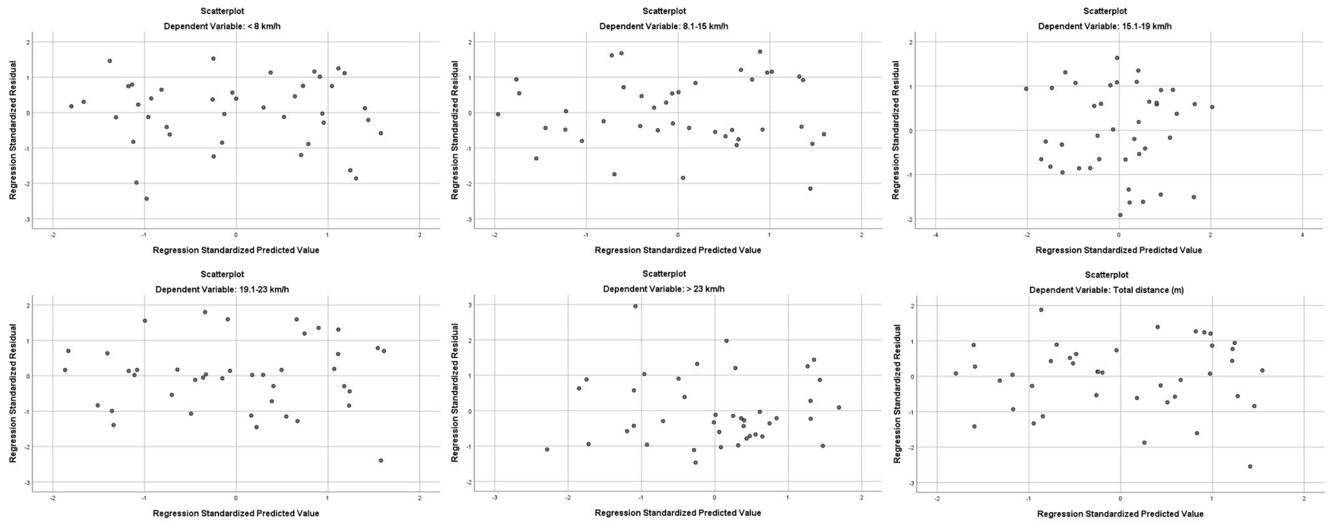

Figure 2. Scatter plot of standardized residuals; VO_2max parameters for dependent MRP variables.

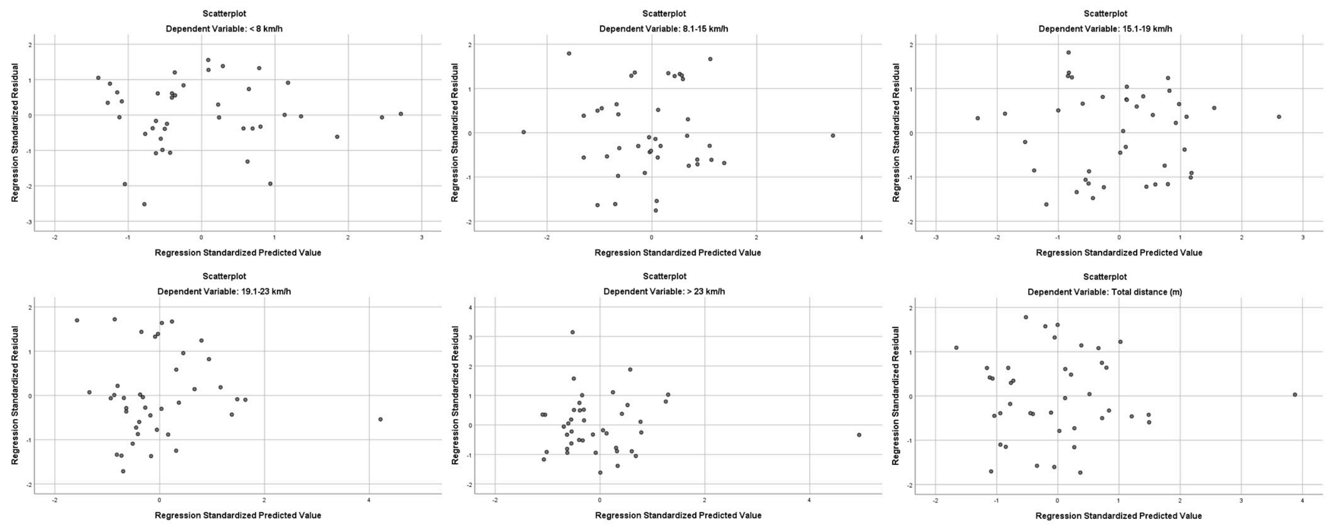

Figure 3. Scatter plot of standardized residuals; lactate parameters for dependent MRP variables.

3.4. Multiple Regression Analysis

The multiple regression results indicate that a model with four independent cardiovascular parameter variables explains a total of 54.3% of the variance in the dependent variable "total distance" (Table 6) at a significant level (p = 0.000). Based on the beta coefficients, the variables that contribute the most to the model are HRmax (0.573), HR 2′ (−0.528), and HR AT (−0.360). When considering different player movement speeds, it should be noted that cardiovascular parameters explain a total of 46.4% of the variance in the dependent variable "high-speed running" at a significant level (p = 0.000). Based on the beta coefficients, the variables that contribute the most to the model are HR 2′ (−0.551) and HRmax (0.526). Additionally, cardiovascular parameters explain a total of 33.6% of the variance in the dependent variable "jogging" at a significant level (p = 0.004), and the variable that contributes the most to the model is HR 2′ (−0.420). There were no significant models for the remaining dependent variables (walking, running, and sprinting).

Table 6. The result of multiple regression for cardiorespiratory and metabolic parameter effects on the match running performance parameters.

	<8 km/h	8.1–15 km/h	15.1–19 km/h	19.1–23 km/h	>23 km/h	Total
HR max	0.258	0.429	0.478	0.526 *	−0.114	0.573 *
HR AT	0.011	−0.311	−0.383	−0.250	−0.168	−0.360 *
HR 1′	0.111	0.087	−0.112	0.059	0.298	0.128
HR 2′	−274	−0.420 *	−0.146	−0.551 *	−0.064	−0.528 *
R	0.379	0.580	0.390	0.681	0.251	0.737
R^2	0.144	0.336	0.152	0.464	0.063	0.543
p	0.219	0.004	0.191	0.000	0.661	0.000
VO_2max	0.472	0.162	0.005	0.197	0.085	0.342
VO_2max/v	−0.272	−0.313	−0.005	−0.262	−0.248	−0.403 *
VO_2max/HR	−0.374	−0.217	−0.204	−0.391	0.034	−0.398
R	0.344	0.371	0.203	0.447	0.196	0.498
R^2	0.118	0.138	0.041	0.200	0.038	0.248
p	0.194	0.135	0.664	0.039	0.690	0.014
LA 4′	−0.500	0.793	0.367	−0.050	−0.869	0.342
LA 10′	1.216	−0.149	−0.178	0.361	1.210	0.534
Index LA	1.072	−0.329	−0.279	0.278	1.300	0.325
Index ME	0.684	0.545	−0.055	0.186	0.360	0.725
R	0.468	0.272	0.240	0.156	0.415	0.368
R^2	0.219	0.074	0.058	0.024	0.173	0.135
p	0.058	0.583	0.699	0.922	0.136	0.250

Legend: R—multiple correlation; R^2—coefficient of determination; p—statistical significance; * denotes statistical significance of $p < 0.05$.

Regression analysis also revealed that a model with four independent derived cardiorespiratory parameters explains a total of 24.8% of the variance in the dependent variable "total distance" at a significant level (p = 0.014). Based on the beta coefficients, the variable that contributes the most to the model is VO_2max/v (−0.403). It was also found that the derived cardiorespiratory parameters explain a total of 20% of the variance in the dependent variable "high-speed running" at a significant level (p = 0.039). All other models were non-significant.

Regarding lactate levels, the model was not significant for any of the dependent variables.

4. Discussion

The aim of this study was to examine the association between cardiorespiratory and metabolic parameters and match running performance (MRP) in national-level football players. Based on multiple regression analysis, the key findings were as follows: (i) cardiac parameters HRmax, HR 2′, and HR AT are associated with total running distance, with HR 2′ and HRmax also being associated with high-speed running, while HR 2′ is associated with jogging; (ii) respiratory parameter VO_2max/v is associated with total running distance; and (iii) lactate parameters are not associated with movement performance.

Upon examining cardiac parameters, it was noted that the average HRmax values among footballers in the top level of competition in Serbia were 192.90 ± 7.95 bpm, which is consistent with findings from other studies, such as 195 bpm in Greece [46], 193 bpm in Greece [47], 192.9 bpm in Belgium [48], 191.3 bpm in Croatia [49], and an HRmax of 188 bpm in Greece [50]. The average values of heart rate at the anaerobic threshold (HR AT) were 167.20 ± 8.02 bpm, which closely corresponds to the values of 169 bpm for Greek footballers [46], but they are slightly lower than the values estimated for Belgium (178.2 bpm) [48] and, especially, for Croatian footballers (182.96 bpm) [49]. However, these differences may be due to different assessment methodologies.

Our resting heart rate (RHR) values, specifically HR 1′ and HR 2′, are 170.05 and 129.44, respectively, with HR 1 representing 88% of HRmax, which aligns with the results for Champions League footballers (91% of HRmax) [51] and Scottish players (90% of HRmax) [52]. The other RHR parameter (HR 2′) is 67% of HRmax; however, it is not possible to compare this data with recent studies as there are no studies that have examined this parameter.

The average values of VO_2max are 61.15 ± 3.89 mL/kg/min, which are slightly lower than the values achieved by footballers from Spain (65.5 mL/kg/min) [53] and approximately align with professional soccer players from other countries such as Norway (63.7 mL/kg/min), England (61.6 mL/kg/min), [54], the United Kingdom (59.4 mL/kg/min) [55], the Czech Republic (59.2 mL/kg/min) [56], and slightly higher values compared to footballers from Greece (58.8 mL/kg/min) [47], Belgium (58.0 mL/kg/min) [48], Croatia (57.63 mL/kg/min) [49], and Cyprus (57.35 mL/kg/min) [57]. It is noteworthy that these values are consistent with the observation that professional soccer players' VO_2max can vary from 55 to 65 mL/kg/min [58,59]. However, it should be noted that these values can vary based on playing position, the playing style of individuals, and the team. Additionally, some authors [60,61] suggest that the VO_2max of elite players should be above 60 mL/kg/min to cope with the demands of modern football, which corresponds to the values achieved by Serbian football players in this study. Other cardiorespiratory parameters were not analyzed in other studies, making them difficult to compare.

One significant finding of this research is that heart parameters, such as HRmax, HR 2′, and HR AT, are associated with the total distance covered during a match. This relationship between heart parameters and total distance has a high degree of correlation (R2 = 54.3%), indicating that cardiac function is crucial for the endurance of football players. Unlike HRmax and HR AT, where a positive correlation was achieved, HR 2′ showed a negative correlation, meaning that a lower heart rate during recovery is associated with a greater overall distance covered. This result may suggest that the speed of recovery after intensive effort is important for the efficiency of football players during matches. In other words, players with better results in these parameters possess a higher level of physical preparedness, enabling them to efficiently execute a greater number of high-intensity movements during the game and eliminate fatigue in shorter time intervals, preparing them for subsequent exertions.

Furthermore, the research indicates that respiratory parameters, such as VO_2max/v, influence the overall distance covered. This emphasizes the importance of optimal respiratory efficiency for achieving better sports results. Concerning high-intensity running, the relationship between heart parameters and fast running has also been confirmed. HR 2′ and HRmax made the most significant contribution to the model, highlighting the role of these two variables in achieving high speeds during matches.

Recent studies have revealed a connection between cardiorespiratory parameters and MRP in football. Studies have shown that average VO_2max values are moderately correlated with the total distance covered [29] and high-intensity running in footballers [30,31]. However, conflicting results were found in a study by Metaxas et al. [32], who did not find a connection between VO_2max and MRP. In our study, although there was no direct link established between VO_2max and MRP, a moderate connection was achieved between the VO_2max model and MRP, with the greatest contribution coming from the VO_2max/v parameter. This suggests that VO_2max and HR should be further examined as they are linearly interconnected [62].

These results highlight the importance of the development of the cardiovascular and respiratory systems in professional footballers. The efficiency of the aerobic energy system, which provides about 90% of the energy during a football match, is crucial for achieving better cardiorespiratory endurance [7]. Adaptive changes, such as an increase in the dimensions of the left ventricle and improved circulation, contribute to an increase in the capacity of oxidative metabolism and overall cardiorespiratory endurance [63]. Therefore, footballers with a more efficient aerobic system can maintain a higher intensity before the onset of fatigue [64,65].

The aerobic and anaerobic system both significantly contribute to match performance [6]. The aerobic energy system plays a crucial role in recovery between high-intensity sprints [7]; however, key moments in football games occur during high-intensity activities that need to be repeated many times [4,66]. Our findings have highlighted the association between cardiorespiratory parameters and high-intensity running, as well as the total distance covered. It is clear that during high-intensity running, functional capacities must be at a higher level to ensure an adequate oxygen supply. On the other hand, football players exhibit developed capacities precisely in these areas, as they perform a large number of intense actions during a match, indicating a high rate of anaerobic energy exchange during a game. There is significant utilization of creatine phosphate, along with the accumulation of lactate [67]. In this regard, for monitoring the physiological response, in addition to heart rate frequencies and VO2, an essential parameter is the concentration of lactate in the blood [68].

When it comes to assessing lactate levels during a football match, post-game lactate levels were mostly evaluated, with lactate max values of 11.0 mmol/L in Belgium [40], 11.2 mmol/L [69], and 11.7 mmol/L [41]. These findings indicate that the rate of lactate production in muscles is high during aa game. It is considered that a fairly high concentration of lactate during a football match [70,71] represents an accumulated/balanced response to a series of high-intensity activities. These values approximately correspond to the load that football players achieved during the multistage treadmill test. Blood lactate concentration after four minutes (LA 4′) was 9.42 ± 1.73 mmol/L, while after 10 min of recovery, lactate levels dropped to 6.94 ± 1.37 mmol/L. Additionally, Index LA and Index ME were assessed, but these parameters are underutilized in recent research.

In our study, we did not find a connection between lactate parameters and movement performance. However, the authors in [72] reported that modifying the testing protocol with progressive stages and lactate analysis procedures can affect physiological parameters. So, instead of laboratory testing, a suggestion for future research would be to measure lactate concentration during effort in a football match and see if it is associated with movement performance. Also, from a methodological standpoint, there are differences in lactate concentration depending on the sampling site, and the most accurate approach would be to take a blood sample from the working muscles [73]. Authors also emphasize that the level of blood lactate concentration can be influenced by reduced glycogen reserves in skeletal muscle cells, a diet with low carbohydrate intake, or previous exhausting physical activities [74], as well as factors such as the type of muscle fibers, the activity of glycolytic and lipolytic enzymes, and the density of capillaries and mitochondria [75]. Therefore, it is clear that there are various reasons as to why lactates have not shown an association with MRP.

When it comes to MRP, it should be noted that the achieved average total distance (10,799.79 m) and distance covered at higher speeds by highly trained Serbian players are somewhat higher than those of better-ranked Croatian football players [76,77]. These values correspond to general elite footballer benchmarks, ranging between 9 and 13 km during matches, with around 5–15% of that distance covered at high running speeds [41,78,79]. It is well known that distance covered at high intensities is traditionally recognized as a key indicator of physical performance in football [15] because key match activities in football may be influenced by higher running performance, especially at higher speeds [80,81]. Thus, in this study, a connection is demonstrated between total distance and high-intensity running and cardiorespiratory endurance.

The explanation of these results is based on the observation that the cardiorespiratory endurance of footballers is a crucial factor for success in football matches. From a physiological perspective, better cardiorespiratory endurance in footballers is directly linked to the development of the cardiovascular and respiratory systems' ability to maintain oxygen delivery to actively engaged muscles during prolonged physical activity, as well as the muscles' ability to obtain the necessary energy through aerobic processes [82,83]. Accordingly, footballers who have shown better results in HR and VO2 parameters, as measures of cardiorespiratory system functioning, achieved greater distances in high-intensity activities and in the overall distance covered. The physiological explanation implies that footballers with greater cardiorespiratory system capacities are able to maintain lower heart rate values at the same running speed, as indicators of system load. In other words, even at the same running speed, the physiological load on the body varies. Our study has shown, through parameters such as HR max and HR AT, that players who achieved higher values of maximum heart rate, as well as lower values of heart rate at the anaerobic threshold, covered a greater total distance and had greater distances in high-intensity activities (above 19 km/h). On the other hand, the HR 2′ parameter indicates that footballers with lower heart rate parameters during recovery have cardiovascular system capacities to recover faster from intensive activities, which is very important as football involves alternating periods of work and rest.

It is recognized that high-intensity running is of great importance for performance in elite football [84,85], as numerous studies have shown that this parameter is discriminative between players at higher versus lower levels of competition [86,87]. High-intensity periods during football matches impose high demands on footballers' bodies, leading to the increased involvement of the anaerobic energy system, with the accumulation of lactic acid and decreased pH values in exercising muscles [71]. The cumulative effects of numerous high-intensity stimuli lead to higher concentrations of lactic acid in the blood of footballers [88]. Therefore, good aerobic fitness of players is important, as it enables better plasma flow through the system, requiring faster removal of harmful metabolic by-products [89] and thus accelerating recovery between intermittent stimuli, while good anaerobic capacity compensates for the high intensities required during play [73].

In our study, a relationship between lactate and MRP was lacking, suggesting that the methodology for assessing lactate and movement performance should be reconsidered. Specifically, from a methodological standpoint, the site of blood sampling for lactate concentration measurement and the laboratory methods used can also influence test results. The authors in [90] suggest that the most accurate approach would be to take blood samples from working muscles, which is not the case in our study. Regarding movement performance, it is noted that other factors related to the complexity of football matches can influence the achieved result. Primarily, these include the playing formation [4], opponent [90], ball possession [91], and the technical level of the footballers [92]. This indicates that some players with high physical capacities do not cover great distances due to the tactical limitations of their role in the team.

This study represents a significant contribution to understanding the impact of cardiorespiratory and metabolic parameters on the MRP of professional football players. One of the key strengths of this research is that the findings have determined which cardiovascular, respiratory, and metabolic parameters are most strongly associated with various running speeds of football players. This constitutes a major contribution to this field, as based on the analysis of previous research, it is noticeable that there is no study that has comprehensively tracked the relationship between physiological and metabolic parameters at different movement speeds. Additionally, it is important to note that this is the first study to gather valuable information about national-level football players in Serbia.

The study's limitation lies in the relatively small sample size of participants; however, one of the restricting circumstances is the challenge of recruiting a sample of national-level football players and subjecting them to detailed analyses. Furthermore, another limitation pertains to the fact that the observed football players in the overall sample were aged between 18 and 32 years, despite the physiological differences between an 18-year-old and a 32-year-old. A suggestion for future research would be to examine lactate levels in competitive conditions and analyze the given parameters based on playing positions, ideally with a large sample size of participants.

Practical Application

Recording the current physiological demands of world-class male football players holds scientific value and direct practical applications, as it is a rare occurrence due to limited access to such subjects. The practical significance of this observation lies in the realization that training these abilities should be developed to the highest possible level.

Furthermore, the direct practical application of this research is that this knowledge can assist coaches in making evidence-based decisions by providing new normative physiological data that can be used for player selection and profiling. Ultimately, these data can be valuable for coaches and fitness trainers in national-level teams to highlight the requirements of higher-level competitions and to design training sessions, which can aid players in transitioning to an elite competition.

5. Conclusions

The purpose of this study was to determine the association between cardiorespiratory and metabolic parameters and running performance in highly trained football players. Based on multiple regression analysis, the key findings were as follows: (i) cardiac parameters HRmax, HR 2′, and HR AT are associated with total running distance, with HR 2′ and HRmax also being associated with high-speed running, while HR 2′ is associated with jogging; (ii) respiratory parameter VO_2max/v is associated with total running distance; and (iii) lactate parameters are not associated with movement performance. Based on this, it can be concluded that the first two hypotheses are partially accepted, while the third hypothesis is rejected.

A detailed analysis of regression results for functional variables emphasizes the significance of heart rate at all levels, particularly at critical points (HR max, HR AT), recovery heart rate (HR 2) as an indicator of intensity and player fatigue, and the efficiency of the respiratory system (VO_2max/v) as an integral factor of functional performance. The explanation for these regression analysis results is based on the observation that functional abilities represent a significant quality/potential for expressing movement performance, a crucial condition for success in football.

This research has contributed to understanding the relationship between cardiorespiratory and metabolic parameters and running performance among highly trained football players in Serbia, and it meticulously determined which cardiovascular and metabolic parameters are associated with different running speeds. Therefore, this study, as one of the few that extensively examine the cardiorespiratory and metabolic domains and their relationship with various movement performances, has contributed to this field by elucidating which physiological parameters should be emphasized in the conditioning of football players.

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