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Comparison of lower and upper extremity anaerobic power in female football players

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Abstract

Background and Study Aim Anaerobic power is a key determinant of athletic performance, influencing an athlete's ability to perform short bursts of high-intensity activity. Monitoring and evaluating anaerobic power are essential for optimizing training strategies and improving competitive performance. Therefore, this study aims to compare the anaerobic power of the lower and upper extremities in female football players

Material and Methods A total of 10 female football players, actively competing in Konya, voluntarily participated in this study. All participants were university students and engaged in regular training and competition schedules. The participants had an average age of 19.50±1.84 years, an average height of 163.90±5.38 cm, and an average weight of 54.00±3.91 kg. To assess anaerobic power in both upper and lower limbs, the Wingate Anaerobic Power Test (WAnT) was utilized. The test was conducted using a Monark 891E arm and 894E leg cycle ergometer. All data collected from the tests were automatically recorded by the system. For statistical analysis, SPSS version 27.0 was used. A paired sample t-test was applied to compare upper and lower extremity anaerobic power outputs. A p-value of <0.05 was considered statistically significant.

Results A statistically significant difference in favor of the lower extremities was found when comparing both absolute and relative peak and mean power values of the upper and lower extremities ($p < 0.05$). Peak power in the legs (402.76 ± 69.90 W) was significantly higher than in the arms (243.75 ± 71.62 W), with a large effect size ($d = 3.63$). Similarly, mean power was greater in the lower extremities (300.78 ± 53.04 W) compared to the upper extremities (127.01 ± 51.43 W, $d = 4.53$). When considering relative values, relative peak power in the legs (7.39 ± 0.92 W/kg) was significantly higher than in the arms (4.39 ± 1.12 W/kg, $d = 3.46$), and relative mean power also showed a significant difference (legs: 5.51 ± 0.66 W/kg; arms: 2.27 ± 0.81 W/kg, $d = 4.71$).

Conclusions The findings of this study confirm that female football players generate significantly greater anaerobic power in their lower extremities compared to their upper extremities. These results highlight the dominant role of lower-body power in football-specific movements such as sprinting, jumping, and rapid directional changes. Understanding these differences can help in optimizing training strategies for female football players.

Keywords: anaerobic capacity, muscle power, performance analysis, female athletes, strength training

Introduction

Women's football has experienced significant growth in recent years, with increasing expectations for performance. Currently, approximately 20 million female football players participate in the sport globally, representing about 10% of the total football population [1]. The expansion of women's football, driven by international tournaments and professional leagues, has provided female athletes with greater opportunities for structured training and high-level competition. In addition to technical and tactical skills, physiological factors play a crucial role in determining players' performance on the field [2].

Among these physiological factors, muscle metabolism and anaerobic capacity are particularly important determinants of performance in female football players. Anaerobic capacity is essential for key football-specific movements such as sprinting, acceleration, directional changes, and jumping [3]. Research indicates that female football players engage in activities of varying intensity every four seconds during a match, with heart rates fluctuating between 152 and 186 beats per minute (bpm) [4]. During high-intensity efforts, anaerobic metabolism plays a dominant role, whereas aerobic metabolism supports lower-intensity phases [5]. Elite female football players are known to cover significant distances during matches, with a substantial portion of their movements requiring high-intensity effort [6]. The sustainability of anaerobic performance is closely linked to muscle glycogen stores. According to Nassis et al. [7],

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muscle glycogen levels decrease by approximately 42% in the second half of a football match, leading to a notable decline in sprint performance. Given the high-speed and endurance demands of football, both lower and upper extremities contribute to overall performance. While the lower extremities are critical for sprinting and jumping, the upper extremities play a key role in balance, resistance in duels, and coordination [8]. Although upper extremity strength is not a primary performance factor in football, it is particularly relevant in aerial duels and physical confrontations [9].

The anaerobic power capacities of the upper and lower extremities significantly influence key performance attributes such as speed, strength, endurance, and explosive power in female football players. Anaerobic power is particularly crucial in short-distance sprints, rapid directional changes, shooting, and aerial challenges. Previous studies have examined the impact of physical training on muscle strength and anaerobic power across different sports, demonstrating that regular training can enhance anaerobic capacity [10].

Moreover, the balance between upper and lower extremity strength, particularly the hamstring-to-quadriceps strength ratio, has been identified as a critical factor, with variations observed across different sports disciplines [11]. Additionally, ergogenic aids aimed at enhancing anaerobic power performance have been shown to positively impact upper extremity muscular endurance and power output [12]. However, in a multifaceted sport such as football, comprehensive studies examining the development and interaction of anaerobic power characteristics between the upper and lower extremities remain limited.

In this context, this study aims to compare the anaerobic power of the lower and upper extremities in female football players.

Materials and Methods

Participants

A total of 10 female football players, who were also university students and actively competing in Konya, voluntarily participated in this study. The participants in the study were in the late follicular phase of their menstrual cycle. All participants were informed about the study's objectives and potential risks. Written informed consent was obtained from each participant and signed by them, and the study protocol was approved by the Ethics Committee of Selçuk University Faculty of Sports Sciences (Protocol No: 106/04.09.2024). Descriptive statistics of the participants are presented in Table 1. The demographic characteristics, including age, height, and body weight, were found to be similar among all athletes.

Table 1. Demographic characteristics of participants

Variable	N	Min	Max	Mean	Std. Dev
Age (years)	10	18	24	19.50	1.841
Height (cm)	10	156	172	163.90	5.384
Weight (kg)	10	50	60	54.00	3.916

Research Design

Participants visited the Sports Sciences Laboratory three times during the experiment. To familiarize themselves with the experimental devices, they were instructed to perform the test once one week before the actual experiment. To neutralize the learning effect, not all participants started with either the upper or lower Wingate test at the same time. On the second test day the half of the group (5 participants) underwent the arm Wingate test, while the other half performed (5 participants) the leg Wingate test. Once the measurements were completed, the data were transferred to a computerized system for analysis. 2 days later, participants returned to the laboratory and switched test conditions: those who had previously performed the arm Wingate test now completed the leg Wingate test, while those who had initially done the leg Wingate test switched to the arm Wingate test. Participants were also instructed to refrain from any strenuous exercise for at least 48 hours before the experiment to minimize potential fatigue effects.

Arm and Leg Wingate Test

The Wingate anaerobic test was conducted using a Monark 891E arm and 894E leg cycle ergometer (Sweden) equipped with a weight basket. The ergometer was connected to a computer system modified for the test and integrated with compatible software for data collection and analysis. Before each test, the machine was individually adjusted according to the participant's height to ensure optimal performance. The external resistance for the test was set at 50 g/kg for the arm and 75 g/kg for the leg, in accordance with standard Wingate test protocols. Prior to testing, participants performed a standardized warm-up protocol for both the upper and lower body Wingate tests. The warm-up consisted of a 5-minute submaximal cycling phase, during which participants pedaled at a cadence of 60–70 revolutions per minute (RPM) with a resistance set at 20% of their calculated test load. This phase aimed to gradually activate the anaerobic energy system and prepare the muscles for high-intensity exertion. Following this, participants completed 2 to 3 short sprints, each lasting 4 to 8 seconds, at maximal pedaling speed while maintaining the same resistance level. These sprints were included to enhance neuromuscular activation and facilitate an optimal power output during the Wingate test.

After the sprint phase, participants underwent a passive rest period of 3 to 5 minutes to allow for complete recovery before performing the actual test. This warm-up protocol was applied uniformly for both the upper (arm) and lower (leg) Wingate tests to ensure consistency in test conditions. For the test, participants were instructed to accelerate to their maximum pedal speed in the shortest time possible, without resistance. Once the athlete reached peak speed (approximately after 3–4 seconds), the predetermined 50 g/kg (arm) and 75 g/kg (leg) load was applied, initiating the test. Participants were required to pedal at maximum effort for 30 seconds against the applied resistance. Verbal encouragement was provided throughout the test to ensure maximal effort. The average power output generated during the 30-second test was recorded for further analysis [13, 14].

Statistical Analysis

The Shapiro-Wilk test (Table 2) was used to assess whether the dataset followed a normal distribution.

Table 2. Shapiro-Wilk test results

Variable	Statistic	df	Sig.
Leg Peak Power	0.918	10	0.340
Rel. Leg Peak Power	0.875	10	0.114
Leg Avg. Power	0.898	10	0.209
Rel. Leg Avg. Power	0.923	10	0.382
Arm Peak Power	0.966	10	0.847
Rel. Arm Peak Power	0.936	10	0.510
Arm Avg. Power	0.933	10	0.482
Rel. Arm Avg. Power	0.911	10	0.285

Note. Rel. - relative; Avg. - average.

Levene's test was conducted to evaluate the assumption of homogeneity of variances. A paired sample t-test was conducted to compare anaerobic power outputs between the upper and lower extremities. Additionally, Cohen's d was calculated as an effect size measure, with values interpreted as small (0.2), medium (0.5), and large (0.8) [15]. An *a priori* power analysis was performed using G*Power 3.1 software to determine the required sample size. With an expected effect size of d = 1.0, an alpha level of 0.05, and a statistical power of 0.80, the minimum required sample size was determined to be 10 participants. For all statistical analyses, SPSS version 27.0 (SPSS Inc., Chicago, IL, USA) was used. Statistical significance was set at $p < 0.05$.

Results

The comparison of anaerobic power between the upper and lower extremities in female football players revealed significant differences. As shown in Table 3, both peak and average power outputs were substantially higher in the lower extremities compared to the upper extremities.

Analysis of Table 3 indicates a statistically significant advantage in peak and average power outputs for the lower extremities compared to the upper extremities ($p < 0.05$). The results suggest that female football players generate considerably greater anaerobic power in their legs, which aligns with the sport's physical demands. Since football involves frequent sprinting, jumping, and rapid directional changes, the predominance of lower-body anaerobic power is expected. The high effect sizes observed indicate a substantial magnitude of difference, reinforcing the importance of lower-body strength and power in football performance.

Although the upper extremities contribute to overall athletic performance, particularly in duels and balance, their anaerobic power output is considerably lower. These findings emphasize the necessity of sport-specific training approaches that prioritize lower-body power development while also considering the functional role of upper-body strength in football.

To further assess anaerobic power differences between the upper and lower extremities, relative peak and average power outputs were analyzed. Table 4 presents the comparison, revealing statistically significant differences, with the lower extremities generating higher relative power than the upper extremities.

As indicated in Table 4, relative peak and average power outputs were significantly greater in the lower extremities than in the upper extremities (p

Table 3. Comparison of peak and average power between upper and lower body in female football players

Parameters	Mean	Sd	95% Confidence Interval of the Difference		t	p	E.S
			Lower	Upper			
Arm Peak Power	243.75	71.62	-190.269	-127.748	-11.506	.000	3.63
Leg Peak Power	402.76	69.90					
Arm Avg. Power	127.01	51.43	-201.194	-146.345	-14.334	.000	4.53
Leg Avg. Power	300.78	53.04					

Note. Avg - average; CI - confidence interval; E.S = effect size; significant differences at p < 0.05.

Table 4. Comparison of relative peak and average power between upper and lower body in female football players

Parameters	Mean	Sd	95% Confidence Interval of the Difference		t	P	E.S
			Lower	Upper			
Arm Peak Power	4.39	1.12	-3.610	-2.375	-10.970	.000	3.46
Leg Peak Power	7.39	.92					
Arm Avg. Power	2.27	.81	-3.728	-2.745	-14.899	.000	4.71
Leg Avg. Power	5.51	.66					

Note. Avg = average; CI = confidence interval; E.S = effect size; significant differences at p < 0.05.

< 0.05). These findings align with the physiological demands of football, where explosive movements primarily rely on lower-body musculature.

The substantial effect sizes observed suggest that the difference in relative anaerobic power is not only statistically significant but also practically meaningful. The lower extremities' dominance in anaerobic performance underscores the importance of specific strength and power training for the legs. While upper-body power plays a secondary role, it may still contribute to overall athletic performance, particularly in balance and physical duels.

Discussion

This study compared the anaerobic power of the upper and lower extremities in female football players. The participants had an average age of 19.50±1.84 years, an average height of 163.90±5.38 cm, and an average body weight of 54.00±3.91 kg. The results revealed that the anaerobic power values of the lower extremities were significantly higher compared to the upper extremities (p<0.05). Specifically, the peak power in the legs was found to be significantly greater than in the arms. Similarly, the mean power values were also higher in the legs compared to the arms. These findings are consistent with previous research indicating that anaerobic power in football players is largely focused on the lower extremities [16, 17]. In contrast, different anaerobic power profiles have been observed in other sports. For instance, in basketball, the anaerobic power of the upper extremities is higher, which provides an advantage in aerial duels and shooting [18]. Similarly, in sports like wrestling and boxing, upper extremity anaerobic power is a determining performance factor [13]. This highlights the sport-specific nature of anaerobic power development, where training adaptations are closely linked to movement demands. Moreover, recent studies emphasize the direct relationship between lower extremity anaerobic power and sprint performance in football players [19].

Specifically, a study by Krustrup et al. [4] showed that muscle glycogen stores in female football players are significantly depleted during a match, directly affecting sprint performance. This finding underscores the importance of integrating nutritional strategies and energy management into training programs for female football players. Furthermore, recent research has shown that anaerobic power can be developed through training, and such improvements can directly impact game performance [2]. While the primary role of anaerobic power in football is attributed to the lower extremities, the contribution of the upper extremities should not be underestimated. Developing upper extremity strength can provide an advantage in balance and contact-dependent positions [20]. For example, upper-body engagement plays a crucial role in shielding the ball, resisting challenges, and maintaining stability during rapid directional changes. Additionally, well-developed upper-body strength may help prevent injuries by improving overall postural control during high-intensity movements.

Understanding the power levels of the upper and lower extremities in female football players is crucial for optimizing training programs. In particular, recent studies demonstrating the impact of lower extremity strength on anaerobic capacity confirm that football players with higher anaerobic power cover greater distances at higher speeds during matches [6]. The results of this study indicate that lower extremity muscle strength is significantly higher, which aligns with the demands of the sport. Since movements such as sprinting, shooting, and changing direction are largely carried out by the lower extremities, the ability of these muscle groups to produce explosive force is crucial. Recent research highlights the critical role of lower extremity strength training in enhancing explosive power and anaerobic endurance [12, 21].

However, the lower upper extremity power output compared to the lower extremities in female football players can be explained by the supportive and stabilizing role of the arms rather than their primary function in force generation [9]. Nevertheless, the importance of the upper extremities in aerial duels and balance should not be overlooked. New research has demonstrated that upper extremity strength can improve endurance during physical confrontations and positively contribute to performance in female football players [21]. Therefore, targeted training programs aimed at enhancing upper extremity strength can contribute to improving overall performance in female football players.

The findings of this study contribute to the growing body of research on anaerobic power distribution in female football players. The observed dominance of lower extremity anaerobic power aligns with previous studies and reflects the physiological demands of football. Furthermore, the role of the upper extremities in balance and physical confrontations highlights the need to consider a holistic approach to performance evaluation. By providing comparative data on anaerobic power between the upper and lower body, this study offers valuable insights into the physical characteristics of female football players.

Conclusions

This study compared anaerobic power between the upper and lower extremities in female football players. The results highlight the need for optimized training programs. The results suggest that priority should be given to developing lower extremity anaerobic power in training regimens. The low number of participants is one of the limitations of our study. However, individualized training programs should also account for physiological variations, menstrual cycle effects, and the interplay between aerobic capacity and anaerobic power. Menstrual cycle effects data on this variable were not collected. If included in future studies, this could strengthen the research.

Future research should include larger sample sizes and examine players of varying age groups and performance levels to provide a more comprehensive understanding of anaerobic capacity. Additionally, implementing next-generation testing protocols and technological analysis systems could contribute to enhancing training strategies and improving overall performance in female football players.

Practical Applications

The findings of this study indicate that lower extremity anaerobic power is higher than upper extremities in female football players, but upper body strength plays a crucial role in aerial duels, physical challenges, and balance maintenance. Therefore, training programs can incorporate exercises that enhance upper body strength. Coaches should implement periodic tests to monitor anaerobic power development and design a training program that balances upper and lower extremity strength.

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Conflicts of Interest

The authors declare no conflict of interest.

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