

ORIGINAL RESEARCH

Anaerobic power differences between upper and lower body in male greco-roman wrestlers: A wingate test analysis

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Abstract. The aim of this study was to compare the anaerobic power outputs of the upper and lower body muscle groups during a 30-second Wingate Anaerobic Test (WAnT) in male Greco-Roman wrestlers. The study specifically aimed to examine the differences between peak and average power over time and how the anaerobic systems contribute to performance in both body regions. The study involved 30 male Greco-Roman wrestlers (mean age: 15.97 ± 1.27 years, mean height: 174.50 ± 5.02 cm, mean body weight: 68.37 ± 11.81 kg). The participants were summoned to the laboratory over three different test days. On the first day, the participants performed a preliminary practice session to familiarize themselves with the equipment used in the study. On the second day of testing, half of the group was randomly assigned to the arm Wingate test, while the other half participated in the leg Wingate test. Each participant performed warm-up exercises before the test. Three days later, the participants returned to the laboratory and swapped their tests. During the 30-second test, peak and average power outputs were recorded, and the averages for each 5-second interval were calculated. Data were analyzed using paired t-tests to compare peak and average power outputs between the arm and leg Wingate tests. Statistical significance was set at $p < 0.05$. Significant differences were found between the leg and arm tests for both peak and average power; leg power was significantly higher in both parameters ($p < 0.01$). Additionally, relative power (Watt/kg) values were significantly higher in the legs compared to the arms. The analysis of power outputs over time showed that leg power was higher in every 5-second interval, with the largest differences observed in the first 10 seconds of the test. The study revealed that despite the emphasis on upper body strength in Greco-Roman wrestling, leg anaerobic power outputs were superior to the arms. This can be attributed to the larger muscle mass in the lower body, a higher proportion of fast-twitch muscle fibers, and biomechanical advantages.

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Introduction

The 30-second Wingate Anaerobic Test (WAnT) is widely regarded as one of the most effective methods for evaluating anaerobic performance, offering valuable insights into an individual's anaerobic power and capacity (Bar-Or, 1987; Tortu & Deliceoglu, 2024; Ziegler et al., 2024). The test measures maximal power output (PO) in two primary modalities: leg-based and arm-based assessments (Kochanowicz et al., 2024; Venckunas et al., 2024). While the leg modality primarily reflects lower-body strength and power (Potteiger et al., 2010; Souissi et al., 2007), the arm modality provides insights into upper-body anaerobic performance (Nowak et al., 2021). Comparing these two modalities allows for a more comprehensive understanding of an individual's total anaerobic power output, making it a valuable tool for assessing performance in various athletic disciplines (Astorino et al., 2024). Moreover, variations in maximal power outputs between the

upper and lower body can offer critical insights into the development of muscular strength, endurance, and training adaptations. Evaluating these differences not only enhances sport-specific conditioning programs but also aids in optimizing anaerobic training strategies.

The Arm Wingate Test is widely recognized for its validity and reliability in assessing anaerobic power and functional performance across various populations, including elite athletes (Kounalakis et al., 2009) and clinical groups (Jacobs et al., 2003). Typically conducted on a cycle ergometer, the Wingate Anaerobic Test (WAnT) requires participants to exert maximal anaerobic effort over a short test duration (Song et al., 2021). This high-intensity exercise primarily engages the anaerobic energy systems, specifically the anaerobic alactic (ATP-PCr) system and the anaerobic lactic (glycolytic) system (Driss & Vandewalle, 2013).

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While numerous studies have explored the contributions of these energy systems—particularly in lower-body WAnT performance (Nara et al., 2022) comparatively less research has examined their role in upper-body anaerobic output. The physiological and biomechanical demands of upper-body exercises differ significantly from those of lower-body exercises, which raises important questions about how energy systems function in the arm modality of the test (Beneke et al., 2002). Previous studies have also reported substantial differences in power output between the upper and lower body, even when normalized for active muscle mass (Weber et al., 2006). These findings suggest that upper-body exercises, such as arm cranking during WAnT, may depend more on specific anaerobic pathways than lower-body activities like cycling. Factors such as muscle mass distribution, fiber composition, and metabolic efficiency likely contribute to these variations (Julio et al., 2019). Given these differences, a deeper understanding of anaerobic system contributions in upper-body WAnT is crucial for optimizing training strategies and performance assessments in upper-body-dominant sports. Investigating these energy system dynamics can provide valuable insights into the physiological demands of upper-body anaerobic power, ultimately enhancing sport-specific conditioning and rehabilitation protocols.

Considering the distinct differences in energy system contributions between the upper and lower body, this study aims to examine and compare the average anaerobic power outputs across 5-second intervals during two separate 30-second Wingate Anaerobic Tests (WAnT). Understanding these variations is essential for advancing our knowledge of anaerobic performance across different muscle groups and has important implications for training strategies and performance assessments. In particular, this research is highly relevant for athletes and individuals participating in upper-body-dominant sports or activities, where anaerobic power plays a crucial role. By gaining deeper insights into the specific energy demands of the upper body, we can develop targeted training programs that enhance anaerobic performance and optimize overall functional capacity.

Materials and Methods

Subjects

Thirty Greco-Roman wrestlers participated in this study. Participants were informed about the study's objectives and associated risks. Written informed consent was obtained from all participants, and the study protocol was approved by the Ethics Committee

of Selçuk University, Faculty of Sports Sciences. The descriptive statistics of the participants are presented in Table 1. Inclusion criteria required that participants had been actively training as licensed Greco-Roman wrestlers for at least two years. Additionally, all participants had to have engaged in regular training at least three times per week over the past six months. Prior to participation, each athlete underwent a medical examination to ensure there were no health conditions that could interfere with intense physical activity.

Exclusion criteria included any musculoskeletal injury affecting the upper or lower extremities (e.g., muscle tear, fracture) within the past three months. Participants were also excluded if they had any diagnosed respiratory, cardiovascular, or neuromuscular disorders.

Experimental Design

The study was conducted over three separate sessions at the Sports Sciences Laboratory. During the first visit, held one week prior to the actual testing, all participants performed a familiarization trial of the Wingate Anaerobic Test (WAnT) using both the arm and leg ergometers. This session aimed to minimize any learning effects and ensure participants were accustomed to the equipment and procedures. On the second visit, following a standardized wrestling-specific warm-up, participants were randomly assigned to one of two groups. One group performed the arm Wingate test, while the other completed the leg Wingate test. All tests were conducted individually under standardized conditions, and power output data were recorded and transferred to a computerized system for further analysis. Three days later, participants returned for the third session and switched test conditions. Those who had previously completed the arm Wingate test now performed the leg test, and vice versa. This crossover design allowed for within-subject comparison of anaerobic performance between the upper and lower body. To control for fatigue-related variability, participants were instructed to abstain from any vigorous physical activity for at least 48 hours prior to each testing session.

Arm and Leg Wingate Test

For the Wingate test, a Monark 891E arm ergometer and a Monark 894E cycle ergometer with a weight basket (manufactured in Sweden) were used. The ergometers were connected to a computer system that had been modified for the test and equipped with compatible software for data collection. Each machine was adjusted according to the individual height of the athletes before testing.

The external resistance load on the ergometer was set at 50 g/kg for the arm test and 75 g/kg for the leg test. A 5-minute warm-up protocol was applied, which included 2 to 3 sprints lasting 4–8 seconds at a pedal speed of 60–70 RPM, using 20% of the calculated test load. After the warm-up, participants rested passively for 3–5 minutes before beginning the test.

Athletes were instructed to reach their maximum pedal speed as quickly as possible without resistance. Once they achieved their peak speed (typically within 3–4 seconds), the calculated resistance load (50 g/kg for arms and 75 g/kg for legs) was applied, and the test began. Participants were encouraged to pedal at maximum effort for 30 seconds against the applied resistance. Throughout the test, they received verbal encouragement to maintain effort levels. The average

power output over the 30-second test period was recorded for analysis (Aktaş & Çakmakçı, 2020; Tatlici & Cakmakci, 2019).

Statistical Analysis

The Shapiro-Wilk test was used to determine that the dataset follows a normal distribution. Performance data obtained from arm and leg wingate measurements were subjected to analysis using the paired sample T-test, comparing different angular velocities and contraction types. Cohen’s d effect sizes ($d \leq 0.2$, small; 0.5–0.79, moderate; ≥ 0.8 , large) (Cohen, 2013) were calculated to assess the magnitude of difference between lower and upper body anaerobic power. All statistical tests were performed using the software package SPSS version 27.0 (SPSS Inc., Chicago, IL, USA). An alpha value of <0.05 was considered to be statistically significant.

Results

Table 1. Descriptive Statistics

	N	Min	Max	Mean	Std. Deviation
Age	30	14	18	15.97	1.27
Height	30	162	181	174.50	5.02
Body Weight	30	47	90	68.37	11.81
Sport age	30	2.00	5.00	3.60	0.67

Table 2. Test of Normality

		Shapiro-Wilk	df	Sig.
		Statistic		
Arm	Peak Power	0.967	30	0.472
	Avg Power	0.975	30	0.687
	0-5 Avg	0.978	30	0.759
	5-10 Avg	0.986	30	0.950
	10-15 Avg	0.936	30	0.072
	15-20 Avg	0.984	30	0.912
	20-25 Avg	0.979	30	0.793
	25-30 Avg	0.982	30	0.876
	Peak Power	0.971	30	0.568
Arm Relative	Avg Power	0.976	30	0.708
	0-5 Avg	0.945	30	0.125
	5-10 Avg	0.974	30	0.668
	10-15 Avg	0.981	30	0.854
	15-20 Avg	0.963	30	0.374
	20-25 Avg	0.971	30	0.561
	25-30 Avg	0.974	30	0.652
	Peak Power	0.979	30	0.785
	Avg Power	0.982	30	0.878
Leg	0-5 Avg	0.977	30	0.739
	5-10 Avg	0.972	30	0.589
	10-15 Avg	0.963	30	0.361
	15-20 Avg	0.963	30	0.360
	20-25 Avg	0.933	30	0.057
	25-30 Avg	0.939	30	0.083
	Peak Power	0.954	30	0.222
	Avg Power	0.965	30	0.415
	0-5 Avg	0.946	30	0.129
Leg Relative	5-10 Avg	0.946	30	0.131
	10-15 Avg	0.983	30	0.889
	15-20 Avg	0.971	30	0.566
	20-25 Avg	0.986	30	0.957
	25-30 Avg	0.985	30	0.938

Table 3. Comparison of participants' peak power and average power for upper and lower body.

Parameters Watt	Mean	Std. Dev.	95% Confidence Interval of the Difference		t	P	E.S
			Lower	Upper			
			Arm Peak Power	462.41			
Leg Peak Power	636.40	139.58					
Arm Avar. Power	284.97	85.52	-215.84	-175.15	-19.65	0.001*	3.58
Leg Avar. Power	480.48	97.70					

Ava: Avarage, *Significantdifferences(p<0.01).

Table 4. Comparison of participants' relative peak power and average power for upper and lower body.

Parameters (Watt/kg)	Mean	Std. Dev.	95% Confidence Interval of the Difference		t	P	E.S
			Lower	Upper			
			Arm Peak Power	6.68			
Leg Peak Power	9.36	1.20					
Arm Avar. Power	4.12	0.96	-3.17	-2.65	-22.93	0.001*	4.18
Leg Avar. Power	7.04	0.80					

Ava: Avarage, *Significantdifferences(p<0.01).

Analysis of the results revealed statistically significant differences in relative peak power and average power between the upper and lower body, with the lower body exhibiting superior performance (p<0.01 for both parameters).

The results indicate that the differences in peak and average power outputs between the upper and lower body were statistically significant, with the lower body demonstrating superior performance (p<0.01 for both parameters).

Table 5. Comparison of participants' average power for upper and lower body at 5-second intervals

Parameters Watt	Mean	Std. Deviation	95% Confidence Interval of the Difference		t	P	E.S
			Lower	Upper			
			0-5 sec. Arm Ava Pow.	272.38			
0-5 sec. Leg Ava Pow.	526.44	118.97					
5-10 sec. Arm Ava Pow.	355.48	94.59	-220.22	-155.11	-11.79	0.001*	2.15
5-10 sec. Leg Ava Pow.	543.15	108.49					
10-15 sec. Arm Ava Pow.	306.76	94.63	-205.34	-145.45	-11.98	0.001*	2.18
10-15 sec. Leg Ava Pow.	482.16	104.57					
15-20 sec. Arm Ava Pow.	267.90	84.47	-191.98	-138.71	-12.69	0.001*	2.31
15-20 sec. Leg Ava Pow.	433.25	98.43					
20-25 sec. Arm Ava Pow.	228.59	66.79	-176.68	-124.55	-11.81	0.001*	2.15
20-25 sec. Leg Ava Pow.	379.21	89.74					
25-30 sec. Arm Ava Pow.	195.10	67.08	-172.75	-125.35	-12.86	0.001*	2.34
25-30 sec. Leg Ava Pow.	344.15	84.54					

Ava: Avarage, *Significantdifferences(p<0.01).

Table 6. Comparison of participants' relative average power for upper and lower body at 5-second intervals.

Parameters (Watt/kg)	Mean	Std. Deviation	95% Confidence Interval of the		t	P	E.S
			Difference				
			Lower	Upper			
0-5 sec. Arm Ava Pow.	3.98	1.38	-4.31	-3.15	-13.18	0.001*	2.40
0-5 sec. Leg Ava Pow.	7.71	1.24	-3.20	-2.25	-11.70	0.001*	2.13
5-10 sec. Arm Ava Pow.	5.19	1.21	-3.24	-2.48	-15.29	0.001*	2.79
5-10 sec. Leg Ava Pow.	7.91	1.14	-2.14	-1.36	-9.27	0.001*	1.69
10-15 sec. Arm Ava Pow.	4.42	1.08	-2.55	-1.90	-14.07	0.001*	2.56
10-15 sec. Leg Ava Pow.	7.28	0.88	-2.44	-1.88	-15.66	0.001*	2.85
15-20 sec. Arm Ava Pow.	3.79	0.92					
15-20 sec. Leg Ava Pow.	5.55	0.81					
20-25 sec. Arm Ava Pow.	3.31	0.79					
20-25 sec. Leg Ava Pow.	5.55	0.81					
25-30 sec. Arm Ava Pow.	2.82	0.83					
25-30 sec. Leg Ava Pow.	4.99	0.80					

Ava: Avarage, *Significantdifferences(p<0.01).

Table 5 shows that the differences in average power between the upper and lower body were statistically significant, with the lower body exhibiting higher power values across all tested time intervals (0–5, 5–10, 10–15, 15–20, 20–25, and 25–30 seconds; p<0.001 for each interval).

Table 6 revealed statistically significant differences between upper and lower body relative average power, with the lower body showing higher values at all tested time intervals (0-5, 5-10, 10-15, 15-20, 20-25, 25-30 seconds) (p< 0.001 for each time interval).

Discussion

The objective of this study was to compare anaerobic power outputs between the arm and leg muscle groups during the Wingate Anaerobic Test (WAnT). From a physiological standpoint, the differences in maximal anaerobic power outputs between the upper and lower extremities can be attributed to the varying contributions of different energy systems. However, these differences may also be influenced by the specific demands of different sports and the athletic specialization of individuals. Notably, wrestlers may exhibit distinct power output patterns compared to athletes in other sports (Ozan et al., 2018). To the best of our knowledge, fluctuations in average and peak power outputs over distinct time intervals during a 30-second maximal effort have not been extensively investigated in wrestlers. Therefore, this discussion is framed within the context of existing literature on energy system contributions to anaerobic performance during the WAnT for both the upper and lower extremities. Beneke et al. (Beneke et al., 2002) have provided valuable insights into how anaerobic energy systems support peak power generation and sustained performance during maximal effort tests like the WAnT.

Although Greco-Roman wrestling heavily relies on upper-body strength, the anaerobic power output of the legs generally surpasses that of the arms, even in this upper-body-dominant sport. This outcome aligns with fundamental human physiology. One of the primary reasons for the greater strength and anaerobic power of the legs is the anatomical structure of the lower and upper body muscles. The larger muscle groups in the legs—such as the quadriceps, hamstrings, glutes, and calves—exhibit significantly greater power-generating capacity compared to the smaller upper-body muscles, including the biceps, triceps, and deltoids (Lovell et al., 2013; McArdle et al., 2010). Additionally, muscle fiber composition plays a crucial role in power output. The leg muscles contain a higher proportion of type II (fast-twitch) fibers, which are essential for generating high-intensity, explosive power. In contrast, the arm muscles have a greater proportion of type I (slow-twitch) fibers, which are more suited for endurance-based activities rather than explosive strength (McArdle et al., 2010).

Furthermore, the biomechanical advantage of the lower body is another key factor contributing to the superior anaerobic power output observed in the legs (Liu & Li, 2022). Due to their larger muscle mass and extended range of motion across multiple joints, the legs can generate greater mechanical work compared to the arms. In terms of anaerobic energy system contributions, the ATP-PCr (alactic) system and the glycolytic (lactic) system are suggested to function differently in the upper and lower body. Due to their greater muscle mass, the legs are generally believed to have a higher capacity for ATP production, which may help explain their superior power generation within a shorter timeframe (Lovell et al., 2013; Tortu et al., 2024).

The study’s findings revealed that average power values at each 5-second interval were consistently

higher during leg anaerobic performance compared to arm performance. Notably, arm power output increased by 30.50% during the 5–10 second period, whereas the increase in leg power over the same interval was considerably smaller (3.17%). In contrast, a sharp decline in arm power was observed during the third time period, while leg power exhibited a more gradual decrease over the final three intervals. These findings align with existing research, which suggests that the upper and lower extremities follow distinct anaerobic power patterns over time, particularly in the first 10–15 seconds of maximal effort (Lovell et al., 2013).

These differences may be attributed to variations in neuromuscular and cardiovascular function between the upper and lower body, both at rest and during exercise (Calbet et al., 2003; Lovell et al., 2013). The upper-body muscles tend to contain a higher proportion of type II fibers, which are better suited for short, explosive efforts (Sanchis - Moysi et al., 2010). Additionally, the upper body typically consumes less oxygen during exercise compared to the lower body, a difference that may be influenced by muscle fiber composition, blood flow, and oxygen delivery mechanisms (Lovell et al., 2013). These physiological distinctions likely contribute to variations in anaerobic energy system activation during maximal efforts, further emphasizing the unique energy demands of the arms and legs during the WAnT. Another potential factor influencing performance differences between the arms and legs in the first 10–15 seconds is the role of the alactic energy system. This system, which relies on phosphocreatine (PCr) stores, provides immediate energy for short, high-intensity bursts of activity (McArdle et al., 2010) and is considered to be particularly important during the initial seconds of the WAnT, according to previous physiological research.

The glycolytic system, which primarily generates energy through anaerobic pathways (Ulupinar & Özbay, 2022), is suggested to play a greater role in upper-body performance during the WAnT, as indicated by previous studies. This finding aligns with the results of Julio et al. (Julio et al., 2019), who investigated energy system contributions in upper and lower body Wingate tests among highly trained athletes. Their study confirmed that the glycolytic system played a more dominant role in the upper body, supporting the notion that upper-body anaerobic power relies more heavily on glycolytic metabolism. Similarly, Lovell et al. (Lovell et al., 2013) found that the anaerobic lactic system was the primary energy contributor during the upper-body Wingate test. While our study did not examine these contributions in detail, the findings highlight the need

for further research in this area. Future studies should explore how both the glycolytic and ATP-PCr systems contribute to anaerobic performance in the upper and lower body, particularly in Greco-Roman wrestling, where upper-body strength plays a critical role.

Conclusion

The greater anaerobic power of the legs compared to the arms can be attributed to several key factors, including anatomical differences, muscle fiber composition, biomechanical advantages, and energy system contributions. The larger muscle mass and higher proportion of fast-twitch fibers in the legs allow for greater force and power generation, making them more efficient in anaerobic activities. Understanding these differences is crucial for optimizing training strategies, enhancing athletic performance, and developing effective rehabilitation programs. By tailoring training regimens to address the specific anaerobic demands of the upper and lower body, athletes can maximize performance in both sports and daily activities.

Practical Applications

Understanding the differences in anaerobic power between the legs and arms has significant implications for training optimization and performance assessment in Greco-Roman wrestling. Since wrestlers primarily depend on upper-body strength for executing techniques such as throws and holds, training programs should prioritize enhancing the anaerobic capacity of the upper body. Strengthening the arms, shoulders, and upper back is essential for improving anaerobic power-dependent movements, including explosive actions and sustained efforts during a match. Furthermore, can be attributed to the varying contributions of different energy systems. leg-based version. The arm Wingate test more accurately reflects the specific physical demands of Greco-Roman wrestling, as it directly assesses upper-body anaerobic capacity, which is critical for wrestling performance. While the leg Wingate test is effective for evaluating lower-body anaerobic power, it does not provide relevant performance data for wrestlers, as the sport places less emphasis on lower-body strength. By utilizing the arm Wingate test for anaerobic power assessments, trainers can gain valuable insights into their athletes' upper-body performance, enabling them to develop more targeted and effective training programs. This approach ensures that wrestlers are better prepared to meet the anaerobic demands of their sport.

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Conflict of interest

The authors declare that there is no conflict of interest regarding this article.

Ethics approval and consent to participate

The study was approved by the local ethics committee (Protocol number 93, 16 July 2024, Ethics Committee of Selcuk University, Faculty of Sports Science, Konya, Turkey) in accordance with the Declaration of Helsinki. Before the assessment, every participant received the same detailed information about the testing procedure. Every participant signed the informed consent.

Authors' Contribution

Study Design: AS, HG, DHA.

Data Collection: AS, HG,

Statistical Analysis: AS, DHA.

Manuscript Preparation: AS, HG, DHA.

Funding Acquisition: AS, HG, DHA.

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