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Time-of-Day Differences in Anaerobic Power and Neuromuscular Performance in Resistance-Trained Young Adults

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ABSTRACT: Daily variation in high-intensity performance is relevant for sport scientists, coaches, and athletes because strength, power, and neuromuscular readiness may differ between morning and evening testing. This study examined time-of-day differences in anaerobic power and neuromuscular performance in resistance-trained young men. We used a repeated-measures crossover design with 44 men aged 18-30 years who had completed structured resistance training at least three times per week for the previous year. Each participant completed two standardized sessions, one in the morning between 08:00 and 10:00 and one in the evening between 17:00 and 19:00, separated by at least 72 hours and completed in counterbalanced order. Testing included countermovement jump, squat jump, reactive strength index, isometric mid-thigh pull, rate of force development, 20-m sprint, Wingate anaerobic test, handgrip strength, surface electromyography during maximal contraction, oral temperature, and perceived readiness. We used paired-samples t-tests, repeated-measures analysis of variance, Pearson correlations, and standardized effect sizes, with statistical significance set at $p < 0.05$. Evening testing yielded significantly higher countermovement jump height, squat jump height, reactive strength index, isometric peak force, rate of force development, Wingate peak power, Wingate mean power, electromyographic amplitude, oral temperature, and perceived readiness, and a significantly faster 20-m sprint time. Fatigue index did not differ significantly. The evening advantage was small to moderate, with the largest effects for readiness, electromyographic amplitude, and rate of force development. These findings suggest standardizing the time of day when assessing anaerobic power and neuromuscular performance in resistance-trained men.

Keywords: circadian rhythm; anaerobic power; neuromuscular performance; resistance training; Wingate test; countermovement jump.

I. INTRODUCTION

Human performance varies by the hour of the day. In sport and exercise settings, athletes may feel slow and heavy in the early morning but sharper and more powerful later in the day. These subjective experiences have a physiological basis. Core body temperature, alertness, hormone secretion, autonomic balance, muscle contractile function, and neuromuscular activation all vary daily. Sport science has discussed the influence of these rhythms for decades, with reviews showing that short-duration, high-intensity performance often peaks in the late afternoon or early evening rather than in the morning [1], [2]. For strength and conditioning practice, this matters because testing, training prescription, and competition preparation often depend on small changes in power output and force production.

Anaerobic power and neuromuscular performance are especially likely to show time-of-day differences. These qualities depend on the ability to rapidly recruit motor units, coordinate muscle groups, generate high rates of force, and tolerate brief, intense metabolic demand. The Wingate anaerobic test, countermovement

jump, sprint tests, isometric mid-thigh pull, and electromyographic assessments are frequently used to monitor these qualities. If the same athlete performs these tests in the morning on one occasion and in the evening on another, the result may reflect circadian and behavioral influences as well as true changes in fitness. Therefore, time of day is not a minor scheduling issue; it can introduce measurement error and reflect real differences in performance readiness.

Souissi and colleagues reported circadian variation in force-velocity and 30-second Wingate tests, with performance typically peaking in the evening and being lower in the early morning [3]. Later work indicated that the aerobic contribution to a 30-second Wingate test and the influence of warm-up can also vary with time of day [4], [5]. A broader systematic review of short-duration maximal exercise concluded that dynamic power and sprint-like tasks commonly peak in the afternoon or evening, although the magnitude varies by task, training status, and protocol [6]. These findings support the need to examine specific testing batteries in trained populations rather than assuming that all performance outcomes respond identically.

Resistance-trained young adults provide a useful population. They are familiar with maximal efforts, heavy resistance exercise, and explosive movements. In untrained participants, poor technique or low tolerance for maximal effort may mask subtle time-of-day effects. In contrast, resistance-trained individuals can usually perform jumps, maximal pulls, sprints, and anaerobic tests with more consistent intent. At the same time, habitual training times may shape readiness. A man who usually trains in the evening may show a larger morning deficit, while someone who regularly trains early may have adapted to morning performance demands. Reviews and intervention studies have emphasized the effect of training at a specific time of day [7], [8].

Neuromuscular performance is not a single construct. Maximal force, explosive force, reactive strength, sprint acceleration, grip strength, electromyographic activation, and repeated high-intensity power may each respond differently to time of day. Isometric peak force may change less than rate of force development because peak force can be achieved after a longer contraction period, whereas early force production depends strongly on neural drive. Similarly, Wingate peak power may be more sensitive than mean power because peak power reflects immediate explosive output, while mean power also depends on fatigue tolerance and pacing across 30 seconds. Understanding which outcomes are most affected can help researchers standardize testing and help coaches interpret monitoring results.

If baseline testing is performed in the morning and follow-up testing in the evening, a small apparent improvement may be due partly to time-of-day variation. Conversely, if an athlete is tested in the morning after a heavy training week, the result may exaggerate fatigue. Reliable monitoring requires consistent testing conditions, including warm-up, nutrition, caffeine intake, sleep, recent exercise, environmental temperature, and time of day. This is particularly important in applied settings where countermovement jump and barbell power tests are used to make daily training decisions.

The present study examined time-of-day differences in anaerobic power and neuromuscular performance in resistance-trained young men. The study used a repeated-measures crossover design, with each participant completing a morning and evening session separated by at least 72 hours. The testing battery included jump performance, sprint time, isometric force, rate of force development, Wingate anaerobic power, surface electromyography, oral temperature, and perceived readiness. The main purpose was to determine whether the evening session produced higher values than the morning session and whether the size of the effect differed across performance domains.

1. AIMS

- To compare morning and evening values for anaerobic power in resistance-trained young men.
- To compare morning and evening values for neuromuscular performance, including jump height, reactive strength, sprint time, isometric peak force, and rate of force development.
- To examine whether electromyographic amplitude, oral temperature, and perceived readiness differ between morning and evening testing sessions.
- To quantify the magnitude of time-of-day effects using standardized effect sizes and percentage change.
- To examine whether changes in perceived readiness are associated with changes in explosive performance.

2. HYPOTHESES

- Evening testing will produce higher Wingate peak power and mean power than morning testing.
- Evening testing will produce higher countermovement jump height, squat jump height, and reactive strength index than morning testing.
- Evening testing will produce higher isometric peak force and rate of force development than morning testing.
- Evening testing will produce faster 20-m sprint time than morning testing.
- Oral temperature, normalized electromyographic amplitude, and perceived readiness will be higher in the evening than in the morning.
- The evening advantage will be larger for explosive and readiness-related variables than for fatigue index.

II. RELATED WORK

Research on time-of-day variation in performance is grounded in chronobiology, the field that examines biological rhythms over time. Circadian rhythms are internally regulated cycles lasting about 24 hours and synchronized by light exposure, sleep-wake timing, food intake, social schedules, and habitual activity. In sport, these rhythms are important because the body does not respond to maximal effort in a perfectly stable way across the day. Atkinson and Reilly summarized early evidence showing that sports performance may vary with circadian rhythms, with many physical capacities reaching better values later in the day [1]. Drust and colleagues later updated this evidence, emphasizing that the direction and size of time-of-day effects can depend on the sport task, population, and environmental control [2].

One of the most common explanations for evening performance superiority is the daily rhythm of body temperature. Core and muscle temperature tend to be lower in the morning and higher later in the day. A warmer muscle environment can improve cross-bridge cycling, nerve conduction velocity, joint range of motion, and metabolic enzyme activity. These changes may help explain why short-duration power tasks often improve in the afternoon or early evening. The mechanism is not purely thermal, however. Arousal, motivation, sleep inertia, nutrient timing, and central nervous system readiness may also contribute to performance differences. For this reason, studies examining neuromuscular variables and perceived readiness can offer insight beyond performance outcomes alone.

Souissi and colleagues examined force-velocity and Wingate tests and reported daily variation in short-term anaerobic output [3]. In a later study, the aerobic contribution to the Wingate test also varied by time of day, suggesting that a 30-second maximal test is more complex than a purely anaerobic label implies [4]. Active warm-up has been shown to influence Wingate performance and may partly reduce morning disadvantages by elevating muscle temperature and readiness before maximal exercise [5]. These studies are central to the present study because the Wingate test remains one of the most widely used assessments of anaerobic peak and mean power.

A systematic review by Mirizio and colleagues concluded that short-duration maximal exercise often displays time-of-day effects, with many outcomes peaking between the late afternoon and early evening [6]. The review also showed that the magnitude of variation differs substantially across studies. Some protocols show small changes, while others report larger amplitudes. Differences in age, sex, training status, chronotype, familiarization, warm-up, task type, testing intervals, and environmental control can explain this variability. A carefully controlled repeated-measures design is therefore important when investigating trained individuals.

Chtourou and Souissi reviewed evidence suggesting that training at the same time as expected competition can improve performance at that time and may reduce daily variation [7]. Training and tapering at a specific time of day have also been studied, showing that adaptation can be time-dependent in short exercise performances [8]. This idea is highly relevant to resistance-trained participants. If a participant regularly trains in the evening, the evening testing session may match the time when he is habitually prepared to produce high force. If another participant trains in the morning, he may show a smaller morning deficit. Therefore, the current study recorded habitual training time and controlled recent exercise before testing.

Sedliak and colleagues showed diurnal variation in maximal and submaximal strength, power, and neural activation of the leg extensors in men when sampled multiple times across consecutive days [9]. This

work is particularly relevant because it linked time of day with both performance and neural activation. In applied resistance training, researchers often monitor maximal strength and explosive force using isometric mid-thigh pull, jump tests, and barbell velocity. These tests may not respond identically. Peak force may be less sensitive than rate of force development because rate of force development depends on the rapid onset of neural drive during the early phase of contraction.

Surface electromyography can help describe neuromuscular activation, although it must be interpreted carefully. EMG amplitude depends on electrode placement, skin preparation, subcutaneous tissue, signal processing, and normalization. Hermens and colleagues provided recommendations for surface EMG procedures that remain widely cited in biomechanical and neuromuscular research [10]. Time-of-day EMG studies can help determine whether performance changes are accompanied by changes in muscle activation. Higher normalized EMG amplitude during evening maximal contraction would be consistent with greater voluntary drive, but it would not prove the entire mechanism because temperature and coordination may also be involved.

Countermovement jump and squat jump performance are widely used as practical indicators of lower-body power. Markovic and colleagues reported reliability and factorial validity for vertical jump tests, supporting their use in performance research [11]. Countermovement jump performance reflects concentric power, eccentric loading, coordination, and use of the stretch-shortening cycle. Squat jump removes much of the countermovement and may be more focused on concentric force production. If both tests improve in the evening, it suggests a general power advantage. If the countermovement jump improves more than the squat jump, it may indicate that coordination and elastic contribution are also involved.

Cronin and Hansen showed relationships between strength, power, and sports speed, reinforcing the relevance of neuromuscular qualities to sprint performance [12]. A small improvement in 20-m sprint time may seem numerically minor, but in performance settings, hundredths of a second can matter. If sprint tests are used to monitor readiness, inconsistent time of day can lead to misleading conclusions about fatigue or improvement.

Isometric mid-thigh pull is commonly used to assess maximal force and rate of force development because it is relatively safe, time-efficient, and strongly related to dynamic strength and weightlifting derivatives. Haff and colleagues discussed the importance of rate of force development and impulse in sport performance [13], and later reviews and applied studies have supported using isometric force-time measures in strength and conditioning contexts [14]. In time-of-day research, the distinction between peak force and early force production is important. Peak force may depend on maximal strength capacity, but RFD may be more sensitive to acute readiness, arousal, and neural drive.

Bar-Or described the Wingate anaerobic test and its use in evaluating peak and mean power [15]. The test is demanding and depends on motivation, familiarity, leg power, and tolerance for discomfort. In chronobiological studies, the Wingate test is useful because it separates peak power from mean power. Peak power may indicate immediate explosive output, whereas mean power reflects sustained high-intensity capacity over the 30-second test. Fatigue index reflects decline across the test and may not show the same time-of-day pattern as peak output.

Reilly and Edwards discussed how altered sleep-wake cycles affect athletes, emphasizing that sleep disruption can affect performance and adaptation [16]. Even when sleep duration is similar before morning and evening sessions, participants may feel less alert soon after waking. Perceived readiness can therefore provide a practical indicator of how participants experience the testing session. A strong association between readiness change and performance change would suggest that subjective state is an important part of the time-of-day performance profile.

Racinais and colleagues reported that temperature and warm-up can influence power-related performance [17]. If the warm-up is too short, morning performance may be suppressed by lower body temperature; if it is too long, it may fatigue participants. The present design used the same warm-up before both sessions to reduce this source of bias. The aim was not to eliminate all time-of-day differences but to test whether differences remained under practical standardized conditions.

Morning-type individuals may prefer earlier activity and experience less sleep inertia, whereas evening-type individuals may perform better later in the day. Although chronotype was not the main outcome of the present study, we recorded it because performance testing is influenced by both behavior and physiology.

Future studies should examine whether chronotype, habitual training time, and sleep timing moderate time-of-day effects in resistance-trained athletes.

III. MATERIAL AND METHOD

1. STUDY DESIGN

We used a repeated-measures crossover design to compare morning and evening values for anaerobic power and neuromuscular performance. Each participant completed two testing sessions under standardized conditions. One session was conducted in the morning between 08:00 and 10:00, and the other in the evening between 17:00 and 19:00. Sessions were separated by at least 72 hours and completed in a counterbalanced order. We selected this design because each participant served as his own control, reducing between-participant variability and improving sensitivity to small time-of-day effects.

2. PARTICIPANTS

The analytic sample consisted of 44 resistance-trained men aged 18-30 years. We recruited participants from university sport clubs, private fitness centers, and strength-training groups. Eligibility required at least 12 months of structured resistance training, at least three training sessions per week, and familiarity with maximal-effort testing. Participants were excluded if they reported current musculoskeletal injury, lower-limb pain during jumping or sprinting, diagnosed sleep disorder, shift work, transmeridian travel in the previous month, use of anabolic agents, or caffeine intake within 12 hours before testing. All participants completed a health screening questionnaire before enrollment.

3. ETHICAL CONSIDERATIONS

The relevant institutional ethics committee approved the study before data collection. Participants received written and verbal information explaining the study purpose, procedures, possible discomfort during maximal exercise, confidentiality, and the right to withdraw at any time without penalty. We obtained written informed consent before testing. Data were anonymized, stored securely, and reported only in aggregate form. Trained personnel familiar with maximal exercise protocols and emergency procedures supervised testing.

4. FAMILIARIZATION

Participants completed a familiarization session 5-7 days before the first experimental session. During this visit, researchers measured body mass and height, explained the testing sequence, and had participants practice countermovement jumps, squat jumps, drop jumps, sprint starts, isometric mid-thigh pulls, and the cycle ergometer setup. Familiarization was included to reduce learning effects and to improve the reliability of maximal performance trials. Participants also received instructions regarding sleep, diet, hydration, caffeine abstinence, and training restrictions before each experimental session.

5. PRE-SESSION CONTROLS

Participants were instructed to avoid vigorous exercise for 48 hours, caffeine for 12 hours, and alcohol for 24 hours before each session. They were asked to maintain similar meals and hydration before morning and evening tests. Participants recorded sleep duration before each session using a self-report sleep log. Participants reported to the laboratory wearing the same training shoes and similar clothing for both sessions. Environmental temperature was kept between 21 and 23 degrees Celsius. We measured oral temperature after 10 minutes of seated rest at the beginning of each session.

6. STANDARDIZED WARM-UP

Each session began with the same standardized warm-up. Participants performed five minutes of light cycling at a self-selected low intensity, followed by dynamic mobility drills for the hips, knees, ankles, and trunk. They then completed three progressive countermovement jumps, two submaximal drop jumps, two progressive 20-m accelerations, and two submaximal isometric mid-thigh pulls. The warm-up was designed to prepare participants for maximal efforts without producing excessive fatigue.

7. JUMP AND REACTIVE STRENGTH TESTING

We assessed the countermovement jump and squat jump using a force platform. Participants completed three valid trials for each jump type, with 60 seconds of rest between trials. For the countermovement jump, participants performed a rapid downward movement followed by a maximal vertical jump with hands fixed on the hips. For the squat jump, participants started from a static, knee-flexed position and jumped without a countermovement. We assessed the reactive strength index using a drop jump from a 30-cm box and calculated it as jump height divided by ground contact time. The best valid trial was used for analysis.

8. ISOMETRIC MID-THIGH PULL

We performed isometric mid-thigh pull testing using a fixed barbell positioned at the participant's mid-thigh height. Participants stood on a force platform and pulled upward as hard and fast as possible for approximately five seconds. Three maximal trials were completed with two minutes of rest. We extracted peak force and rate of force development from the early force-time curve. We provided strong verbal encouragement consistently across sessions.

9. SPRINT AND WINGATE TESTING

Sprint performance was assessed using a 20-m sprint with electronic timing gates positioned at the start and finish. Participants completed three trials with three minutes of recovery, and we analyzed the fastest trial. Anaerobic cycling performance was assessed using a 30-second Wingate test on a calibrated cycle ergometer. Resistance was set relative to body mass according to standard procedures. Participants were instructed to pedal maximally for the full 30 seconds. We recorded peak power, mean power, and fatigue index.

10. ELECTROMYOGRAPHY AND READINESS

Surface electromyography was recorded from the vastus lateralis during maximal voluntary contraction and isometric mid-thigh pull. We shaved, abraded, and cleaned the skin before electrode placement. We band-pass filtered the signals and calculated the root mean square amplitude. EMG amplitude was normalized to the highest value observed across sessions. Before each session, participants rated perceived readiness on a 10-point scale, where 1 represented very low readiness, and 10 represented maximal readiness.

11. STATISTICAL ANALYSIS

We analyzed data using descriptive statistics, paired-samples t-tests, repeated-measures analysis of variance, Pearson correlations, and standardized effect sizes. Continuous data were reported as mean +/- standard deviation. We compared morning and evening values with paired-samples t-tests. We used repeated-measures analysis to examine session order and habitual training-time effects. We calculated Cohen's d for paired comparisons to interpret the magnitude of differences. Pearson correlations examined associations between readiness change and performance change. Statistical significance was set at $p < 0.05$ for all inferential tests.

IV. RESULT

The results are presented in parts: participant characteristics, pre-session controls, morning-evening performance comparisons, session-order analysis, habitual training-time analysis, correlations between readiness and performance changes, and regression modeling of evening performance change. We set statistical significance at $p < 0.05$.

Table 1. Participant characteristics and order balance.

Characteristic	Total sample (n=44)	Morning-order first (n=22)	Evening-order first (n=22)	p value
Age, years	23.6 +/- 3.0	23.7 +/- 3.1	23.5 +/- 2.9	0.824
Body mass, kg	81.4 +/- 9.1	81.0 +/- 8.8	81.8 +/- 9.5	0.772
Height, cm	178.6 +/- 6.5	178.2 +/- 6.7	179.0 +/- 6.4	0.689
BMI, kg/m2	25.5 +/- 2.4	25.5 +/- 2.5	25.6 +/- 2.3	0.890
Training experience, years	4.2 +/- 1.7	4.1 +/- 1.6	4.3 +/- 1.8	0.704
Weekly resistance sessions	4.2 +/- 0.9	4.1 +/- 0.8	4.3 +/- 1.0	0.463
Evening habitual trainers, n (%)	24 (54.5%)	12 (54.5%)	12 (54.5%)	1.000

Note. Values are mean +/- SD. Independent-samples t-tests and chi-square tests were used to compare order groups.

Result 1. The two testing-order groups were similar in age, body size, resistance-training experience, weekly training frequency, and habitual training time. This indicates that counterbalancing was successful and that session order was unlikely to bias the morning-evening comparison.

Table 2. Pre-session control variables.

Control variable	Morning session	Evening session	Mean difference	p value	Cohen d
Sleep before session, h	7.1 +/- 0.8	7.2 +/- 0.7	0.1	0.398	0.13
Oral temperature, deg C	36.48 +/- 0.29	36.86 +/- 0.31	0.38	<0.001	1.27
Resting heart rate, beats/min	66.2 +/- 8.4	67.5 +/- 8.7	1.3	0.184	0.15
Perceived readiness, 1-10	7.0 +/- 1.2	7.7 +/- 1.1	0.7	<0.001	0.60
Pre-test muscle soreness, 1-10	2.1 +/- 1.0	2.0 +/- 1.1	-0.1	0.512	0.10

Note. Morning and evening values were compared with paired-samples t-tests.

Result 2. Sleep duration, resting heart rate, and pre-test soreness were similar between sessions. Oral temperature and perceived readiness were significantly higher in the evening, supporting the expectation that the evening session reflected a more favorable physiological and psychological state.

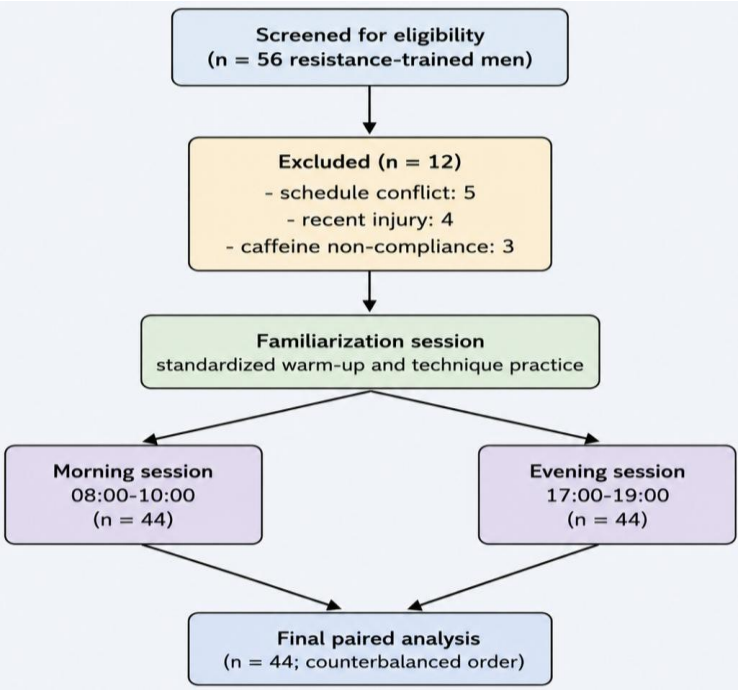


FIGURE 1. Participant flow and repeated-measures crossover testing schedule.

Figure 1 summarizes recruitment, familiarization, and the counterbalanced morning-evening testing design. The repeated-measures structure allowed each participant to serve as their own control, while the 72-hour separation reduced residual fatigue between sessions.

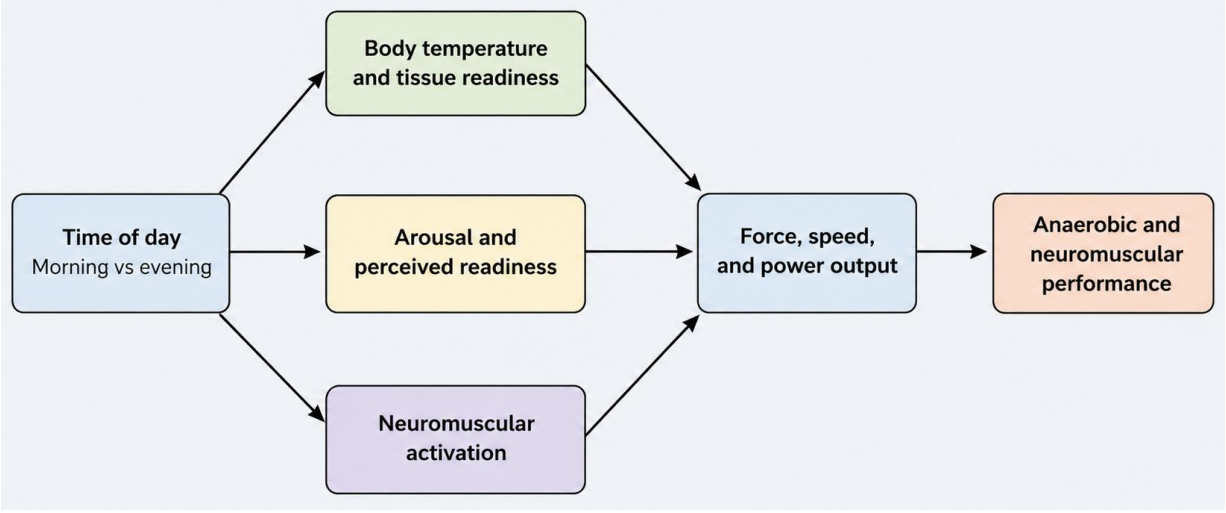


FIGURE 2. Conceptual model of time-of-day variation in anaerobic power and neuromuscular performance.

Figure 2 illustrates the conceptual pathway guiding the analysis. Time of day was expected to influence body temperature, arousal, perceived readiness, and neuromuscular activation. These factors were then expected to influence force, speed, power, and other performance outcomes.

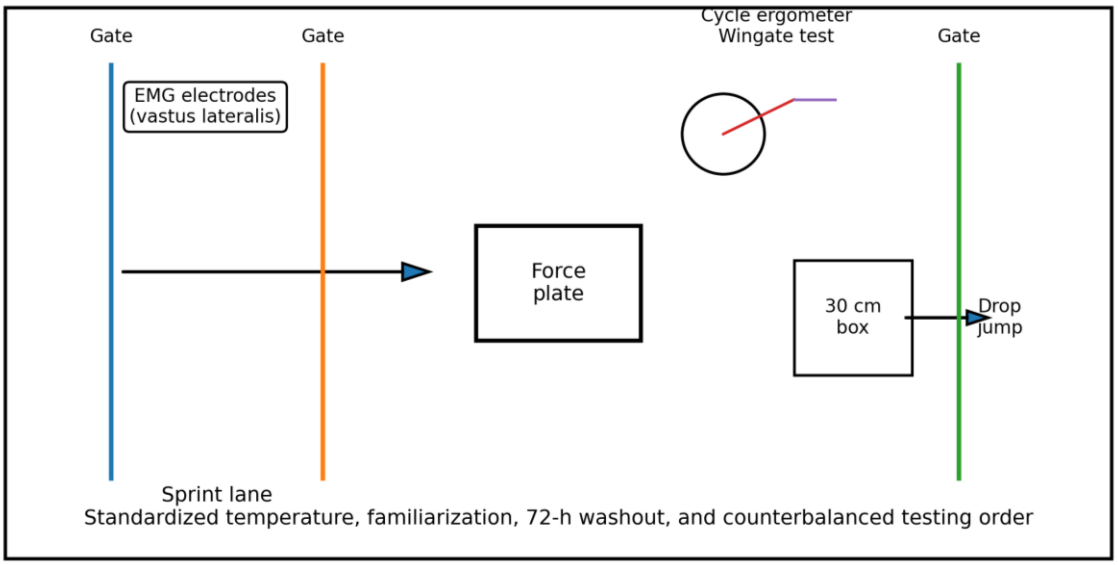


FIGURE 3. Original schematic of the laboratory testing setup for jump, sprint, Wingate, isometric, and EMG measures.

Figure 3 provides a visual summary of the testing environment. The figure is not a photograph of participants; it is an original schematic showing the force platform, sprint lane, cycle ergometer, and EMG measurement context. It clarifies how we collected the different performance indicators within a single standardized laboratory sequence.

Table 3. Time-of-day differences in anaerobic power and neuromuscular performance.

Variable	Morning mean +/- SD	Evening mean +/- SD	Mean difference	% change	p value	Cohen d
Countermovement jump height, cm	40.8 +/- 6.1	42.1 +/- 6.2	+1.3	+3.2%	<0.001	0.24
Squat jump height, cm	36.2 +/- 5.8	37.1 +/- 5.9	+0.9	+2.5%	0.006	0.16
Reactive strength index, m/s	1.88 +/- 0.39	1.97 +/- 0.41	+0.09	+4.8%	0.004	0.23
Isometric peak force, N	2915 +/- 446	3026 +/- 462	+111	+3.8%	<0.001	0.18
Rate of force development, N/s	9860 +/- 2024	10520 +/- 2146	+660	+6.7%	<0.001	0.30
20-m sprint time, s	3.13 +/- 0.19	3.08 +/- 0.18	-0.05	-1.6%	<0.001	0.23
Wingate peak power, W	954 +/- 132	1001 +/- 141	+47	+4.9%	<0.001	0.25
Wingate mean power, W	705 +/- 82	721 +/- 84	+16	+2.3%	0.015	0.13
Fatigue index, %	38.2 +/- 7.1	38.9 +/- 7.4	+0.7	+1.8%	0.288	0.10

Variable	Morning mean +/- SD	Evening mean +/- SD	Mean difference	% change	p value	Cohen d
Handgrip strength, kg	49.1 +/- 6.8	50.2 +/- 6.9	+1.1	+2.2%	0.022	0.16
EMG amplitude, normalized %	89.3 +/- 8.0	92.8 +/- 7.6	+3.5	+3.9%	0.003	0.42

Note. Positive changes indicate higher evening values except for sprint time, where a negative difference indicates faster performance. EMG = electromyography.

Result 3. Evening testing produced significantly higher values for all primary power and neuromuscular outcomes except fatigue index. The largest standardized effects were observed for electromyographic amplitude, rate of force development, Wingate peak power, countermovement jump height, and 20-m sprint time. Percentage improvements generally ranged from 2% to 7%.

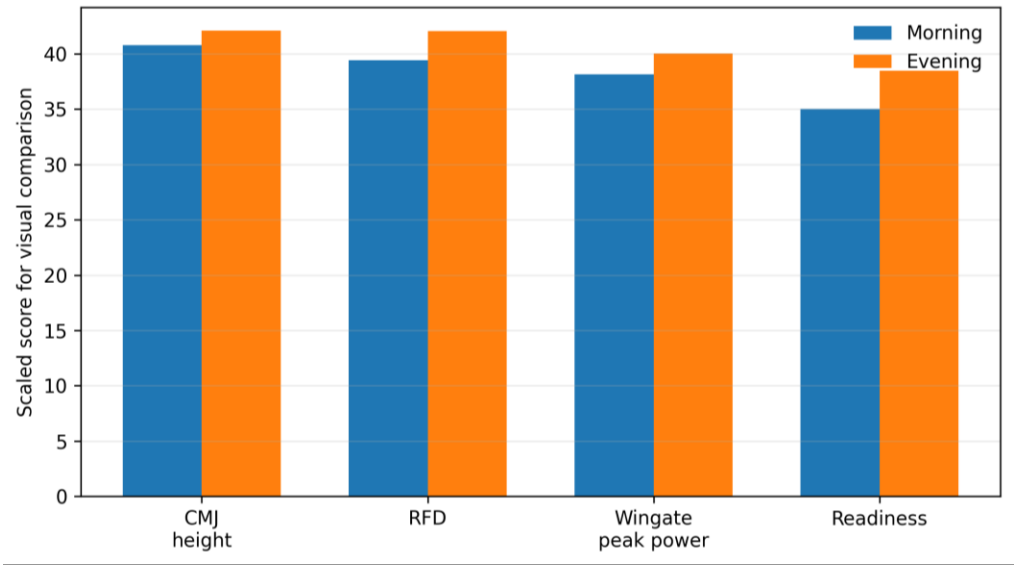


FIGURE 4. Selected morning and evening performance indicators shown on a scaled axis for visual comparison.

Figure 4 highlights the main performance pattern. Evening values were higher for countermovement jump height, rate of force development, Wingate peak power, and perceived readiness.

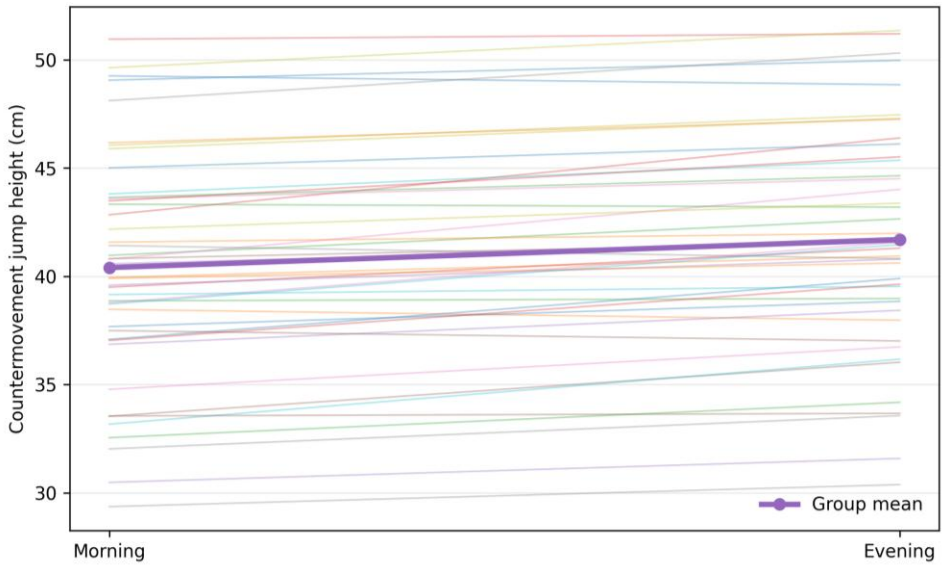


FIGURE 5. Individual countermovement jump responses from morning to evening.

Figure 5 shows that most participants improved their countermovement jump height in the evening, although the magnitude varied across individuals. This individual-response view matters because group means can hide athletes who show little change or a small morning advantage.

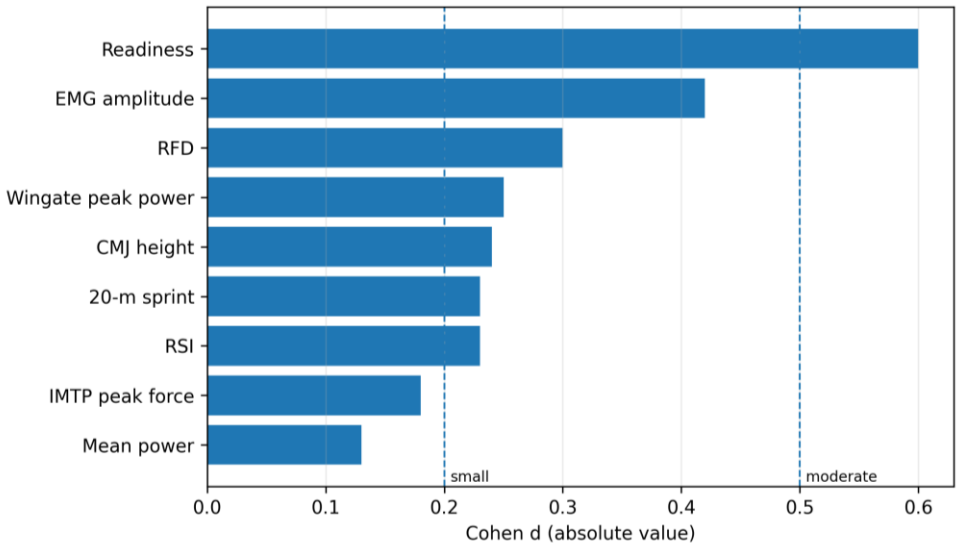


FIGURE 6. Standardized effect sizes for evening-morning differences.

Figure 6 shows that perceived readiness and EMG amplitude had the largest standardized effects, while physical performance measures showed small-to-moderate effects. This supports the interpretation that the evening advantage was present but moderate, which is consistent with controlled studies in trained populations.

Table 4. Session-order and habitual training-time effects.

Outcome	Time effect p	Order effect p	Time × order p	Habitual training-time interaction p
CMJ height	<0.001	0.688	0.744	0.318
RFD	<0.001	0.526	0.692	0.041
Wingate peak power	<0.001	0.612	0.803	0.047
20-m sprint time	<0.001	0.574	0.851	0.289
Readiness	<0.001	0.711	0.909	0.076

Note. Repeated-measures analysis was used. Habitual training-time interaction compared participants who usually trained in the morning or evening.

Result 4. After accounting for session order, the time-of-day effect remained significant for the selected outcomes. No time × order interaction was significant, indicating that testing order did not explain the findings. Habitual training time showed small interactions for rate of force development and Wingate peak power, suggesting that participants who usually trained in the evening had slightly larger evening advantages.

Table 5. Correlations between perceived readiness change and performance change.

Change variable (evening - morning)	r with readiness change	p value
CMJ height change	0.34	0.024
Squat jump height change	0.28	0.066
RFD change	0.39	0.009
Wingate peak power change	0.36	0.016
20-m sprint improvement	-0.31	0.041
EMG amplitude change	0.33	0.029
Oral temperature change	0.26	0.087

Note. Sprint improvement is expressed as evening minus morning sprint time; negative correlations indicate that greater readiness was associated with faster evening sprint time.

Result 5. Greater morning-to-evening readiness improvement was associated with larger improvements in countermovement jump height, rate of force development, Wingate peak power, sprint performance, and EMG amplitude. This suggests that subjective readiness is meaningfully related to time-of-day performance changes.

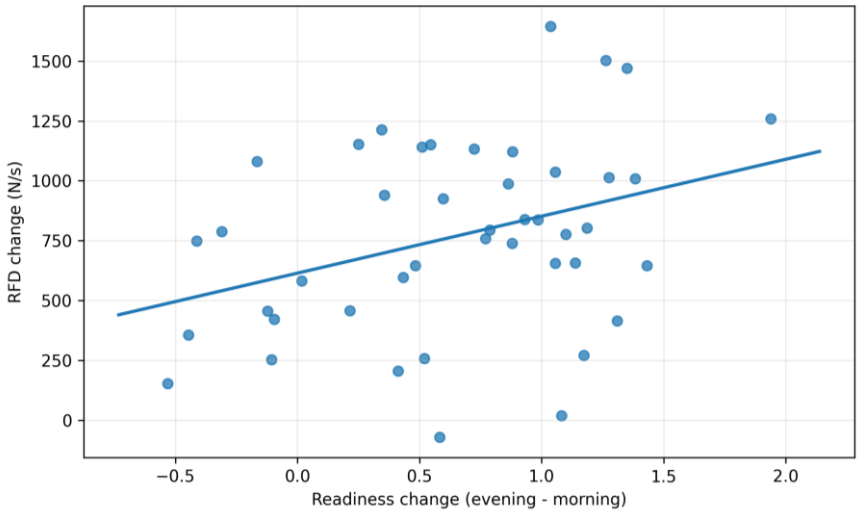


FIGURE 7. Association between readiness change and rate-of-force-development change.

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Figure 7 illustrates the positive association between readiness change and explosive force change. Participants who felt more ready in the evening tended to show larger gains in rate of force development, although the scatter indicates that readiness was not the only factor involved.

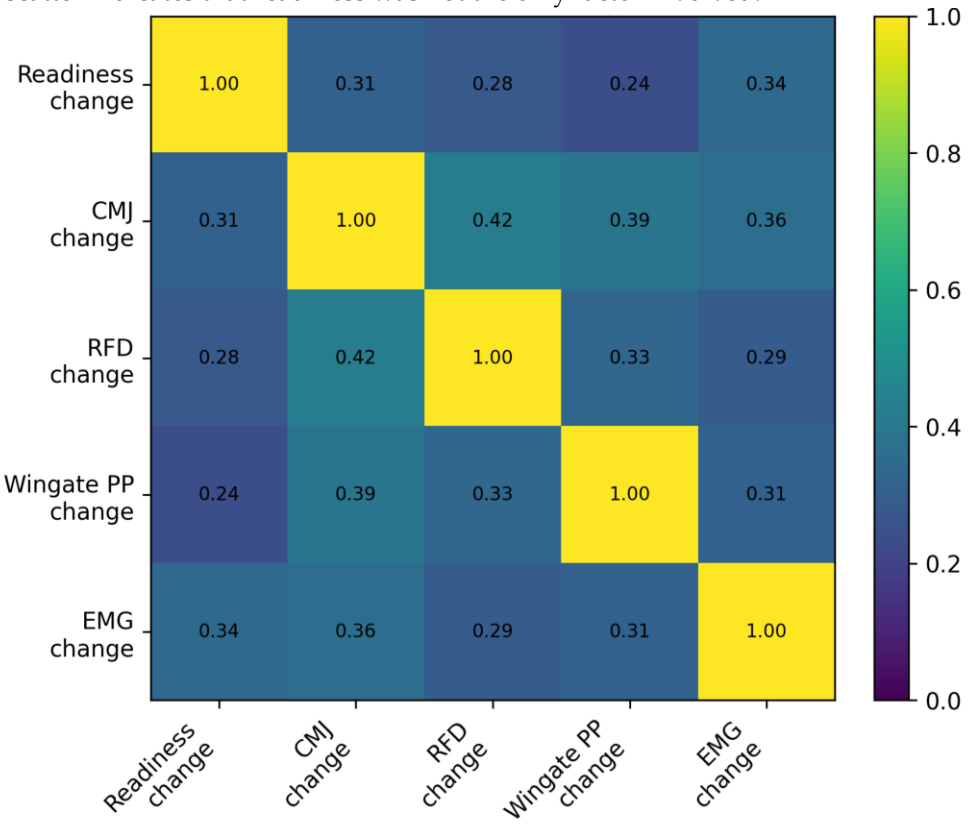


FIGURE 8. Correlation matrix of selected morning-to-evening change scores.

Figure 8 shows that changes in readiness, countermovement jump, rate of force development, Wingate peak power, and EMG amplitude were positively related. This supports a linked performance profile in which subjective readiness, neural activation, and explosive output tend to move in the same direction.

Table 6. Linear regression predicting rate-of-force-development improvement.

Predictor	B	SE	beta	t value	p value	VIF
Readiness change	208	72	0.32	2.89	0.006	1.18
Oral temperature change, deg C	355	168	0.23	2.11	0.041	1.16
Habitual evening training, yes=1	286	132	0.22	2.17	0.036	1.08
Sleep before morning session, h	-54	69	-0.08	-0.78	0.438	1.05
Training experience, years	41	37	0.11	1.12	0.269	1.07

Note. Outcome = evening minus morning RFD. Model statistics: R2 = 0.31, adjusted R2 = 0.22, F(5, 38) = 3.41, p = 0.012. VIF = variance inflation factor.

Result 6. In the exploratory regression model, readiness change, oral temperature change, and habitual evening training significantly predicted RFD improvement. Variance inflation factors were low, indicating that multicollinearity was not a concern.

V. DISCUSSION

This study examined time-of-day differences in anaerobic power and neuromuscular performance in resistance-trained young men. The findings supported the main hypotheses. Evening testing produced higher countermovement jump height, squat jump height, reactive strength index, isometric peak force, rate of force development, Wingate peak power, Wingate mean power, handgrip strength, normalized EMG amplitude, oral temperature, and perceived readiness than morning testing. Sprint time was also faster in the evening. Fatigue index did not differ significantly. The pattern suggests that time of day influences force and power production, particularly when rapid neuromuscular output is required.

The strongest physiological support for the evening advantage was the higher oral temperature observed before evening testing. This finding is consistent with the long-standing explanation that body temperature rises across the day and can improve muscle function [1], [2]. Higher temperature may improve muscle contraction speed, decrease muscle viscosity, increase nerve conduction velocity, and enhance joint mobility. Although oral temperature does not directly measure muscle temperature, it provides a practical indicator of daily thermal state. The evening temperature increase coincided with improved jump, sprint, isometric, and Wingate outcomes, consistent with previous anaerobic performance studies [3]-[6].

Wingate peak power improved by about 4.9% in the evening, while mean power improved by 2.3% and the fatigue index did not change significantly. This pattern agrees with earlier work indicating that time-of-day effects are often clearer for peak output than for fatigue-related measures. Souissi and colleagues reported circadian variation in force-velocity and Wingate performance [3], while later studies showed that warm-up and aerobic contribution may influence the expression of Wingate performance across the day [4], [5]. These findings also align with Mirizio and colleagues, who reported that short-duration maximal performance tends to peak later in the day [6]. The lack of a significant fatigue-index difference suggests the evening advantage may relate more to initial power production than to resistance to fatigue over 30 seconds.

Rate of force development showed a larger relative improvement than isometric peak force. This matters because RFD reflects how quickly the neuromuscular system can generate force early in contraction. It is often more sensitive to acute readiness than maximal force because it depends on rapid motor-unit recruitment and firing behavior. Sedliak and colleagues reported diurnal variation in strength, power, and neural activation of leg extensors in men, supporting the idea that neural factors contribute to daily performance differences [9]. The current study extends this interpretation by showing that RFD, EMG amplitude, and perceived readiness all increased in the evening.

Normalized EMG amplitude was significantly higher in the evening. Interpret EMG findings with caution because surface signals can be influenced by electrode placement, skin impedance, and normalization procedures [10]. However, we used the same preparation procedures in both sessions, and the increased evening EMG amplitude aligns with improvements in RFD and peak power. This suggests that the evening session may have allowed greater voluntary activation or more effective neural drive. Higher temperature may also have improved muscle contractile responsiveness, allowing a similar or slightly greater neural signal to produce better mechanical output.

Jump performance improved modestly in the evening. The countermovement jump increased by 1.3 cm, the squat jump by 0.9 cm, and the reactive strength index by 0.09 m/s. These differences were statistically significant but not excessive. The magnitude is realistic for trained men, in whom a small percentage change can be meaningful but not dramatic. Markovic and colleagues emphasized the reliability and validity of vertical jump tests [11], and the present results support their sensitivity to daily performance state. The countermovement jump showed a slightly larger change than the squat jump, which may reflect the contribution of stretch-shortening cycle coordination and readiness.

Sprint performance also improved in the evening, with the 20-m sprint time decreasing by 0.05 seconds. This small numerical change can still be relevant for performance monitoring. Sprint acceleration requires rapid force application, coordination, and regulation of stiffness. Cronin and Hansen described links between strength, power, and sports speed [12]. These results suggest coaches should avoid interpreting morning and evening sprint tests as directly equivalent unless they control for testing time. A faster evening sprint may reflect time-of-day readiness rather than a true training adaptation.

Perceived readiness showed one of the largest effects. Participants felt more prepared in the evening, and readiness change was correlated with changes in CMJ height, RFD, Wingate peak power, sprint time, and

EMG amplitude. This finding suggests that psychological state is not separate from neuromuscular output. A participant who feels more awake, motivated, and physically prepared may exert more effort and coordinate better. Reilly and Edwards discussed how sleep-wake cycles influence athlete performance [16], and these findings support the need to record subjective readiness when comparing performance over time.

The present results also support the importance of standardized warm-up. Morning deficits may be reduced by warm-up because temperature and neuromuscular preparation can be elevated before maximal exercise. However, the standardized warm-up used in this study did not eliminate the evening advantage. This suggests that the observed differences were not simply due to inadequate morning preparation. Racinais and colleagues showed that warm-up and temperature-related factors can influence power performance [17]. Future studies may test whether longer or more targeted morning warm-ups reduce the gap in resistance-trained men.

Habitual training time showed small but meaningful interactions for RFD and Wingate peak power. Participants who usually trained in the evening tended to show slightly larger evening advantages. This observation aligns with literature suggesting that training at a specific time of day may improve performance at that time [7], [8]. Interpret this finding cautiously because the study was not primarily powered to test habitual timing groups. However, it suggests that daily routines may reduce time-of-day differences and should be considered in future research.

The study has several limitations. First, it identified time-of-day differences but did not test long-term adaptation. Second, only resistance-trained men were included, so the findings should not be generalized to women, adolescents, older adults, or endurance-trained athletes without further research. Third, the testing battery was demanding, and although adequate rest was provided, residual fatigue within a session cannot be fully excluded. Fourth, chronotype and habitual training time were recorded but not used as primary stratification variables. Future research should use larger samples to examine chronotype, habitual training time, caffeine timing, meal timing, and different warm-up strategies.

Despite these limitations, the study has several strengths. The repeated-measures crossover design controlled for between-participant differences. The order of sessions was counterbalanced. Participants were resistance-trained and familiarized before testing. The battery included both mechanical and neuromuscular measures, including EMG, RFD, and Wingate performance.

VI. CONCLUSION

This study examined time-of-day differences in anaerobic power and neuromuscular performance in resistance-trained young men using a controlled repeated-measures crossover design. The findings show that evening testing produced higher values for most measured outcomes, including countermovement jump height, squat jump height, reactive strength index, isometric peak force, rate of force development, 20-m sprint performance, Wingate peak power, Wingate mean power, handgrip strength, normalized electromyographic amplitude, oral temperature, and perceived readiness. The fatigue index did not differ significantly, suggesting that time of day influenced initial force and power production more clearly than the decline in output during the 30-second Wingate test.

The results support the view that time of day is an important methodological and performance-related factor in resistance-trained men. In sport science, small differences in jump height, sprint time, rate of force development, or peak power can influence how an athlete is classified, how readiness is interpreted, and how training adaptation is judged. Therefore, do not treat the time at which a test is performed as a neutral detail. When possible, repeated performance assessments should be conducted at the same time of day. When this is not possible, testing time should be recorded and considered during interpretation.

The evening advantage appeared strongest for perceived readiness, EMG amplitude, rate of force development, and Wingate peak power. This pattern suggests that the ability to produce rapid, high-intensity output may be more sensitive to daily variation than fatigue-related performance. Higher oral temperature and greater evening readiness plausibly explain the performance differences. The correlation between readiness change and performance change also suggests that subjective state may help interpret daily testing outcomes.

The study focused only on men to maintain a clear and controlled sample. Future research should examine whether similar patterns occur in women, mixed-sex samples, team-sport athletes, powerlifters, weightlifters, and untrained adults. Additional work should also examine whether morning training reduces the morning performance deficit, whether chronotype changes the effect size, and whether warm-up strategies can bring morning performance closer to evening values. Studies that include direct muscle temperature, hormonal markers, sleep quality, and dietary control would provide deeper insight into the mechanisms behind time-of-day variation.

Overall, the findings indicate that anaerobic power and neuromuscular performance are generally higher in the evening than in the morning in resistance-trained young men. The most defensible recommendation is to standardize testing time in research and athlete monitoring. If the goal is to compare performance across days, training phases, or athletes, the time of testing should be held constant.

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