Chronobiology and physical performance in sport "the biological clock"

Cronobiología y rendimiento físico en el deporte "el reloj biológico"

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Abstract

Introduction: Chronobiology, the discipline that studies biological rhythms, has shown that the time of day when physical activity is performed has a significant influence on athletic performance.
Objective: This systematic review aims to analyze the current state of research on the contribution of chronobiology to sports and its benefits for athletes, sportspeople, and individuals who engage in high-intensity exercise.
Methodology: The search included articles published between 2015 and 2025. To this end, databases without language restrictions were utilized, yielding 296 articles in the initial search.
Results: A total of 14 studies were finally selected based on the methodological process, considering the variables of chronobiology, sport, strength, and body temperature.
Conclusions: Studies on chronobiology and sports demonstrate that training programs informed by knowledge of circadian rhythms are a crucial tool for enhancing athletic performance and mitigating the risk of fatigue and injury.

Keywords

Cortisol; chronobiology; sport; strength: melatonin, body temperature.

Resumen

Introducción: La cronobiología, disciplina que estudia los ritmos biológicos, ha demostrado que la hora del día en que se realiza la actividad física influye de manera significativa en el rendimiento deportivo.
Objetivo: Esta revisión sistemática tiene como objetivo analizar el estado actual de la investigación sobre la contribución de la cronobiología al deporte y sus beneficios para los atletas, deportistas y personas que realizan ejercicio de alta intensidad.
Metodología: La búsqueda incluyó artículos publicados entre 2015 y 2025. Para ello, se utilizaron bases de datos sin restricciones de idioma, lo que arrojó 296 artículos en la búsqueda inicial.
Resultados: Finalmente, se seleccionó un total de 14 estudios basados en el proceso metodológico, considerando las variables de cronobiología, deporte, fuerza y temperatura corporal.
Conclusiones: Los estudios sobre cronobiología y deporte demuestran que los programas de entrenamiento basados en el conocimiento de los ritmos circadianos constituyen una herramienta crucial para mejorar el rendimiento deportivo y mitigar el riesgo de fatiga y lesiones.

Palabras clave

Cortisol; cronobiología; deporte; fuerza; melatonina; temperatura corporal.

Introduction

Chronobiology, known as the internal biological clock, is a scientific discipline that studies biological rhythms and has gained significant relevance in the world of sports and physical activity. From a physiological standpoint, the human body has a primary clock located in the hypothalamus, specifically in the suprachiasmatic nucleus (SCN), which coordinates the individual clocks of each cell to regulate vital functions in humans. These rhythms, known as circadian rhythms (CR), are endogenous biorhythms with a period of approximately 24 hours that influence a wide range of physiological systems (Hatfield, Nicoll, & Kraemer, 2016). Therefore, when discussing chronobiology or time in biology, one must first understand its molecular process and relationship with genes and variables that change according to each person, given that the biological clock can become unbalanced, or what is commonly known as social jet lag, in situations where activities are performed against the biological clock, such as people who work at night. Causing health problems, which are related to breast cancer and metabolic diseases, accompanied by mental health problems, according to scientific evidence in morning and evening populations.

In the context of sports, training times tailored to each person's chronotype are crucial for achieving greater performance and enhancing physical abilities. According to contemporary studies, it has been shown that the time of day when sports or physical activity is practiced significantly influences physical performance. Therefore, research has indicated that muscle power and strength production are greater in the mid-afternoon or evening than in the morning (Robertson et al., 2024). This diurnal variation in performance has been attributed to various mechanisms, both internal (endogenous) and external (exogenous) (López-Samanes et al., 2016). This argument is shared by Reilly & Waterhouse (2008), who relate these factors to changes in physical performance. The difference in short-term maximum performance is partly explained by the circadian rhythm of resting core temperature (RCT), which acts as a passive warming mechanism, as well as motivational and peripheral factors (Mhenni et al., 2017). This argument is shared by Edwards et al. (2025), who state that diurnal variation in muscle strength production has been attributed to higher rectal and muscle temperatures at night.

Time-of-day-dependent fluctuations in athletic performance have been documented in different disciplines, affecting both endurance and strength exercises (Mirizio et al., 2020). Most published studies have shown that performance in short-duration maximal exercises, such as sprints, jumps, or isometric contractions, peaks between 4:00 p.m. and 8:00 p.m. (Mirizio et al., 2020). For example, research by Blazer et al. (2020) showed that maximum power during cycling sprints was significantly higher in the afternoon than in the morning, demonstrating that bench press strength and 25m swimming time were higher at the end of the day. Similarly, electromyography (EMG), a laboratory instrument that measures bioelectrical tension in muscles during anaerobic exercise, also varies, with the highest biopotential amplitude values being recorded in the afternoon and evening (Stawiarska et al., 2024).

The chronotype of athletes, that is, their natural preference for training in the morning or at night, significantly influences their performance and recovery, especially in endurance sports such as triathlon (Vitale et al., 2019). This factor is crucial for training and competition planning. Additionally, sleep quality is considered crucial for athletic performance, and its disruption can have detrimental effects on competition (Vitale et al., 2019). Although female participation in sports has increased, there is a notable scientific gap, according to an analysis by Gaos et al. (2023), which revealed that none of the 44 studies examined had included exclusively female athletes, suggesting a need for further research in this field to understand gender variations in the chronobiology of athletic performance. Current studies have highlighted a significant impact of diurnal variations on cognitive and physical performance indices in the female population (Orhan et al., 2025). Despite ample evidence supporting diurnal variation, some studies have reported that time of day has little or no impact on specific performance measures. However, this may be related to exercise adherence and personal preference (Blazer et al., 2020). The article addresses topics such as chronobiology in sport, strength, and body temperature, which are relevant to understanding this phenomenon. Its objective is to analyze the current state of research on the contribution of chronobiology to sport and how this benefits athletes, sportspeople, and individuals who engage in high-intensity exercise.

Chronobiology and body temperature

The term "CIRCADIEM," meaning "close to a day," is fundamental to understanding the relationship between chronobiology and athletic performance, whether at a competitive or recreational level. It has been shown that the time of day when exercise is performed influences power and speed in multiple modalities of anaerobic endurance exercise (Blazer et al., 2020), highlighting the preference for daytime or evening exercise, which plays a crucial role in adherence and training behavior, presenting patterns of vigor and greater attitude and aptitude in motor performances.

One of the most significant factors affecting physical performance is body temperature, which, along with the sleep-wake cycle, constitutes one of the primary circadian rhythms (Atkinson & Reilly, 1996). The acrophase of the body temperature curve peaks at dusk, between 5:00 and 6:00 p.m., respectively, a time that is associated with improvements in various components of physical performance, linking it to maximum arousal, which is related to better pattern recognition, faster reaction speed, and muscle strength, extending the adaptation until 9:00 p.m. In addition, the perception of effort decreases, fatigue is reduced, and maximum effort is better tolerated (Shephard, 1984). Although maximum body temperature in the late afternoon acts similarly to a "warm-up," it is important to note that moderate hyperthermia can reduce muscle performance (Edwards et al., 2025). This suggests that short-duration maximal exercise performance throughout the day is controlled not only by body temperature, hormone levels, motivation, and mood, but also by a versatile circadian system within skeletal muscle (Mirizio et al., 2020).

Evidence suggests that aerobic performance tends to be higher in the afternoon than in the morning, as highlighted by studies in cyclists. These studies have shown that the aerobic contribution to energy release is greater in the afternoon, resulting in better efficiency and faster VO_2 kinetics (Lericollais et al., 2009). Additionally, afternoon training appears to favor muscle hypertrophy and tissue repair, as levels of hormones such as IGFBP-3 and antioxidant activity reach their peak in the afternoon (Ayala et al., 2021). However, responses to these fluctuations are not uniform in both genders. Muscle performance in women may be influenced by the integration of two distinct body temperature rhythms: circadian and circamensal (Birch & Reilly, 2002). Therefore, hormonal fluctuations throughout the cycle, such as increased progesterone, have a thermogenic effect that can raise body temperature and ventilation during exercise (Bambaeichi et al., 2004). Although body temperature is significantly higher in the afternoon for both genders, studies have shown that men experience performance improvements, while women's performance remains constant (Ünver & Cinemre, 2019). This difference underscores the importance of considering the physiological and hormonal differences between genders when planning training and competitions.

Chronobiology in sport

The influence of periods of light and darkness has a significant impact on neuromuscular and metabolic variables, specifically in relation to hormones, which can be regulated, modified, or adapted according to the type of activity. These characteristics are specific to each person, regardless of the type of activity, so larks (active in the morning) or owls (active at night) must identify their metabolic acrophase in order to adapt their activity accordingly. Tom Reilly, considered the father of Sports Science in the United Kingdom, states that in the field of chronobiology related to sport, he determines chronobiological characteristics such as: lark (higher performance in the morning) and evening (higher performance in the afternoon), which can influence the enhancement of physical performance by improving physiological, metabolic, and hormonal processes; with a period of maximum physiological activity between 4:00 and 7:00 a.m. (Atkinson & Reilly, 1996).

Chronobiology plays a crucial role in planning and developing activities for athletes and individuals who engage in regular physical activity. Among the most relevant circadian variables, the scientific literature has identified melatonin, cortisol, and body temperature as key factors in regulating physiological processes directly related to athletic performance. First, melatonin is a hormone produced mainly by the pineal gland, whose secretion is regulated by the cycle of light and darkness. Darkness stimulates its release, while exposure to light inhibits it, with maximum levels reached between 11:00 p.m. and 5:00 a.m. This pattern coincides with a decrease in blood pressure and heart rate (Serin & Acar Tek, 2019). In the field of athletic performance, it has been suggested that melatonin, as a factor in sleep perception and activation, contributes to the control of circadian rhythms and could reduce the symptoms of jet lag in athletes (Drust et al., 2005). Secondly, variations in basal body temperature and hormone concentrations, such as testosterone and cortisol, are noteworthy. These circadian changes can modify physiological processes related to the balance or homeostasis of body fluids, metabolite excretion, and cardiac response, all of which are aspects of great importance for physical activity (López-Samanes et al., 2016). Cortisol is one of the most influential hormones in regulating circadian performance. It is a glucocorticoid secreted by the adrenal glands, with a release pattern characterized by peak levels in the morning, shortly after waking up, and minimum levels at night, which promotes both alertness and energy availability (Lightman, 2008). Along these lines, Anderson et al. (2023) analyzed blood and saliva samples to determine the effect of exercise on the cortisol response after waking up; their results showed that concentrations of this hormone were significantly lower in the morning after an evening exercise session. These findings suggest that cortisol can be considered a valuable biomarker for monitoring responses to physical training.

Similarly, the importance of using non-invasive biomarkers, such as salivary cortisol measurement, is highlighted, supported by advances in wearable technologies that allow for more accurate and affordable monitoring of the physiological response to exercise (Vanegas-Castillo & Peña, 2024). Given the above, circadian biomarkers, such as melatonin, cortisol, and body temperature, are fundamental tools for the scientific and sports communities. Their integration into evaluation and monitoring processes not only contributes to health prevention but also allows for the optimization of athletic performance. Therefore, training planning must take into account the circadian cycles and the morning or evening condition of each athlete, recognizing the interaction between endogenous and exogenous processes that determine their physiological reality.

Method

Search procedure

This research employed a systematic review design of experimental studies in athletes and individuals who exercise, examining the relationship between chronobiology and physical performance in sports. The search for scientific articles was conducted between 2015 and 2025, utilizing the databases PubMed, SPORTDiscus, EBSCOhost, and Web of Science. The keyword "chronobiology" was used as a search criterion, allowing for the identification of most studies that present this characteristic. This meant that the terms sport, body temperature, melatonin, and cortisol, among others, remained as subordinate keywords to the former, linked by the Boolean operators "AND, NOT, OR" in the search carried out according to the PICO strategy. This generated the following criteria: ((sport OR game) NOT (children OR recreation)) AND (Chronobiology OR circadian cycles) AND (force OR power) AND (melatonin OR cortisol OR body temperature). The terms were used in English; for the correct use of terminology, the UNESCO Health Sciences Thesaurus descriptors were consulted.

Exclusion and inclusion criteria

The selection of scientific studies was based on the following inclusion criteria: a) Randomized and crossover experimental studies; b) experimental studies; c) open access studies; d) no language restrictions were established; e) full-text studies; f) studies from 2015 to 2025; g) age of participants, sample between 20 and 30 years old. The following exclusion criteria were established: a) Qualitative research; b) Review/comparative/descriptive studies; c) Studies related to sports nutrition; d) Publication format, abstract, and/or short communications; e) Studies that presented a population with a genetic, cardiac, cognitive, or endocrine condition, or a social condition, as well as emotional or psychological disorders, sleepiness, or stress.

Evaluation of the quality of the articles

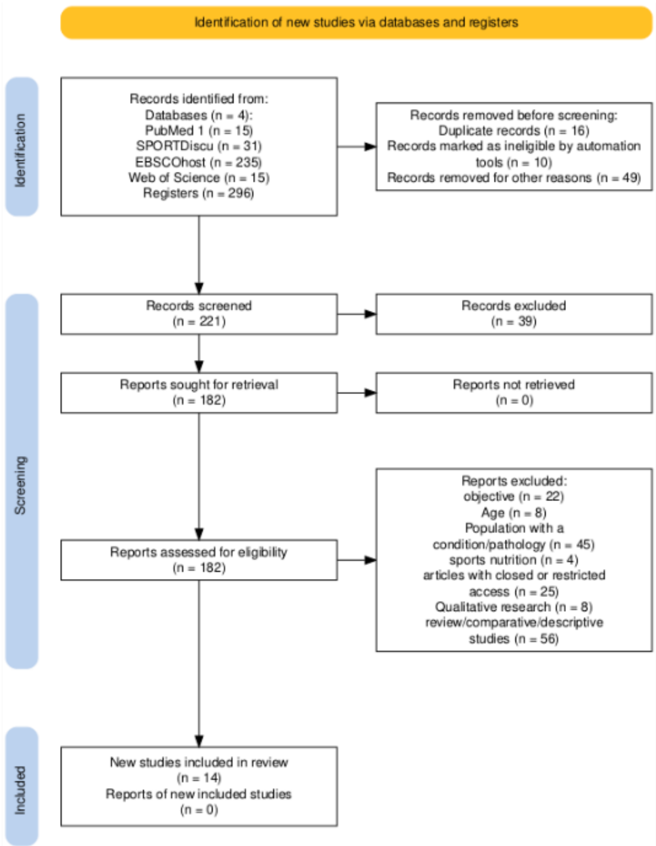
After selecting the sources of information, the quality and relevance of the scientific articles were evaluated taking into account seven components, giving a score to each component: a) type of study (experimental 2 points - randomized/crossed experimental 3 points); b) chronobiological component 1 point; c) strength component 1 point; d) body temperature/ e component 1 point; e) description of data and validity 1 point; f) melatonin and cortisol 1 point; g) ethical parameters 2 points. The maximum score possible is 10 points. To avoid information bias, the studies were evaluated as follows: 0-5 points, low methodological quality; 6-8 points, medium methodological quality; and 9-10 points, high methodological quality. For this review, studies of high and medium quality were considered (Table I).

Note: (Table I), validated using the Delphi methodology. A consensus was reached among the group of experts, comprising three doctors specializing in the area. The objective, validity, and reliability of the studies were highlighted.

Results

According to the results of the search process, 14 studies were selected that met the selection criteria and the quality assessment process: 10 articles of medium methodological quality and four articles of high methodological quality, of which six were published in PubMed, 4 in SPORTDiscu, 2 in Web of Science, and 2 in EBSCOhost. Subsequently, a critical review of each document was conducted.

Figure 1. Selection process flow chart



Fuente: Database search process. PRISMA flow chart

Design/type of study

Among the studies found, four investigations stand out, most of which employ a randomized and crossover/controlled experimental design, presenting a homogeneous population with experience in weight training. These studies highlight biomarkers through analyses of blood, saliva, body temperature, and blood pressure, complemented by perception variables such as motivation and hydration. Table II presents experimental studies, as well as randomized and crossover/controlled studies of the methodological process, comprising a total of fourteen articles.

Analysis of the geographical distribution highlights the scientific community's concern with chronobiology and physical performance in sport. The first studies to analyze physiological and neuromuscular variables in combination were conducted by López-Samanes et al. (2016) and Hatfield et al. (2016). These studies highlight the relationship between circadian variation and physical performance in tennis players and university students. More recent research, such as that by Edwards & Gibbins (2025) and Edwards & Boyle (2025), reports that mood variables are a relevant component of an athlete's chronotype. There have been a steady two publications per year.

Table 1. Study evaluation - Study quality (n = 14)

Articles	Type of study	Component Chronobiology	Strength component	Body temperature component	Data description and validity	Melatonin and cortisol	Ethical and Bioethical Parameters	Judged quality standard
Anderson et al. (2023)	Randomized crossover trial.	Yes	No	No	Yes	Yes	Yes	Average
Robertson et al. (2024)	Experimental	Yes	Yes	Yes	Yes	No	Yes	Average
Robertson et al. (2018)	Experimental	Yes	Yes	Yes	Yes	No	Yes	Average
Pullinger et al. (2019)	Experimental	Yes	Yes	Yes	Yes	No	Yes	Average
Stawiarska et al. (2024)	Experimental	Yes	Yes	Yes	Yes	Yes	Yes	High
Mhenni et al. (2017)	Experimental	Yes	Yes	Yes	Yes	No	Yes	Average
López-Samanes et al. (2016)	Experimental	Yes	Yes	Yes	yes	No	Yes	Average
Blazer et al. (2020)	Randomized crossover trial.	Yes	Yes	Yes	Yes	No	Yes	Average
Ünver & Cinemre (2019)	Experimental crossover.	Yes	Yes	Yes	Yes	No	Yes	High
Gaos et al. (2023)	Experimental	Yes	Yes	Yes	yes	No	Yes	Average
Edwards & Gibbins (2025)	Controlled randomized trial	Yes	Yes	Yes	Yes	No	Yes	High
Edwards & Boyle (2025)	Experimental	Yes	Yes	Yes	Yes	No	Yes	Average
Pullinger et al. (2018)	Experimental	Yes	Yes	Yes	Yes	No	Yes	Average
Hatfield et al. (2016)	Experimental	Yes	Yes	Yes	yes	yes	yes	High

NOTE: Assessment of the quality and relevance of scientific articles

The United Kingdom is the country where the most studies have been conducted, with a total of six investigations: Robertson et al. (2024); Robertson et al. (2018); Pullinger et al. (2019); Edwards and Boyle (2025); Edwards and Gibbins(2025); Pullinger et al. (2018), followed by Spain and the United States, with a total of four studies characterized by their experimental methodological process. Gaos et al. (2023); Hatfield et al. (2016). Finally, Switzerland, Brazil, Tunisia, and Turkey make significant contributions to the field of sports chronobiology.

Table 2. References of selected scientific studies (n = 14)

Type of study	Work
Randomized and crossover/controlled experimental study	Anderson et al. (2023); Blazer et al. (2020); Ünver and Cinemre (2019); Edwards et al. (2025).
Experimental	Robertson et al. (2024); Robertson et al. (2018); Pullinger et al. (2019); Stawiarska et al. (2024); Mhenni et al. (2017); López-Samanes et al. (2016); Gaos et al. (2023); Edwards et al. (2025); Pullinger et al. (2018); Hatfield et al. (2016).

NOTE: Characterization of studies by methodological process

Based on Table III, most of the research (85.7%) was conducted on a population of athletes, while the remaining 14.3% was conducted on an untrained population with homogeneous characteristics. The sample of athletes was consistent, comprising bodybuilders and individuals who engage in high-intensity exercises. In terms of the study's objectives, the analysis of biomarkers, particularly temperature, using various techniques, stands out. The findings are classified as follows. Circadian variation: analyzed in eight studies; motivational values: investigated in two studies; physical performance: evaluated in fourteen studies; hormonal analysis: two specific studies were conducted (Hatfield et al., 2016; Stawiarska et al., 2024).

Table 3. Classification of studies by country, context in which they were conducted, and objectives (n = 14)

Study	Country	Context	Objectives
Anderson et al. (2023)	Switzerland	Participants with homogeneous characteristics	Blood and saliva cortisol hormone levels, heart rate, blood pressure, and hydration biomarkers.
Robertson et al. (2024).	United Kingdom	Trained athletes with experience in weightlifting and a regular level of physical activity.	Rectal/muscle temperature, strength, speed, circadian variation, and mood.
Robertson et al. (2018).	United Kingdom	Resistance-trained athletes: maximum strength and muscle power	Rectal/muscle temperature, strength, peak speed, circadian variation,
Pullinger et al. (2019).	United Kingdom	Trained athletes with experience in strength training	Rectal/muscle temperature, strength, peak speed, circadian variation,
Stawiarska et al. (2024)	Brazil	Untrained men	Circadian variability in muscle tone, body temperature, hormone concentrations such as cortisol and testosterone
Mhenni et al. (2017).	Tunisia	Handball athletes	Circadian rhythm in physical performance
López-Samanes et al. (2016)	Spain	Tennis athletes	Circadian rhythm in physical performance
Blazer et al. (2020)	United States	Experience in muscle training	Strength and motivation
Ünver & Cinemre (2019)	Turkey	Regular training	Jump height (JH), jump performance index (RSI), and ground contact time (GCT)
Gaos et al. (2023).	Spain	Basketball players	Neuromuscular and technical performance
Edwards & Gibbins (2025).	United Kingdom	Athletes with strength training experience	Rectal/muscle temperature, maximum strength, perceived exertion, and mood.
Edwards & Boyle (2025).	United Kingdom	Recreational runners	Performance and circadian variation
Pullinger et al. (2018)	United Kingdom	Experience in muscle training	Diurnal variation in strength performance
Hatfield et al. (2016)	United States	College students	Circadian variations in muscle power production and hormonal changes

NOTE: Characterization of studies by country of origin.

Population/sample characteristics

A total of 223 participants were assessed in the various studies, representing an arithmetic mean of 15.9%. Only one study, by Ünver and Cinemre (2019), demonstrated a relatively large sample of 33 mixed-gender athletes, representing 14.8% who were not identified by chronotype. Looking at the characteristics of the sample, it can be seen that only 22.5% included women, Gaos et al. (2023); Ünver and Cinemre (2019); Mhenni et al. (2017), highlighting the scarcity of studies on the female population in relation to sports training topics. The chronotype of the general population shows that 57.2% have an intermediate chronotype, 7.2% have a morning-evening chronotype, 14.3% have a varied chronotype (intermediate, morning, evening), and 22% do not report a chronotype. This indicates that the participants are neither morning nor evening people.

Table 4. Characteristics of the study sample (n = 14)

Study	Number	Gender	Age	Characteristics	Chronotype
Anderson et al. (2023)	11	Male	N/A	Homogeneous	Not reported
Robertson et al. (2024)	20	Male	21.5 ± 1.1	Athletes	Intermediate
Robertson et al. (2018)	20	Male	21.7 ± 1.4	Athletes	Intermediate
Pullinger et al. (2019)	10	Male	21.0 ± 1.3	Athletes	Intermediate
Stawiarska et al. (2024)	16	Male	21.6 ± 0.62	Untrained men	Intermediate
Mhenni et al. (2017)	15	Female	20.1 ± 1.5	Athletes	Intermediate
López-Samanes et al. (2016)	13	Male	22.5 ± 3.7	Athletes	Not defined 69.2%, morning 23.1%, evening 7.6%
Blazer et al. (2020)	12	Male	21.0 ± 1.7	Athletes	Morning and afternoon
Ünver & Cinemre (2019)	33	Male and female	Men 23.47±2.9; Women 22.25± 2.27	Athletes	Not reported

Gaos et al. (2023)	2	Female	23 ± 4	Athletes	(65%) Intermediate (30%), morning (30%), and evening (5%).
Edwards & Gibbins (2025)	24	Male	25.5 ± 1.9	Athletes	Intermediate
Edwards & Boyle (2025)	12	Male	21.8 ± 2.9	Athletes	Intermediate
Pullinger et al. (2018)	10	Male	21.0 ± 1.3	Athletes	Intermediate
Hatfield et al. (2016)	7	Male	23.6 ± 1.3	Athletes	Not reported

Note: Sample characterization

Hormonal variations and biomarkers

Hormones such as cortisol and testosterone exhibit significant fluctuations throughout the day, with concentrations varying between 10% and 30%. Notably, testosterone levels are higher in the afternoon, which has a positive impact on psychomotor efficiency (Carvalho et al., 2019). Cortisol, in particular, shows a response upon waking that can be influenced by acute exercise (Anderson et al., 2023). Its measurement has been linked to the prediction of depressive disorders, underscoring the interaction between the axis of the neuroendocrine system (HPA) and sleep (Adam et al., 2010; Buckley & Schatzberg, 2005). Insulin, a hormone produced by the pancreas to regulate blood sugar, also has a direct relationship with biological rhythms.

In addition to hormones, body temperature is a key biomarker, as mentioned above. It follows a circadian pattern with a peak in the late afternoon (3:00-6:00 p.m.), correlating with better physical performance in aspects such as speed, agility, distance covered, and jumping power (Candotti et al., 2008). It is at this time of day that the perception of effort also tends to be lower, suggesting a greater ability to tolerate workload. Average strength, maximum strength, and maximum torque also reach their peak during this period, specifically between 4:18 p.m. and 6:34 p.m. (Robertson et al. 2024), with an increase in muscle activity that can reach 15% to 20% (Stawiarska et al., 2024; Castaingts et al., 2004).

Chronotraining and individual chronotype

Understanding and applying the principles of chronobiology has proven to be of great importance, especially in the field of sports and health. In the context of sports, chronobiology offers significant tools for chrono-training, an approach that seeks to optimize performance and physiological adaptations by aligning physical activity with natural biological rhythms.

For optimal sports planning, it is crucial to consider the individual chronotype and the variation in athletic performance throughout the day, which is due, in part, to endogenous mechanisms, highlighting the importance of individualizing training schedules. Desynchronization of these rhythms can lead to decreased physical performance and, in the long term, negatively impact overall health. Given the evidence, people with a night chronotype are more likely to train outside their optimal schedule, while the tendency for morning people to do so increases with age. Therefore, chrono-training is based on the idea that the time of day when exercise is performed directly influences performance and results. This is due to the diurnal variation of various physiological and hormonal variables, which affect the neuromuscular system.

The relevance of chronobiology extends beyond sports, as it has a direct impact on overall health. Living against your internal biological clock, known as "social jet lag," can have serious health consequences, as highlighted in the research by Asmat Inostrosa et al. (2018), who highlights the relationship between the desynchronization of circadian rhythms and an increased risk of diseases such as breast cancer in healthcare workers with night shifts, as well as obesity and metabolic diseases.

Table 5. Circadian variation in athletic performance, men (M) and women (F).

Variable	Population	Main findings	Circadian trend
Strength	Male athletes (strength, handball, basketball, tennis)	15–20% increases in the afternoon. ↑ 15–19.3% grip strength (no differences in isometric grip); ↑ 18.3% average strength; ↑ 6.8–8.8% CMJ jump.	Highest performance between 5:00 p.m. and 9:00 p.m.
	Non-athletes H and M	5–12% increases in strength and power in the afternoon; muscle tone ↑ 15–20% "between 10:00 a.m.–6:00 p.m."; explosive strength ↑ 8.7%. A greater jump height was	Higher in the afternoon

		observed in the afternoon for both males and females, with a similar average maintained across sessions. EMG: no differences.	
Power	Male Athletes	Increases of 10–15% in the afternoon; ↑ 10% power speed.	Afternoon peak (5:30–9:00 p.m.)
	Non-athletes	5–12% increases in the afternoon.	Higher in the afternoon
Speed/Sprint	Male athletes (handball, basketball)	↑ 1.4–8.5% in the afternoon. Peak speed is up to 10.5% lower in the morning; the time to maximum speed ↑ increases by 5% in the afternoon. Morning percentage decrease (3.1–3.4%).	Higher in the afternoon, 5:30 p.m.
Body/muscle temperature	Male athletes	↑ 1.4–4.4% in the afternoon (rectal, muscle, ear). Rectal 36.8°C (morning) vs. 37.3°C (afternoon).	Peak between 5:00 p.m. and 9:00 p.m.
	Non-athletes H	An increase of 1–2°C correlated with higher performance.	3:00–6:00 p.m.
Mood (vigor, happiness, fatigue)	Athletes H	Vigor ↑ 94%; happiness ↑ 30.8%; fatigue ↓ 63% in the afternoon.	Better psychological state in the afternoon
Perceived exertion (RPE)	Male athletes (strength)	Mixed results: Overall ↓ 37.5% fatigue in the afternoon; some studies report ↑ 3.4%. Perceived exertion.	Tendency toward lower perceived exertion in the afternoon
Hormones (cortisol, testosterone)	Untrained athletes	10–30% increase in the afternoon, promoting psychomotor efficiency and recovery.	Greater endocrine activity in the afternoon
Agility	Athletes H (handball, tennis)	↑ 10.6% in the afternoon	Higher in the afternoon
Flexibility/Balance	Overall	No significant differences were observed.	No relevant changes

NOTE: Characterization of athletic performance and circadian trends. (Atkinson & Reilly, 1996; Robertson et al., 2024; Edwards et al., 2025).

Circadian variation in athletic performance

The chronobiology of performance indicates that the afternoon (5:00–9:00 p.m.) is the period of most significant physical and psychological capacity in most of the variables analyzed (strength, power, speed, agility, mood, and hormones). These effects are explained by the synchrony between peak body/muscle temperature, neuromuscular activation, and improved mood, highlighting that only flexibility and balance appear to be unmodulated by the circadian rhythm.

Analysis of the data reveals that physiological and psychological variables, including strength, power, speed, body temperature, and mood, fluctuate throughout the day and are influenced by the circadian rhythm, the body's internal biological clock, which regulates processes such as the sleep-wake cycle, hormone production, and body temperature regulation. Most studies cited indicate that performance peaks occur in the afternoon, coinciding with the body's peak temperature. Consequently, higher body temperature optimizes muscle function by increasing elasticity, reducing viscosity, and enhancing the speed of metabolic reactions. In contrast, the morning is often associated with lower performance and a greater perception of effort. However, there are exceptions and individual variations, such as in morning chronotype athletes.

Table 4. Variables analyzed from the different intervention studies (n = 14)

Articles	Type of exercise	Chronobiology	Maximum muscle strength	Morphological parameters	Mood	Biomarkers
Anderson et al. (2023)	Cycle ergometer	Cortisol				Hydration in urine, cortisol in blood, and saliva
Robertson et al. (2024)	Weightlifting	Rectal/muscle temperature	Linear Encoder		POMS questionnaire	
Robertson et al. (2018).	Weightlifting	Rectal/muscle temperature	Linear Encoder			
Pullinger et al. (2019).	Weightlifting	Rectal/muscle temperature	Linear Encoder	Skin fold calipers		
Stawiarska et al. (2024)	Not reported	Muscle temperature	Electromyography			Blood analysis
Mhenni et al. (2017).	Regular training	Resting oral temperature	Digital hand dynamometer	Anthropometric measurements		Blood tests
López-Samanes et al. (2016).	Regular training	Temperature	Hand dynamometer			Bioimpedance
Blazer et al. (2020).	Muscle training		Linear position (GymAware)		Visual analog scale	
Ünver & Cinemre (2019)	Regular training	Temperature			Standardized scale	Heart rate
Gaos et al. (2023)	Athletes	Tympanic temperature	Handheld dynamometer			

Edwards & Gibbins (2025).	Weightlifting	Rectal temperature and muscle temperature	Isometric dynamometer		POMS questionnaire	
Edwards & Boyle (2025).	Athletes	Rectal/muscle temperature	Isometric dynamometer		POMS questionnaire	
Pullinger et al. (2018).	Weightlifting	Rectal temperature and muscle temperature	Hand dynamometer			Testosterone
Hatfield et al. (2016).	Bench press throws and squat jumps.	Cortisol, digital tympanic thermometer	Handheld dynamometer			Heart rate

NOTE: Characterization of variables and method of analysis.

Mental and emotional health

Circadian rhythms also influence mood (Table V), demonstrating that levels of happiness and vigor are significantly higher in the afternoon. At the same time, fatigue is reduced by 63% compared to the morning (Edwards et al., 2025). These components are vital for physical preparation and daily motor activities, so the application of chronobiology in medicine, known as chronotherapy, seeks to improve the effectiveness of treatments, given that according to research such as that of Párraga García et al. (2025), circadian rhythms undergo significant alterations during aging, directly impacting processes such as hormone secretion, body temperature, immune activity, and metabolism in the human body, contributing to the management of pathologies in older adults. In summary, chronobiology is a multidisciplinary science that provides valuable information for optimizing athletic performance and maintaining mental and physical health, while respecting the natural rhythms of the human body.

Discussion

Given the systematic search for scientific articles on the subject of Chronobiology and Sports Performance. The available scientific evidence, derived from multiple studies, establishes a consistent relationship between the time of day and physical performance, with a clear advantage for exercising in the afternoon. This superiority is attributed to the synchronization of several physiological processes that reach their peak in the afternoon, which directly affects neuromuscular capacity and force production (Atkinson & Reilly, 1996).

Physical performance is intrinsically linked to circadian rhythms, which refer to the physiological and hormonal variations that occur in a 24-hour cycle. One of the key variables supporting better afternoon performance is body temperature. Studies by Robertson et al. (2024, 2018) show that muscle and rectal temperature reach their highest peaks in the afternoon (around 4:35 p.m. and 5:03 p.m.), resulting in a 4.4% increase in muscle temperature and a 0.5 °C increase in rectal temperature compared to the morning. A higher body temperature optimizes enzyme function and muscle elasticity, both of which are essential for producing strength and power.

Several authors agree that muscle strength and power performance are significantly higher in the afternoon, the time of day when physical performance is at its highest, as indicated by measures such as speed, agility, distance traveled, jumps, and strength. This suggests that the perception of effort is also lower in the afternoon. Robertson et al. (2024) observed that average strength in weightlifting activities was 20.0% higher at 9:00 p.m. compared to 3:00 a.m., with peak performance between 4:18 p.m. and 6:34 p.m. These findings are consistent with the research of Pullinger et al. (2019), who also reported superior performance in the afternoon for exercises such as bench press and back squats.

In the case of female athletes, Mhenni et al. (2017) demonstrated significant improvements in afternoon performance, with increases of 19.3% in grip strength, 8.5% in sprint speed, 10.6% in agility, and up to 8.8% in jump tests. These data underscore that circadian variations are relevant for both sexes. However, given the characteristics of the sample, it is noted that only 22.5% included women, Gaos et al. (2023); Ünver and Cinemre (2019); Mhenni et al. (2017), highlighting the scarcity of studies on female populations in relation to sports training topics, thus highlighting a gap in scientific knowledge that must be addressed in order to generate circadian characterizations, which in this case are circamensal.

Improvements in the afternoon are not limited to strength and power; therefore, tests that evaluate neuromuscular and kinematic performance also show an afternoon advantage. López-Samanes et al. (2016) recorded reductions in performance in the morning in variables such as serve speed/accuracy (-6.5%), counter-movement vertical jump (CMJ) (-4.5%), agility test (-2.3% in time), and 10 m sprint (-2.9% in time). These results indicate better coordination and efficiency of the neuromuscular system in the afternoon.

An interesting finding by López-Samanes et al. (2016) is that isometric strength did not show significant diurnal variations, suggesting that the speed of contraction component could be the primary driver of circadian performance. In addition to physiological factors, mood also follows a circadian pattern. Robertson et al. (2024) identified peaks of vigor and happiness in the afternoon (4:11 p.m. to 4:03 p.m.) and a minimum of fatigue in the morning. This alignment between mood and physical performance can create a positive cycle that favors activity and the achievement of results.

On the other hand, research by Anderson et al. (2023) highlights the importance of cortisol as a biomarker of emotional well-being. Acute exercise can influence the cortisol response upon waking, suggesting a possible protective role of physical activity on mental health. No, however, the need for further research in this area is highlighted to understand the complex relationship fully.

Despite strong scientific evidence in favor of evening exercise, it is crucial to consider individual chronotype, as these adaptations depend on physiological and hormonal factors. Although most people peak in the afternoon, the morning chronotype, which generally shows better performance, may occur in the morning. A study by Kunorozva et al. (2014) found that South African endurance athletes tended to be morning types, highlighting the need to tailor recommendations to each individual's preferences and biological rhythms. Given the above, the heterogeneity of both aerobic and anaerobic sports makes it challenging to generalize when to train, highlighting potential areas for future research. Characterizing it by disciplines, abilities, and exogenous and endogenous variables that can symbolize significant changes for science and sports training is also important. Thus, the trend increases with age, highlighting the need for training sessions to be planned according to the optimal schedule for each individual, particularly those who engage in regular physical activity. It is essential to consider individual chronotypes, as the desynchronization of circadian cycles can lead to a decrease in physical performance, regardless of the type of sport or activity.

Conclusions

According to the research, it is clear that the time of day for training and competition is a critical factor, as scientific evidence suggests that, for most athletes, optimal performance occurs in the afternoon due to a series of physiological, hormonal, and neuromuscular adaptations. However, practical application of chronobiology in sport requires a more nuanced and personalized approach, highlighting the knowledge gap among coaches when generating training plans without prior chronobiological characterization, which would help to empower amateur athletes.

Data analysis confirms that most key performance variables, such as strength, power, and speed, peak in the afternoon (Gaos et al., 2023; Pullinger et al., 2018). This phenomenon is driven by the circadian variation in body temperature, which peaks in the evening. This increase in temperature is not insignificant, as it improves muscle efficiency by increasing elasticity, reducing viscosity, and accelerating metabolic reactions, which can result in a 2-5% improvement in performance (López-Samanes et al., 2016).

In addition to temperature, neuromuscular performance, as analyzed through jumping and sprinting ability, is also superior in the afternoon, correlating with greater strength production and a higher development rate (Robertson et al., 2024; Gaos et al., 2023). These effects are complemented by hormonal responses, such as cortisol, which suggest that the timing of training influences hormonal homeostasis and recovery (Anderson et al., 2023).

Despite the superiority of afternoon performance in the general population, the application of chronobiology cannot be uniform, as it is vitally important to consider the individual chronotype of each athlete and individuals who regularly engage in physical activity. Athletes with a morning chronotype may perform better and be more motivated in the mornings compared to their evening counterparts (Blazer et al., 2020). This finding highlights the importance of individualized planning, where training sessions and competitions are scheduled to align with the athlete's optimal biological rhythm, thereby maximizing their performance, recovery, and injury prevention.

While chronobiology is a powerful tool for sports training, it is not the only variable that modulates athletic performance. Evidence indicates that other factors, such as training intensity, age, nutritional status, activity level, and sleep quality, also have a significant influence (Mhenni et al., 2017). These variables are of great interest to science, which has determined that the relationship between physical activity and sleep quality in the university population is a subject worthy of study, highlighting the benefits of exercise on sleep (Valle et al., 2025). Therefore, for optimal planning, the principles of chronobiology must be integrated into a holistic view of athlete preparation; such integration not only seeks to improve performance but also to prevent fatigue and reduce the risk of injury, ensuring complete and adequate preparation.

References

Anderson, T., Vrshek-Schallhorn, S., Adams, WM et al. The effect of intense exercise on cortisol response upon awakening. *Eur J Appl Physiol* 123, 1027–1039 (2023). https://doi.org/10.1007/s00421-023-05132-4

Asmat Inostrosa, Marita del Pilar, De La Torre Robles, José Manuel, Casares Del Rio, María Victoria, & Espadas Lazo, Carmen. (2018). Night work and breast cancer in healthcare personnel*. Journal of the Spanish Association of Occupational Medicine Specialists*, 27(3), 141-149. Epub December 28, 2020. Retrieved October 7, 2025, from http://scielo.isciii.es/scielo.php?script=sci_arttext&pid=S3020-11602018000300141&lng=es&tlng=es.

Atkinson, G., Reilly, T. Circadian variation in athletic performance. *Sports Med* 21, 292–312 (1996). https://doi.org/10.2165/00007256-199621040-00005

Ayala, V., Martínez-Bebia, M., Latorre, JA, Giménez-Blasi, N., Jiménez-Casquet, MJ, Conde-Pipo, J., ... Mariscal-Arcas, M. (2021). Influence of circadian rhythms on athletic performance. International Chronobiology, 38 (11), 1522-1536. https://doi.org/10.1080/07420528.2021.1933003

Bambaeichi, E., Reilly, T., Cable, NT, & Giacomoni, M. (2004). Isolated and combined effects of menstrual cycle phase and time of day on muscle strength in eumenorrheic women. *Chronobiology International*, 21(4–5), 645–660. https://doi.org/10.1081/CBI-120039206

Birch, K., & Reilly, T. (2002). DIURNAL RHYTHM IN ISOMETRIC MUSCLE PERFORMANCE DIFFERES WITH MENSTRUAL CYCLE PHASE IN EUMENORRHEUIC WOMEN*. Chronobiology International*, 19(4), 731–742. https://doi.org/10.1081/CBI-120006083

Blazer, H. J., Jordan, CL, Pederson, J. A., Rogers, R. R., Williams, T. D., Marshall, M. R., & Ballmann, C. G. (2020). Effects of Training Time Preference on Endurance Exercise Performance Research Quarterly for Exercise and Sport, 92(3), 492–499. https://doi.org/10.1080/02701367.2020.1751032

Drust, B., Waterhouse, J., Atkinson, G., Edwards, B., & Reilly, T. (2005). Circadian rhythms in athletic performance: An update. *Chronobiology International*, 22(1), 21–44. https://doi.org/10.1081/CBI-200041039

Edwards, BJ, Boyle, BB, Burniston, JG, Doran, DA, Doran, D., Giacomoni, M., ... Pullinger, SA (2025). Evidence of circadian variation in 10 km laboratory time trial performance, where a standardized approach has been employed. *Chronobiology International*, 42(2), 244–258. https://doi.org/10.1080/07420528.2025.2459668

Edwards, B.J., Gibbins, K.P., Morgan, C.J., Giacomoni, M., Robertson, C.M., Low, D.A., & Pullinger, S.A. (2025). Investigating the effects of moderate hyperthermia on two phases of the circadian cycle of core temperature (heat gain and peak) on maximum voluntary contraction strength of the quadriceps. *Chronobiology International*, 42(5), 622–639. https://doi.org/10.1080/07420528.2025.2494631

Mhenni, T., Michalsik, LB, Mejri, MA, Yousfi, N., Chaouachi, A., Souissi, N., & Chamari, K. (2016). Morning-evening difference in short-term maximum physical performance related to handball in female handball players. *Journal of Sports Sciences*, 35(9), 912–920. https://doi.org/10.1080/02640414.2016.1201212

Mirizio, GG, Nunes, RSM, Vargas, DA, et al. Effects of time of day on maximum short-duration exercise performance. Sci Rep 10, 9485 (2020). https://doi.org/10.1038/s41598-020-66342-w

Orhan, B. E., Hazra, S., Biswas, S., Karak, P. K., Mondal, S., Halder, S., & Gaur, M. P. (2025). Effect of diurnal variations on cognitive and physical performance among female athletes. *Retos*, *68*, 874-888. https://doi.org/10.47197/retos.v68.113742

Párraga García, V. L., Chica Aguilar, G. A., Román Macías, B. Y., Muñoz Ureta, N. M., & Ponce Alencastro, J. A. (2025). Chronobiology and chronopharmacology in old age: Fundamentals and perspectives for geriatric care. *Revista Social Fronteriza*, 5(4), e–806. https://doi.org/10.59814/resofro.2025.5(4)806

Pullinger, S., Robertson, CM, Oakley, AJ, Hobbs, R., Hughes, M., Burniston, JG, & Edwards, BJ (2018). Effects of active warm-up on bench press and back squat variation (upper and lower body measures). *Chronobiology International*, 36(3), 392–406. https://doi.org/10.1080/07420528.2018.1552596

Robertson, CM, Pullinger, SA, Robinson, WR, Smith, ME, Burniston, JG, Waterhouse, JM, & Edwards, BJ (2018). Is diurnal variation in muscle strength detected when analyzing multi-joint movements with the MuscleLab force-velocity encoder? *Chronobiology International*, 35(10), 1391–1401. https://doi.org/10.1080/07420528.2018.1485685

Robertson, CM, Pullinger, SA, Robinson, WR, Smith, ME, Burniston, JG, & Edwards, BJ (2024). Circadian variation in muscle strength in males using isokinetic and isometric dynamometry: can we observe it in multi-joint movements using the MuscleLab force-velocity encoder? Are they similar in peak and magnitude? *Chronobiology International*, 41(5), 709–724. https://doi.org/10.1080/07420528.2024.2348011

Serin, Y., & Acar Tek, N. (2019). Effect of Circadian Rhythm on Metabolic Processes and the Regulation of Energy Balance. *Annals of nutrition & metabolism*, 74(4), 322–330. https://doi.org/10.1159/000500071

Shephard, RJ Sleep, Biorhythms, and Human Performance. *Sports Medicine* 1, 11–37 (1984). https://doi.org/10.2165/00007256-198401010-00003

Souissi, A., Yousfi, N., Souissi, N., Haddad, M., & Driss, T. (2020). The effect of diurnal variation on the performance of exhaustive continuous and alternated-intensity cycling exercises. PloS one, 15(12), e0244191. https://doi.org/10.1371/journal.pone.0244191

Stawiarska, A., Gajdosz, R., Chwała, W., & Gajdosz, A. (2024). Circadian variability of bioelectric muscle tone in static and dynamic anaerobic exercises in men. Acta of bioengineering and biomechanics, 26(4), 111–122. https://doi.org/10.37190/abb-02527-2024-02

Ünver, E., & Cinemre, Ş. A. (2019). The effect of circadian rhythm on drop jump performance. *Isokinetics and Exercise Science*, 27(4), 333-339. https://doi.org/10.3233/IES-192174

Valle Flores, J. A., Rosado Álvarez, M. M., Hidalgo Torres, J. L., Villamar Vásquez, G. I., Jurado Auria, S. A., Valenzuela Burbano, K. G., & Bazurto Hidalgo, C. E. (2025). Relationship between physical activity and sleep quality in university students: a cross-sectional study. *Retos*, 68, 1477-1486. https://doi.org/10.47197/retos.v68.116008

Vanegas-Castillo, J. E., & Peña Ramírez, W. A. (2024). Biotechnology and physical performance in sport: "the mutants of the future." *Retos*, 61, 1458-1467. https://doi.org/10.47197/retos.v61.110314

Vitale, JA, Bonato, M., La Torre, A., & Banfi, G. (2019). Heart rate variability in sports performance: Do time of day and chronotype influence it? *Journal of Clinical Medicine*, 8 (5), 723.https://doi.org/10.3390/jcm8050723

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