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REVIEW ARTICLE

# Circadian rhythm in sportspersons and athletic performance: A mini review

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**ABSTRACT**
Circadian rhythms in the physiological and behavioral processes of humans play a crucial role in the quality of living and also in the magnitude of success and failure in various endeavors including competitive sports. The rhythmic activities of the body and performance in sportspersons do have a massive impact on their every cutthroat competition. It is essential to schedule sports activities and training of players according to their circadian typology and time of peak performance for improved performance and achievement. In this review, the focus is on circadian rhythms and diurnal variations in peak athletic performance in sportspersons. Accuracy and temporal variability in peak performance in an individual could be attributed to various factors, namely chronotype, time of the day, body temperature, jetlag, hormones, and prior light exposure. Circadian rhythm of mood, alertness, T-core, and ultimately athletic performance is not only affected by sleep but also by circadian variations in hormones, such as cortisol, testosterone, and melatonin. There are, however, a few reports that are not consistent with the conclusions drawn in this review. Nevertheless, circadian rhythm and performance among sportspersons and athletes are important areas of research. This review might be useful to the managers and policymakers associated with competitive sports and athletic events.

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Athletes; chronotype; circadian rhythm; jetlag; performance; sleep; sportspersons; time of day

## Introduction

Humans experience day-night and seasonal cycles attributed, respectively, to the rotation of the Earth on its axis and its revolution around the Sun. In humans, almost all physiological functions, such as heart rate, body temperature, sleep-wake cycle, mood, stress, and menstrual physiology exhibit rhythms and remain in sync with the periodicities in nature. This phenomenon of rhythm synchronization is mediated through internal biological clock(s).

Depending upon the time of completion of one cycle, there are different types of rhythms, such as circadian rhythm, ultradian rhythm, infradian rhythm, lunar rhythm, tidal rhythm, seasonal rhythm, and circannual rhythm (Pati 2001). Of these circadian rhythms are the most investigated.

Although circadian rhythms are largely influenced by the onset of light and darkness, organisms under continuous light (LL) or constant darkness (DD) exhibit rhythms with altered phases and periods. This suggests that these rhythms are endogenously controlled in almost all organisms, including humans (Kunorozva et al. 2012; Pati 2001). Components of physical performance (aerobic-anaerobic power, muscle endurance, and flexibility) and hormone secretion exhibit circadian rhythm. For this reason, it is advised to the organizers and trainers of competitive games and sports to consider the effects of circadian rhythm on sportspersons and their performance (Sabzevari Rad et al. 2021).

In this review, our focus is on the circadian rhythms of sportspersons and their psychomotor and physical performance variables. The relationship between temporal variabilities in peak performance and various psycho-physiological functions, namely chronotype, sleep, body temperature, hormones, prior light exposure, and so forth have been examined taking into reference the relevant research papers published during the last two decades.

## Methodology of literature search

The relevant reviews and original research papers were searched using PubMed-NCBI Advance search resources, Google's Advanced Scholar search, and Scopus. The words, "circadian rhythm," "diurnal rhythm," "chronotype," "sportsperson," "athletic performance," "sleep," "jetlag" and "mood" were used as keywords in different combinations while searching

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these online databases and compiled original research papers in Table 1 and review papers in Table 2.

## Effect of chronotype on athletic performance

Chronotype broadly constitutes three phenotypes, namely morning type (MT), evening type (ET), and intermediate type (IT), based on an individual's endogenous clock and sleep behavior (Kunorozva et al. 2012). It has been shown that the physiology of these chronotypes differs from one another significantly (Facer-Childs and Brandstaetter 2015b). Kentiba et al. (2020) found that chronotype is independent of sport and gender. With the knowledge of general characteristics and parameters of chronotype, and biological rhythms and their effects on physical performance, an athlete and a sports physician can establish the best form of competitive activity (Bellastella et al. 2019).

Facer-Childs and Brandstaetter (2015b) pinpointed that the best performance of athletes might vary according to their circadian typology. They emphasized that the time after entrained awakening is a better predictor of the time of peak athletic performance than the time of the day alone. In another cross-sectional study, sportspersons were identified as having early chronotype (ECT), intermediate chronotype (ICT), and late chronotype (LCT) (Facer-Childs and Brandstaetter 2015a). The authors observed that the time of peak performance of the ECT group was located earlier (13:52 h) as compared with the LCT group (20:59 h). The findings evidenced that "night owls" are compromised earlier in the day because habitual sleep patterns and circadian rhythms impact cognitive and physical measures of performance (Facer-Childs et al. 2018). ET elite swimmers, swim up to 6% slower and expend 50–70% more effort in the morning. Similarly, MT swimmers required 5–7 times more effort in the evening than ET swimmers (Anderson et al. 2018). Kunorozva et al. (2014) studied the rating of perceived exertion on 20 male MT cyclists and found out that the maximum exertion was perceived in the evening (at 18:00 h and 22:00 h) when the heart rate was the maximum. Gaina et al. (2006) demonstrated that ET players are associated with morning bad feelings, daytime sleepiness, and longer sleep latency, whereas MT players were associated with higher sleep drive at night and a better lifestyle. A study on 26 swimmers showed that the MT swimmers best perform in the morning, in contrast, the ET swimmers perform their best in the evening. Interestingly, only the peak performance time was affected by chronotype, but the performance ability remained the same in both groups (Rae et al. 2015). Similar results were obtained for the athletes of the rowing crew, sprint, and standing broad jump (Brown et al. 2008). Roveda et al. (2020) demonstrated that sports training must be scheduled according to the player's circadian preference as they found that MT players performed the jump test, agility test, and run test significantly better in the morning than evening and vice versa in the ET. Lim et al. (2021) reported athletic performance is much better in the early chronotype than in the late chronotype. Not only physical performance but cognitive performance is also affected by the chronotype of the performer, as Facer-Childs et al. (2018) found a significant difference in psychomotor vigilance and isometric grip strength of early chronotype and late chronotype. Lastella et al. (2016) studied the chronotype, sleepiness at night, sleep satisfaction, and sleep quality of 114 elite athletes in Australia and found that the prevalence of MT among sportspersons was the highest. These authors recommended that the coaches must consider the athletes' chronotype during the selection of the sports and also during the finalization of the training schedules.

Although the chronotype of the player is a good predictor for the best performance, the timings of the peak performance depend on the type of sport as well. Drust et al. (2005) concluded that morning time is better for skill-based sports performance that depends upon complex strategies, quick decisions and delivery, and the ability to memorize instructions, while evening time is best suited for sports that require physical effort and strength.

Peak physical performance is also determined by the endogenous circadian system (Lok et al. 2020). A variable number tandem-repeat (VNTR) polymorphism has been demonstrated in the *PERIOD3* gene (*PER3*) and the *PER-3*$^{5}$ allele is linked to the MT chronotype, whereas the *PER-3*$^{4}$ allele is responsible for the ET chronotype. This South African study reveals a strong association between chrono-phenotype and *PER3 VNTR* genotype (Kunorozva et al. 2012). Another finding supports this by concluding that the participants homozygous for the PER3$^{4,4}$ performed 3–6% slower in the morning (Anderson et al. 2018). It has been demonstrated in another study that MT runners perform their best in the morning than in the evening; but in contrast, the author discovered that the same allele of *PER-3* and *VNTR* polymorphism is seen in all the groups in similar proportion but their performance with the time of day is entirely different. Based on this result the author concluded that the *PER-3* gene is not associated with chronotype (Henst et al. 2015). Further intensive studies may resolve this controversial issue.

Again, the contrasting result of Silveira et al. (2020) makes this topic more debatable as they reported no significant circadian effects in the mountain bike

**Table 1.** Review of literature in the domain of circadian rhythm in athletic performance.

| S. No. | Areas of study | Variable | Sample structure and size | Methodology | Outcome | Reference |
|---|---|---|---|---|---|---|
| 1. | Circadian rhythm and exercise | Maximal power (P-max), Wingate test, Oral temperature, and body mass | 19 male athletes<br>Age: 21.8 ± 0.6 y | • Maximal power (P-max), peak power (P-peak), and mean power (P-mean) were measured during 30 s Wingate test conducted on each subject at a different time of the day, but on different days with at least 28-h interval between 2 successive tests.<br>• The oral temperature and body mass of each subject were measured before the test. | • Significant diurnal variations were found in P-max, P-peak, P-mean, and oral temperature. These findings may have serious repercussions on sports performance. | Souissi et al. (2004) (France) |
| 2. | Chronotype and sports | MEQ, and daytime sleepiness | 23 elite triathletes<br>16 males; Age: 20.9 ± 2.1 y<br>7 females; Age: 20.8 ± 3.6 y | • Horne and Östberg Morningness-Eveningness Questionnaire and Epworth Sleepiness Scale were used to assign the subjects to a particular chronotype group and to assess daytime sleepiness in each group. | • No significant difference was observed between Neither type and the Morning type concerning daytime sleepiness, sleep quality, and sleep satisfaction. No gender effect was detected. | Lastella et al. (2010) (Australia) |
| 3. | Chronotype and sports | Chronotype, sleepiness, sleep satisfaction, and sleep quality | 114 elite athletes (players of Cricket, Cycling, Hockey, Soccer, and Triathlon)<br>88 male athletes, Age: 21.9 ± 3.8 y<br>26 female athletes, Age: 22.6 ± 4.1 y | • Horne and Östberg Morningness-Eveningness Questionnaire, Epworth Sleepiness Scale, and questions concerning sleep satisfaction and sleep quality were administered. | • No difference between paired chronotype groups was reported for sleepiness, sleep satisfaction, and sleep quality.<br>• A significant relationship between sports and the chronotype group was observed with a higher frequency of morning types involved in sports that required morning training (Cycling and Triathlon). | Lastella et al. (2016) (Australia) |
| 4. | Effect of chronotype on motor skill | Chronotype, Sargent Jump Teat (SJT), Illinois Agility Test (IAT), and 6-min Run Test (6MRT) | 141 (total subject) male soccer players<br>75 (subsample)<br>Age: 14.9 ± 1.79 y | • Adolescent soccer players filled out the Horne and Östberg Morningness-Eveningness Questionnaire.<br>• 75 out of 141 (25 morning type, 25 neither type, 25 evening type) performed SJT, IAT, and 6MRT at 09:00 h and 18:00 h. | • M-type performed all three tests significantly better in the morning than evening, and E-type performed significantly better in the evening than morning. In contrast, no significant difference was seen in the performance of either type between the sessions.<br>• The sports training schedule should be according to the player's circadian preference to improve performance. | Roveda et al. (2020) (Italy) |
| 5. | Chronotype and choice of sport participation and training time | Chronotype, and training time | 174 players (126 males and 48 females)<br>Age: 21.65 ± 2.05 y | • Training time was collected from players, and chronotype preference was investigated using the Horne and Östberg Morningness-Eveningness Questionnaire. | • The distribution of chronotype was as follows: Morning type = 82 players (47%), Intermediate type = 92 players (53%), and Evening type = 0 players (0%).<br>• Chronotype preference was found to be independent of the gender of the player.<br>• Authors suggested that athlete's chronotype preferences should be considered when designing training sessions. | Kentiba et al. (2020) (Ethiopia) |

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**Table 1.** (Continued).

| S. No. | Areas of study | Variable | Sample structure and size | Methodology | Outcome | Reference |
|---|---|---|---|---|---|---|
| 6. | Chronotype, cognitive performance, and physical performance | Chronotype, cognitive performance, physical performance, and psychomotor vigilance task | 56 healthy individuals (23 males and 33 females)<br>Age: 21.8 ± 3.8 y | • Munich Chronotype Questionnaire (MCTQ) and actigraphy were used to quantify the participant's subjective and objective chronotypes, respectively.<br>• Cognitive and physical performance were measured at 14:00 h, 20:00 h, and 08:00 h. Participants self-reported their daytime sleepiness using the Karolinska Sleepiness Scale.<br>• A 6-s isometric grip strength test was performed using an electronic hand dynamometer.<br>• The cognition test consisted of a psychomotor vigilance task, and memory and attention tests. | • Based on the MCTQ, 25 participants were identified as early chronotypes (ECT) and 31 participants were late chronotypes (LCT).<br>• There was a significant difference in daytime sleepiness, psychomotor vigilance, and isometric grip strength between ECT and LCT.<br>• Results revealed that the performance of "night owls" was compromised earlier in the day.<br>• Habitual sleep patterns and circadian rhythms influence cognitive and physical measures of performance. | Facer-Childs et al. (2018) (UK) |
| 7. | Chronotype, core body temperature, and sports performance | Oral temperature, heart rate, peak expiratory flow rate, grip strength, vertical jump, 50-yard dash, mood state, flexibility, and playing skill | 53 male subjects<br>(15 Judo players, 23 Basketball players, and 15 control subjects)<br>Age range: 18–26 y | • Profile of Mood States (POMS) questionnaire and Horne and Östberg's Morningness-Eveningness Questionnaire (MEQ) were used to assess mood state and chronotype, respectively, and simultaneously the oral temperature, heart rate, peak expiratory flow rate, grip strength, vertical jump, 50-yard dash, flexibility, playing skill measured for 5 consecutive days at 6-time points between 06:00 h and 21:00 h. | • All biological variables and all physical variables showed statistically significant circadian rhythm.<br>• Elevated oral temperature was found to be significantly associated with better sports performance. | Gupta (2008) (India) |
| 8. | Chronotype and daytime sleepiness among sportspersons | Excessive daytime sleepiness, heart rate, physical activity, and energy expenditure | 75 healthy subjects<br>Age range: 20–27 y | • Subjects comprised 52 sportspersons and 23 non-sportspersons.<br>• Excessive daytime sleepiness and chronotype were analyzed using the Epworth Sleepiness Scale (ESS) and Horne and Östberg Morningness-Eveningness Questionnaire (MEQ), respectively. Heart rate, physical activity, and energy expenditure were recorded for 3 d using Actiheart-2. | • 68% of subjects were neither type.<br>• Excessive daytime sleepiness was found at 8.73 h for sports persons and 9.26 h for non-sportspersons.<br>• The heart rate of sports persons was found to be significantly lower than that of the non-sports persons. Physical activity was significantly higher among sportspersons. | Patel (2011) (India) |

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**Table 1.** (Continued).

| S. No. | Areas of study | Variable | Sample structure and size | Methodology | Outcome | Reference |
|---|---|---|---|---|---|---|
| 9. | Chronotype and sleep management strategy among sailors | Chronotype, sleep quality, sleepiness, sleep management strategy, distance traveled offshore, and sailors' arrival time. | 42 solo sailors (35 males and 7 females)<br>Age range: 25–37 y | • All participants completed the Epworth Sleepiness Scale (ESS), Pittsburgh Sleep Quality Index (PSQI), and reduced version of the Morningness-Eveningness Questionnaire (rMEQ), a questionnaire on pre-race sleep management strategy adopted.<br>• Arrival times for each race of each sailor were recorded by the organization team. | • 40% of participated solo sailors were morning types and 60% were intermediate types.<br>• Sailors who adopted the sleep strategy traveled significantly more miles offshore than sailors who did not adopt the strategy, but the sleep strategy did not significantly influence the final arrival time. | Filardi et al. (2020) (Italy) |
| 10. | Sleep quality and athletes' performance | chronotype and habitual time | 340 elite athletes (261 males and 79 females)<br>Age: $17.55 \pm 3.81$ y | • Chronotype and sleep quality were assessed by the Korean versions of the Horne and Östberg Morningness-Eveningness Questionnaire (MEQ) and Pittsburgh Sleep Quality Index (PSQI) respectively.<br>• PSQI global score, PSQI sleep quality, PSQI sleep onset latency, PSQI sleep disturbance, and PSQI daytime dysfunction were assessed using the Pittsburgh Sleep Quality Index and power drop, mean power, and peak power assessed by Wingate Anaerobic Test (WAnT) by cycling ergometer. | • All PSQI sleep variables were significantly different among chronotypes. Similarly, power drop, mean power, and peak power were also significantly different between the other chronotype groups.<br>• A negative correlation was found between the PSQI score and all variables measured by WAnT, indicating a significant adverse effect of poor sleep on the players' mean power and peak power. Sleep quality and athletic performance are much better in the early-type chronotype than in the late-type chronotype. | Lim et al. (2021) (Republic of Korea) |
| 11. | Phase advancement and physical performance | Total sleep time, sleep efficiency, sleep quality, and core body temperature | 16 male athletes<br>Age: $22.2 \pm 1.7$ y | • All the subjects spent 1 night in baseline condition followed by 2 d of 5-h phase advanced condition.<br>• Phase shifting was recorded by electroencephalography.<br>• Core body temperature was assessed throughout the study continuously. | • Total sleep time and sleep efficiency decreased on the first night with the phase advancement.<br>• Phase advancement did not show any association with physical performance. | Petit et al. (2014) (France) |
| 12. | Daytime nap and sleep pattern | Polysomnography, visual analog score, and sleep quality | 6 males<br>Age: $22.5 \pm 2.4$ y | • Subjects performed 90 min endurance physical training and took naps for 90 min at either 10:30 h or 11:30 h.<br>• Polysomnography and a visual analog scale were used to measure nap, sleep quality, and alertness. | • Slow wave sleep (SWS) duration during 11:30h naps ($13.7 \pm 9.0$ min) was significantly longer than 10:30h naps ($6.9 \pm 8.8$ min).<br>• Daytime naps after endurance exercises appeared to be a potential and valuable tool for recovery. | Daniel et al. (2010) (Australia) |
| 13. | Sleep and chronotype | Chronotype and sleep variables (sleep onset, sleep offset, total sleep time, sleep latency, sleep efficiency, wake after sleep onset, and daytime sleepiness) | 8 Wheelchair rugby athletes<br>Age: $28 \pm 4.2$ y | • Horne and Östberg Morningness-Eveningness Questionnaire (MEQ) was used to determine chronotype. Pittsburgh Sleep Quality Index (PSQI) and Epworth Sleepiness Scale (ESS) were used for subjective sleep data, and actigraphy was used (20 d) to collect objective sleep data (10 d pre-season and 10 d in-season). | • Athletes had low sleep quality (sleep efficiency ˂85%, high score in the PSQI questionnaire, elevated sleep latency, and an increased episode of waking after sleep onset) during the competitive season using both methods. It was attributed to heavy training and exercise load. | Sanz-Milone et al. (2021) (Brazil) |

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**Table 1.** (Continued).

| S. No. | Areas of study | Variable | Sample structure and size | Methodology | Outcome | Reference |
|---|---|---|---|---|---|---|
| 14. | Sleep, nap, and physical performance | Alertness, short-term memory, intra-aural temperature, heart rate, choice reaction time, grip strength, 2 m and 20 m sprint time | 10 healthy male subjects<br>Age: 23.3 ± 3.4 y | • Half of the subjects napped and the rest half did not take a nap after lunch; at 13:00 h to 13:30 h post night of sleep debt (slept from 23:00 h to 03:00 h).<br>• Alertness, short-term memory, intra-aural temperature, heart rate, choice reaction time, grip strength, and 2 m and 20 m sprint time were measured after half an hour of the experiment. | • Post-lunch napping lowered the heart rate and intra-aural temperature.<br>• Alertness, short-term memory, accuracy, sprint time, and reaction time improved following napping.<br>• Post-lunch naps significantly improved mental as well as physical performances. | Waterhouse et al. (2007) (UK) |
| 15. | Sleep and fatigue among athletes | Wrist activity, fatigue, and sleep variables | 70 elite athletes (46 Males and 24 Females)<br>Age: 20.3 ± 2.9 y | • Wrist activity monitors, sleep/training diaries, and self-reported fatigue on a 7-point scale were used on each subject.<br>• A linear mixed model was used to analyze data. | • On pre-nights of the training days, the sleep onset and wake-up times were significantly earlier and the duration of sleep was significantly shorter than the nights before the rest days.<br>• A relationship between sleep duration and subjective feeling of fatigue was found. The shorter the sleep duration; the more the perceived fatigue.<br>• These findings give a cue to the coaches to optimize the time of training. | Sargent et al. (2014) (Australia) |
| 16. | Sleep and athletes | Insomnia, daytime sleepiness, and sports-related concussion risk | 190 athletes (103 males and 87 females)<br>Mean age: 20.59 y | • All athletes completed questionnaires online; Insomnia Severity Index (ISI), Pittsburgh Sleep Quality Index (PSQI), Fatigue Severity Scale (FSS), and National Health and Nutrition Examination Survey.<br>• The player's sleep data and injury data were extracted from the student's athletic, and medical records. | • Clinically moderate-to-severe insomnia severity and excessive daytime sleepiness increased concussion risk in sports persons. | Raikes et al. (2019) (USA) |
| 17. | Sleep and athletes | Sleep problems, general health, sleep hygiene, mood, chronotype, and injury | 58 elite multi-sport athletes (34 males and 24 females)<br>Age: 21.8 ± 2.2 y | • Cross-sectional study.<br>• Athlete-Sleep-Screening-Questionnaire, Horne and Östberg Morningness-Eveningness Questionnaire, Sports Profile of Mood State, Sleep Hygiene Index, Subjective Health Complaints, and Self-reported injury data were obtained from all participating athletes. | • 43% of athletes had no clinical sleep problems, 41% had mild clinical sleep problems, and 16% had moderate clinical sleep problems. Not a single athlete reported severe clinical sleep problems.<br>• 16% exhibited a significant clinical sleep problem.<br>• Athletes with clinically significant sleep problems had worse sleep hygiene, more general health complaints, and mood disturbance.<br>• A significant association was not found among sleep problems, chronotype, and self-reported injury. | Biggins et al. (2019) (Ireland) |

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**Table 1.** (Continued).

| S. No. | Areas of study | Variable | Sample structure and size | Methodology | Outcome | Reference |
|---|---|---|---|---|---|---|
| 18. | Sleep and reaction time | Total sleep time (TST), sleep onset latency (SOL), and sleep stages (light, deep, and REM sleep) | 98 elite athletes (42 males and 56 females)<br>Age: 18.8 ± 3.0 y | • Sleep was assessed for seven consecutive nights using an Actiwatch device, and sleep stages were recorded by a wireless, self-logging headband. Within this period, measures of sport-specific performance (accuracy, endurance, and power) were tested.<br>• Reaction time was measured by a Psychomotor performance test for 10 min. | • The average total sleep time was 7.50 ± 1.08 h.<br>• Longer total sleep time was associated with faster reaction times.<br>• Sleep quantity (total sleep time, sleep onset latency) and sleep staging (light sleep) affected gross motor performance but produced no effects on motor skill performance. | Knufinke et al. (2018) (Netherlands) |
| 19. | Sleep among soccer players | Sleep quality with all sleep variables, daytime sleepiness, and insomnia data | $N$ = 111 male soccer players<br>Age: 23.7 ± 4.8 y | • All the participants completed three questionnaires, such as the Pittsburgh Sleep Quality Index (PSQI), Insomnia Severity Index (ISI), and Epworth Sleepiness Scale (ESS).<br>• PSQI ≥ 5, ISI ≥ 11, and ESS ˃ 8 were considered poor sleep. | • 68.5% had poor sleep quality (PSQI ≥ 5), 27.0% were detected as prone to insomnia, and 22% of soccer players exhibited daytime sleepiness.<br>• Players with short sleep duration had good sleep efficiency, but they struggled with low sleep quality, insomnia, and daytime sleepiness. | Khalladi et al. (2019) (Qatar) |
| 20. | Sleep and performance | Sleep quality, sleepiness, and anxiety | 27 (16 males and 11 females)<br>Age: 28 ± 6 y | • Sleep quality, sleepiness, chronotype, and anxiety were measured by the Pittsburgh Sleep Quality Index, Epworth Sleepiness Scale, Horne and Östberg Morningness-Eveningness Questionnaire, and State-Trait Anxiety Inventory, respectively. | • 71.4% of athletes were identified as morning type.<br>• 72% of athletes presented medium anxiety levels.<br>• Athletes with poor sleep quality showed significantly lower sleep efficiency and greater sleep latency.<br>• The authors found poor sleep quality before the competition. | Silva et al. (2012) (Brazil) |
| 21. | Sleep quality and performance | Athletic performance, sleep variables | 149 (68 males and 81 females)<br>Age: 32.01 ± 7.49 y | • Pittsburgh Sleep Quality Index and CrossFit (workout and gymnastic performance-based questions) were administered through an online survey. | • Subjects with higher sleep quality reported higher values (better scores) in all physical performance-related questions.<br>• The findings revealed a significant positive effect of high sleep quality on performance. | Klier et al. (2021) (Germany) |
| 22. | Sleep and athletic performance | Sleep quality and sleep efficiency | 10 male Rugby players | • Sleep quality and sleep efficiency were measured over twenty nights (18 non-game nights and 2 game nights) using the BodyMedia SenseWear Unit (BSU). | • Sleep quality significantly decreased and time to sleep onset became later on game nights.<br>• Sleep efficiency and time of wake-up did not alter.<br>• It was concluded that late sleeping time and reduced sleep quality have an association with reduced performance. | Eagles and Lovell (2016) (Australia) |

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**Table 1.** (Continued).

| S. No. | Areas of study | Variable | Sample structure and size | Methodology | Outcome | Reference |
|---|---|---|---|---|---|---|
| 23. | Sleep and chronotype among football players | sleep quality, insomnia severity, daytime sleepiness, sleep apnea risk, circadian preference, and injury during a training session | 94 male football players<br>Age: 19.6 ± 1.7 y | • All participants completed 5 validated sleep-related questionnaires: Pittsburgh Sleep Quality Index (PSQI), Insomnia Severity Index (ISI), Epworth Sleepiness Scale (ESS), Sleep Medicine Associates of Maryland (SMAM), and Horne and Östberg Morningness-Eveningness Questionnaire (MEQ) to assess sleep quality, insomnia severity, daytime sleepiness, sleep apnea risk, and circadian preference respectively.<br>• Sleep-wake data were collected by wrist actigraphy.<br>• University sports medicine staff recorded injury data of all subjects. | • 67.4% of players scored above the clinical threshold in at least 1 questionnaire that indicates sleep disorder risk.<br>• Players reported a 7.27 ± 1.30 h average sleep duration but a 6.07 ± 0.68 h average sleep duration recorded through an Actiwatch device. Sleep metrics (quality and quantity) were not associated with an increased risk of injury. | Burke et al. (2020) (Maryland) |
| 24. | Sleep deprivation and exercise | Autonomous activity, endocrine function, heart rate variability, cortisol and plasma adrenocorticotropic hormones, Adrenocorticotropin, and cortisol levels in the blood | 10 male subjects<br>Age: 22.6 ± 0.7 y | • Subjects experienced 2 d of control sleep (23:00 h to 07:00 h) and 2 d of sleep deprivation (34 h).<br>• Autonomous activity, endocrine function, and heart rate variability were measured during two days of sleep deprivation.<br>• Adrenocorticotropin and cortisol levels in the blood were measured. | • Heart rate, cortisol, and plasma adrenocorticotropic hormones were found to be significantly higher under sleep deprivation.<br>• The effect of sleep deprivation on autonomic regulation was found to be the time-of-day dependent. | Konishi et al. (2013) (Japan) |
| 25. | Sleep, mood, and well-being of cyclist | Quality of sleep, and Mood state | 21 male cyclists<br>Age: 22.2 ± 2.7 y | • Sleep diaries, wrist activity monitors, Brunel Mood Scale (BMS), and Visual Analogue Scale (VAS) were used to assess sleep, mood, and general well-being. | • Amount and quality of sleep improved according to self-reported data but declined according to wrist activity monitor during the simulated grand tour.<br>• Mood state and well-being declined during the simulated tour. | Lastella et al. (2015a) (Australia) |
| 26. | Sleep/wake behavior of cyclists | Sleep/wake activity, and Sleep duration | 21 male cyclists<br>Age: 19.9 ± 1.7 y | • Sleep/wake activity was assessed using Wrist Activity Monitors for 6 baseline nights, 3 nights before the competition, and 2 nights after the competition. | • Sleep duration significantly decreased before and during the competition (6.5 ± 0.9 h and 6.8 ± 0.8 h, respectively) than baseline nights (7.4 ± 0.6 h).<br>• Cyclists went to bed later and woke up earlier during and just before the competition and the schedule of the competition also disrupted the sleep/wake behavior. | Lastella et al. (2015b) (Australia) |
| 27. | Sleep and athletic performance | Sleep patterns, sleep quality, and athletic performance | 137 athletes (73 males and 64 females)<br>Mean age: 15.7 y | • Sleep patterns and academic athletic performance of subjects were determined using questionnaires and collecting their grades (from the trainer), respectively. | • Daily sleep duration during school time (8.22 ± 0.38 h) was shorter than holidays (10.02 ± 1.16 h).<br>• Subjects reported poor sleep quality with poor academic performance. | Poussel et al. (2014) (France) |

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**Table 1.** (Continued).

| S. No. | Areas of study | Variable | Sample structure and size | Methodology | Outcome | Reference |
|---|---|---|---|---|---|---|
| 28. | Night-time exercise and sleep | Sleep quality, sleep latency, and total sleep time | 1000 adult Americans<br>Age range: 23–60 y | • Sleep quality, sleep latency, total sleep time, and waking up unrefreshed were determined using self-reports.<br>• Subjects were categorized into 3 groups according to their time of exercise (morning group, afternoon, and evening group).<br>• The International Physical Activity Questionnaire was used to assess the intensity of exercise. | • Evening exercise was not associated with worse sleep.<br>• Individuals habituated to exercise in the evening reported 97% better sleep quality and 98% better sleep duration than the non-exercising person. | Buman et al. (2014) (USA) |
| 29. | Sleep, blood pressure, heart rate, and cardiac output | Sleep, BP, HR, and Cardiac Output | 6 physically active males<br>Age: 31 ± 7 y | • Subjects were allowed to have 4 h of nocturnal sleep, and exercise at 04:00 h, 06:00 h, 08:00 h, and 10:00 h. On another day subjects slept 4 h in the afternoon and exercised at 16:00 h, 18:00 h, 20:00 h, and 22:00 h.<br>• Before and after exercise BP, HR, and Cardiac Output were measured and analyzed using repeated measures ANOVA. | • Arterial BP was found 8–14 mmHg significantly higher after exercise at 04:00h than other corresponding BP values.<br>• Highest reactivity of arterial BP recorded after exercise bout on cycling ergometer in morning hours. | Jones et al. (2009) (UK) |
| 30. | Effect of sleep debt on driving performance | Driving performance | 41 male subjects<br>Age: 22.8 ± 2.2y | • Subjects were categorized into 3 groups: The control group: 9.33 h of sleep, the moderate sleep restriction group: 7 h of sleep, and the severe sleep restriction group: 4.66 h of sleep.<br>• Each group performed 10 min simulated driving and data were analyzed using the standard deviation of lateral position (SDLAT) and ANOVA. | • Reduced sleep duration and extended wake time significantly decreased driving performance at all times of the day. | Matthews et al. (2012) (Australia) |
| 31. | Sleep deprivation, cognition, mood, and exercise | Fatigue, vigor, depression, reaction time, and sleep | 6 male subjects<br>Age: 22 ± 0.3 y | • 20 min cycling on a Cycle Ergometer was performed at 2-h intervals during 30 h of sleep deprivation.<br>• The mood was assessed using the Profile of Mood States questionnaire. Reaction time tasks, a computerized tracking task, and a number cancellation task performed by all players.<br>• After 1 week, the protocol was repeated. | • Sleep deprivation was significantly associated with fatigue, vigor, depression, and reaction time.<br>• Exercising persons were less vulnerable as compared to non-exercising persons.<br>• Sleep deprivation was associated with a high risk of an accident because of the low capacity to respond quickly. | Scott et al. (2006) (UK) |
| 32. | Sleep deprivation and injury rates | Injury, and sleep | 112 adolescent athletes (54 males and 58 females)<br>Age: 15 ± 1.5 y | • Hours of sleep/night (reported by students) and injury records during the athletic performance (collected by the school's athletic department) were observed.<br>• Multivariate and correlational techniques were used to analyze the data. | • Athletes; who slept ˂8 h/night were 1.7 times more likely to have an injury compared with the athletes, who slept for ≥8 h.<br>• An optimal amount of sleep helps athletes to protect against injury during athletic performance. | Milewski et al. (2014) (USA) |

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**Table 1.** (Continued).

| S. No. | Areas of study | Variable | Sample structure and size | Methodology | Outcome | Reference |
|---|---|---|---|---|---|---|
| 33. | Sleep, mood, and athletic performance | Mood, sleep quality and quantity, and total sleep time | 103 athletes<br>40 males; Age: 32.9 ± 7.9 y<br>63 females; Age: 33.8 ± 10.2 y | • The Brunel Mood Scale (BRUMS) questionnaire was used to analyze mood and the Pittsburg Sleep Quality Index (PSQI) was used to assess the sleep quality and quantity of athletes before the competition. | • Poor sleep quality was recorded in 70% of participants.<br>• Negative moods, like fatigue and tension, were negatively correlated with sleep quality, total sleep time, and the number of awakenings.<br>• Precompetitive sleep disruption was psychologically and physically detrimental. | Lastella et al. (2014) (Australia) |
| 34. | Sleep, mood, and quality of life with aerobic physical exercise | Sleep quality, sleep latency, sleep duration, daytime dysfunction, sleep efficiency, and physical exercise | 17 (1 male and 16 females) facing insomnia problem<br>Age: 61.6 ± 4.3 y | • Half of the subjects performed the aerobic physical exercise with sleep hygiene and the remaining half did not perform any physical activity till 16 weeks.<br>• Sleep quality, sleep latency, sleep duration, daytime dysfunction, and sleep efficiency were assessed using the Pittsburg Sleep Quality Index, Short Form 36 (SF-36), and the Center for Epidemiological Studies Depression Scale (CES-D). | • The group, who performed exercise had improved sleep quality, vitality, sleep latency, sleep duration, daytime dysfunction, and sleep efficiency and had reduced depressive symptoms, and daytime sleepiness compared to the baseline score.<br>• Aerobic physical exercise and sleep hygiene education are very effective for persons facing chronic insomnia. | Reid et al. (2010) (USA) |
| 35. | Mood and exercise | Mood (Anger, depression, confusion, fatigue, tension, and vigor), and exercise | 71 retired male national-level athletes<br>Age: 46.2 ± 2.1 y | • All subjects were randomly classified into two exercise groups, i.e., morning (08:00 h) and evening (18:00 h) exercise groups.<br>• Participants did 60 min of aerobic exercise with a maximum of 80% heart rate, 3 times a week for 12 weeks. Profile of Mood States questionnaire was used to evaluate the mood. | • All mood components, anger, depression, confusion, fatigue, tension, and vigor, had a significant improvement following morning and evening exercise; however, exercise responses were not statistically significantly different in the morning and evening groups.<br>• Retired elite athletes should maintain regular exercise to support their mental health and reduce the risk of psychological problems. | Irandoust et al. (2019) (Iran) |

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**Table 1.** (Continued).

| S. No. | Areas of study | Variable | Sample structure and size | Methodology | Outcome | Reference |
|---|---|---|---|---|---|---|
| 36. | Sleep and Mood of athletes | All variables of sleep, insomnia risk, depression, anxiety, and daytime sleepiness | 17 professional male athletes<br>Age: 20 ± 3.5 y | • All participating athletes [South Korea ($N$ = 8), Australia ($N$ = 4), and the United States ($N$ = 5)] wore a wrist-activity monitor for 7 to 14 days and filled out subjective sleep and mood questionnaires.<br>• Participants completed the following inventories: (1) Centre for Epidemiological Studies-Depression (a 20-item self-report instrument used to assess symptoms of depression), (2) State-Trait Anxiety Inventory (a 20-item measure of state anxiety), (3) Pediatric Daytime Sleepiness Scale (an 8-item measure of daytime sleepiness), and (4) Insomnia Severity Index (a 7-item questionnaire that was used to assess the severity of insomnia). | • Participants had a median total sleep time of 6.8 hours and a sleep efficiency of 86.4% per night. Participants had an average median sleep onset latency of 20.4 min and a prolonged wake-after-sleep onset of 47.9 min. Korean players had significantly higher depression scores and trained longer per day compared to the other groups.<br>• Depression score strongly correlated with the number of awakenings, wake after sleep onset and daily training time. | Lee et al. (2021) (South Korea, Australia, and the United States) |
| 37. | Sleep pattern and chronotype | Sleep latency, psychological feeling, daytime sleepiness, and morningness-eveningness preference | 638 school students (308 males and 330 females)<br>Age range: 12–15 y | • Chronotypes were assessed using the Japanese version of the Morningness-Eveningness Questionnaire and a self-administered questionnaire administered to assess lifestyle habits and sleep-wake patterns. | • The distribution of chronotype was as follows: Morning type: 6.6%, Evening type: 29.3%, and Intermediate type: 64.1%.<br>• The prevalence of morningness was found significantly higher in girls as compared to boys.<br>• Evening preference was associated with morning bad feelings, daytime sleepiness, and longer sleep latency, whereas morning preference was associated with a higher sleep drive at night and a better lifestyle. | Gaina et al. (2006) (Japan) |
| 38. | Effect of training on sleep | Rating of perceived exertion, sleep variables, and fatigue | 12 male elite soccer players<br>Age: 18.5 ± 1.4 y | • All subjects performed high-intensity training followed by either cold water immersion or none.<br>• Rating of perceived exertion, all sleep variables, fatigue, and recovery measured at high-intensity training condition and control condition. | • Fatigue rating was higher in players not using cold water immersion after training.<br>• The rating of sleepiness was significantly higher during the training condition (7 ± 2 h) than the control condition (6 ± 1 h).<br>• Early evening high-intensity training does not inversely affect sleep quality and quantity. | Robey et al. (2014) (Australia) |

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| S. No. | Areas of study | Variable | Sample structure and size | Methodology | Outcome | Reference |
|---|---|---|---|---|---|---|
| 39. | Sleep extension effects on performance | Reaction time, mood, sleep-wake activity, and daytime sleepiness | 11 male Basketball players<br>Age: 19.4 ± 1.4 y | • Reaction time, mood, sleep-wake activity, and daytime sleepiness were measured using the Psychomotor Vigilance Task, Profile of Mood States questionnaire, actigraphy, and Epworth Sleepiness Scale, respectively, during baseline sleep and extended sleep.<br>• During baseline, subjects maintained their 6–9 h sleep for 2–4 weeks, and during sleep extension, they slept 10 h/night for 5–7 weeks.<br>• Every day between 12:00h-15:00h, subjects performed timed sprints and basketball shooting from 2 different line points, and time and accuracy were measured. | • The basketball players exhibited a faster-timed sprint following sleep extension. They basketed the ball more accurately and their mood state improved after extended sleep (10 h per night for 5–7 weeks), i.e., the value of negative mood states (like fatigue, depression, and confusion) decreased as well as the rating of positive mood (like vigor) increased significantly. | Mah et al. (2011) (USA) |
| 40. | Salivary cortisol levels of athletes | Salivary cortisol, and mood state | 11 male athletes<br>Age: 21.5 ± 2.16 y | • Saliva samples were collected upon awakening (at 07:00 h) and 30 min and 60 min after awakening.<br>• Saliva samples were collected just before the competition (at 16:00 h) and after the competition (at 18:20 h, 18:40 h, and 19:00 h), and salivary cortisol levels were estimated.<br>• To measure mood state and performance the Profile of Mood States questionnaire and self-reports of performance were used, respectively. | • Levels of cortisol concentration in saliva samples were different when measured before and after the competition.<br>• Higher levels of salivary cortisol were found to be associated with feelings of tension, anxiety, and hostility. | Díaz et al. (2013) (Brazil) |
| 41. | Circadian rhythm and salivary cortisol of gymnasts | Stress, and cortisol concentration | 320 (total); 239 Elite Artistic Gymnasts (AGs; 97 males; Age: 16.8 ± 1.1 y and 142 females; Age: 16.0 ± 1.6 y) and 81 adolescents (41 males; Age: 15.3 ± 2.0 y and 40 females; Age: 16.0 ± 1.4 y) | • Saliva samples were collected before (in the morning) and after (in the afternoon) completion of the competition.<br>• Acute stress was assessed by questionnaire and salivary cortisol concentration was measured by the Chemiluminescence method. | • No significant difference was found when both male and female gymnasts were compared with their respective controls, but females had higher cortisol concentrations than males.<br>• Female gymnasts reported higher psychological stress than males. | Georgopoulos et al. (2011) (Greece) |
| 42. | Salivary cortisol in athletes | Serum cortisol and salivary cortisol | 25 male players<br>Age: 27 ±1 y | • All subjects were allowed to rest for 30 min, then blood and saliva samples were collected between 08:00 h and 09:00 h, and serum cortisol and salivary cortisol were analyzed immediately after the collection of samples. | • Salivary cortisol and serum cortisol concentrations were significantly correlated. Therefore, salivary cortisol directly reflects the cortisol released into the blood by the adrenal gland.<br>• It is concluded that the measurement of salivary cortisol in athletes to measure stress levels is an appropriate approach. | Lippi et al. (2009) (Italy) |

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| S. No. | Areas of study | Variable | Sample structure and size | Methodology | Outcome | Reference |
|---|---|---|---|---|---|---|
| 43. | Salivary Immunoglobin A, cortisol, and testosterone in swimmers | Salivary Immunoglobin A (sIG-A), cortisol (sC), testosterone (sT), and stress | 21 swimmers<br>Age range: 11–15 y | • Saliva samples were collected during control week and competition week. Salivary Immunoglobin A (sIG-A), cortisol (sC), testosterone (sT), and testosterone to cortisol ratio (T/C) were measured. | • During control and competition week the concentrations of sIG-A = 47.9 ± 4.4 and 54.9 ± 5.2 µg/ml; sC = 2.7 ± 0.2 and 2.5 ± 0.2 ng/ml; sT = 181.3 ± 11.5 and 154.5 ± 11.3 pg/ml and T/C ratio = 83.4 ± 7.0 and 77.9 ± 7.7 were found, respectively.<br>• Pre-competition stress was not reported and immunity remained unchanged in young swimmers. | Papadopoulos et al. (2014) (Canada) |
| 44. | Cortisol, testosterone, and mood in Rugby players | Countermovement jump performance, salivary hormones (testosterone, cortisol, and T/C) mood state, and peak power output (PPO) | 14 male Rugby players<br>Age: 24.9 ± 4.4 y | • Thirty-six [36] h before and 12, 36, and 60 h after the rugby match, salivary hormones (testosterone, cortisol, and T/C), mood state, and peak power output (PPO) were measured by collecting saliva samples, administrating questionnaire and recording countermovement jump performance, respectively. | • PPO, salivary testosterone, and T/C ratio initially after the match decreased as compared to baseline concentration, but after 36 h of the match these variables started to recover.<br>• Salivary cortisol and mood disturbance increased, but during 36–60 hours of post-match, they became normal.<br>• No significant association among all the variables was found. It is concluded that the recovery time courses must be considered during match schedule formation. | West, Finn et al. (2014) (UK) |
| 45. | Salivary cortisol, testosterone, and T/C ratio in golf players | Salivary cortisol concentration and T/C ratio, anxiety level | 80 male golf players<br>Age: 20.3 ± 1.5 y | • Forty-five [45] min before the game and just after all 36-hole rounds, saliva samples were collected (a total of 37 samples from each player) and salivary cortisol and testosterone concentrations were determined using Radioimmunoassay.<br>• Data were analyzed using ANOVA, correlation, and LSC post hoc test. | • Salivary cortisol concentration and T/C ratio continuously declined after each hole round as compared to the previous round and baseline cortisol and T/C concentration, but salivary testosterone did not change significantly.<br>• During different tournaments across the seasons, different chronic responses were obtained. This could be due to season-dependent altered anxiety levels. | Doan et al. (2007) (USA) |
| 46. | Diurnal cortisol and aerobic exercise | Cortisol secretion, aerobic exercise | 9 male soccer players<br>Age: 19.9 ± 0.4 y | • Saliva samples were collected at awakening, 30 min after awakening, and after every 2 h between 08:00 h and 22:00 h, on separate days; without exercise, with morning exercise (10:00 h –11:30 h) and with afternoon exercise (14:00 h –15:30 h). | • After awakening, cortisol, but not dehydroepiandrosterone (DHEA), secretion suddenly increased, although both are the adrenal steroid hormones.<br>• It was evident that intense 90-minute aerobic exercise does not show a significant impact on the diurnal secretion of cortisol and DHEA. | Labsy et al. (2013) (France) |

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| S. No. | Areas of study | Variable | Sample structure and size | Methodology | Outcome | Reference |
|---|---|---|---|---|---|---|
| 47. | Salivary cortisol, testosterone, and body temperature in players | Squat jump (SJ), countermovement jump (CMJs), F-peak, P-peak, Salivary cortisol, testosterone, and aural temperature | 20 male players<br>Age: 23.8 ± 3.6 y | • Squat jump (SJ), countermovement jump (CMJs), and isometric mid-thigh pull (IMTPs) were performed at 08:00 h, 12:00 h, 16:00 h, and 20:00 h, and saliva samples along with the aural temperatures were collected.<br>• Maximal force production ($F_{peak}$) and maximal power output ($P_{peak}$) were measured during all the performances. | • A significant rhythmic variation was found on $F_{peak}$, $P_{peak}$, salivary cortisol, testosterone, and aural temperature but all these variables were not found to be significantly associated with each other.<br>• For the measurement of peak physical performance, aural temperatures were found to be a better indicator than hormones. | Teo, McGuigan et al. (2011) (Australia) |
| 48. | Salivary testosterone and exercise | Salivary testosterone secretion, and exercise | 20 male recreational weightlifters (with 2 years of experience)<br>Age: 18.0 ± 1.3 y | • Subjects were randomly categorized into the resistance exercise ($n$ = 10) or control ($n$ = 10) group<br>• Subjects performed resistance weightlifting exercises 3 times a week in the afternoon, with 6–7 repetitions.<br>• Saliva samples were collected at two-hour intervals. | • No significant difference was found in the diurnal variation of salivary testosterone secretion between the exercising group and the control group.<br>• No effect of exercise was detected on testosterone secretion. | Shariat et al. (2015) (Malaysia) |
| 49. | Effect of exercise on the circadian rhythm of salivary testosterone | Salivary testosterone | 10 resistance-trained males<br>Age: 21.6 ± 1.1 y | • Saliva samples were collected before 5 min of exercise (at 06:15 h), then all subjects performed 10 sets of prescribed/determined exercise from 06:20 h. Second saliva sample was collected during exercise (at 07:00 h) and after that, saliva samples were collected every hour from 08:00h to 22:00 h.<br>• On another day, saliva samples were collected at the same time, from the same subjects but without exercise. This group was treated as the control. | • No significant differences in salivary testosterone concentration were found between exercising protocol and control.<br>• It was concluded that resistance exercise does not affect the circadian pattern of salivary testosterone secretion. | Kraemer et al. (2001) (USA) |
| 50. | Body temperature rhythm and physical performance | Countermovement jump, Core temperature (T-core), and peak power output (PPO) | 16 male Rugby players<br>Age: 21 ± 4 y | • The players performed countermovement jumps.<br>• Core temperature (T-core) and peak power output (PPO) were measured in the morning and evening.<br>• Paired sample t-tests and correlation were used for data analysis. | • T-core and PPO significantly increased from am to pm.<br>• T-core and PPO were significantly associated.<br>• Athletic performance improved with increasing T-core. | West, Cook et al. (2014) (UK) |

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| S. No. | Areas of study | Variable | Sample structure and size | Methodology | Outcome | Reference |
|---|---|---|---|---|---|---|
| 51. | Body temperature, blood plasma, blood glucose, and athletic performance | Rectal temperature (Tc), skin temperature (Tsk), and heart rate (HR) | 9 male cyclists<br>Age: 24 ± 2 y | • Rectal temperature, skin temperature, and heart rate were recorded. Blood and expired air samples were collected at 06:45 h and 18:45 h, in the conditions: 65% exhaustion, 60% relative humidity, and 35°C ambient temperature. | • Time to exhaustion was significantly longer in am (45.8 ± 10.7 min) than in pm (40.5 ± 9.0 min).<br>• Tc and Tsk at rest did not significantly differ when morning and evening values were compared (at morning – 38.7 ± 0.9°C and at evening – 38.8 ± 0.6°C). Both Tc and Tsk were greater in am than pm when exhaustion increased. It was just the reverse in the case of HR. No significant change was found in blood glucose and plasma volume.<br>• The study suggested that the endurance exercise capacity is significantly high in the morning. | Hobson et al. (2009) (UK) |
| 52. | Effect of body temperature and dart throwing performance | Intra-aural temperature, fatigue, and dart-throwing performance | 12 male right-hander dart throwers (players)<br>Age: 21.4 ± 1.0 y | • Dart-throwing accuracy was measured from two distances from dart-board short throws (normal distance) and long throws (50% more than normal distance).<br>• Intra-aural temperature, fatigue, and dart-throwing performance (radial distance of dart from bull-eye) were measured. | • Long-distance dart throws improved significantly throughout the daytime with increasing intra-aural temperature but no significant correlation was seen between subjective fatigue and performance.<br>• Short distance throws were less associated with intra-aural temperature, but were highly associated with fatigue.<br>• The effect of the time of the day upon performance depended upon the relative importance of force and accuracy. | Edwards et al. (2007) (UK) |
| 53. | Melatonin in athletes | Intra-aural temperature, alertness, short-term memory, heart rate, nocturnal activity, altered rhythmicity of wrist temperature, and activity time | 12 athletes<br>Age: 25.2 ± 5.0 y | • At 11:45 h, 5 mg of melatonin was ingested by the participants. The intra-aural temperature, alertness, short-term memory, heart rate, and reaction time were measured at 13:00 h and 17:00 h. | • Melatonin ingestion at 11:45h reduced intra-aural temperature, alertness, short-term memory, heart rate, and reaction time measured in the afternoon and evening in athletes. | Atkinson et al. (2005) (UK) |

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| S. No. | Areas of study | Variable | Sample structure and size | Methodology | Outcome | Reference |
|---|---|---|---|---|---|---|
| 54. | Melatonin treatment and circadian pattern in athletes | Salivary melatonin, wrist temperature, motor activity, and body position rhythmicity | 24 trained male athletes<br>Experimental group $N$= 12; Age: 20.3 ± 0.71 y<br>Control group $N$= 12; Age: 19 ± 0.33 y | • The experimental group was orally treated with 100 mg/d of melatonin (melatonin capsule) at 30–60 min before bedtime till 4 weeks and the control group was equally treated with a placebo.<br>• Saliva samples (2 ml each time) were collected at 20:00 h, 23:00 h, 02:00 h, 05:00 h, and 08:00 h on the prior night of melatonin treatment start and the last night of melatonin treatment.<br>• Wrist temperature (using temperature wristband), body position, and rest-activity (using HOBO Pendant G Accelerometer armband) data were collected continuously for 7 d before melatonin treatment and the last 7 d during melatonin treatment. | • Melatonin reduces nocturnal activity and alters the rhythmicity of wrist temperature, activity, and body position.<br>• Melatonin treatment at bedtime improved sleep efficiency and beneficially modulated the sleep-wake cycle. | Leonardo-Mendonça et al. (2015) (Spain) |
| 55. | Effect of melatonin ingestion on cognition and physical performance | Reaction time, vigilance task, medicine-ball throw (MBT), 5 jumps, handgrip strength (HG), and agility | 12 soccer players<br>Age: 17.9 ± 1.3 y | • Subjects ingested 5 mg melatonin or placebo in the morning and performed cognitive and physical tests at 08:00 h, 12:00 h, 14:00 h, and 16:00 h.<br>• Reaction time, vigilance task, medicine-ball throw (MBT), 5 jumps, handgrip strength (HG), and agility test were assessed. | • Physical and cognitive performances were found to be significantly higher at 16:00 h as compared to 08:00 h.<br>• Melatonin ingestion did not affect physical and cognitive performance at noon in soccer players.<br>• Ingestion of melatonin in the morning did not produce any unfavorable effect on afternoon physical and cognitive performances. | Ghattassi et al. (2016) (Tunisia) |
| 56. | Time of the day effect on performance | Mechanical, kinematic, and physiological variables | 16 international-level mountain bike male athletes<br>Age: 34.81 ± 5.76 y | • Athletes performed two field time trials; one in the morning (06:30h-10:30 h) and the other in the afternoon (14:30 h-18:30 h) of 20 min at maximum intensity using the same mountain bike (MTB). | • No significant circadian effects were observed in the MTB performance of athletes. Therefore, it is not justifiable to plan differently for the morning or afternoon periods. | Silveira et al. (2020) (Portugal) |
| 57. | Effect of physical training at different times of day | Oral temperature, athletic performance (squat jump and countermovement jump), and muscle strength | 31 male players<br>Age: 23.1 ± 1.98 y | • Subjects were categorized into 3 groups: The morning training group (MTG) trained from 17:00 h to 18:00 h = 10 players; Evening training group (ETG) trained from 17:00 h to 18:00 h = 11 players; and Control group (CG) not trained = 10 players<br>• Oral temperature, athletic performance (squat jump and countermovement jump), and muscle strength were measured during the performance. | • No significant difference was found in muscle strength and athletic performance in MTG and ETG.<br>• The author concluded that training for physical performance can be carried out at any time of the day with the same benefit. | Chtourou et al. (2012) (Tunisia) |

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**Table 1.** (Continued).

| S. No. | Areas of study | Variable | Sample structure and size | Methodology | Outcome | Reference |
|---|---|---|---|---|---|---|
| 58. | Effect of time of day on cycling performance | Peak power (PP), mean power in the first 30s (MP 30s) and MP 60s, and fatigue | 16 male cyclists<br>Age: 23.5 ± 1.1 y | • Subjects performed a 60 s Wingate test at 06:00 h or 18:00 h with at least a 36h gap between two successive performances.<br>• Peak power (PP), mean power in the first 30 s (MP 30 s) and MP 60 s, and fatigue were measured and analyzed. | • PP, MP 30 s, and MP 60 s at 18:00h were significantly higher (8.2%, 7.8%, and 7.8%, respectively) than those at 06:00h. | Lericollais et al. (2009) (France) |
| 59. | Effect of time of day on cycling performance | Mean power (P-mean), peak-power (P-peak), fatigue index (FI), the evolution of power output, and core body temperature | 22 male cyclists<br>Age: 23.2 ± 1.9 y | • Subjects performed 30-s Wingate cycling tests at 07:00 h and 17:00 h.<br>• Mean power (P-mean), peak-power (P-peak), fatigue index (FI), and evolution of power output (5-s span) were assessed. | • Resting core body temperature, P-mean, P-peak, and FI were found significantly higher in the evening session test than in the morning test.<br>• No significant difference was noticed between 07:00h and 17:00h, during the 30-s Wingate test. | Chtourou et al. (2011) (Tunisia) |
| 60. | Time of day effect on performance | Gymnastic performance and oral temperature | 92 (42 female gymnasts; Age: 13.3 ± 0.5 y; 50 female control subjects; Age: 12.8 ± 1.7 y) | • Gymnastic performance and oral temperature were measured twice a day: in the morning (08:30–09:30) and then in the evening (19:00–20:00).<br>• MANOVA was performed to analyze data. | • The strength test and gymnast performance results were significantly better in the evening.<br>• According to the authors, the trainer should not bother about the time of day as an important factor for coordination because they perform better at the time when they are habituated to perform. | di Cagno et al. (2013) (Italy) |
| 61. | Time of day and athletic performance | Athletic performance | - | • The retrospective data were analyzed of the West Coast (WC) and East Coast (EC) teams that participated in the National Football League over a period of 25 years (from 1970 to 1994).<br>• Logistic regression was used to analyze the data of winning-loss records, time of EC, WC, and time zone, where tournaments were organized. | • WC time and EC time differed by 3 h from game place time zone and matches were played at 21:00 h which means WC players played at 18.00 h which is the peak performance time and EC players played at 00.00 h am (mid-night) which is the worst performance time according to their home place time zone/internal body clock.<br>• It was seen that the WC team won 63% of matches with an average of 14.7 points than the EC team who won 36.5% of matches.<br>• It was concluded that the team gets a home-field advantage. | Smith et al. (1997) (USA) |

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| S. No. | Areas of study | Variable | Sample structure and size | Methodology | Outcome | Reference |
|---|---|---|---|---|---|---|
| 62. | Effect of time of day on performance | $VO_2$, peak power output (PPO), and HR | 9 male cyclists<br>Age: 31 ± 7.3 y | • According to the study design, the subjects visited the laboratory 4 times and there were approximately 48 h, 96 h, and 168 h time gaps between two successive time of laboratory visits, respectively.<br>• Anthropometric assessment and incremental test were carried out on the first visit; during the 2nd visit, they performed a 1000-m cycling familiarization trial, and the actual 1000-m cycling time trial (TT) was performed on the third and fourth visits.<br>• $VO_2$ was measured by a Zirconium sensor.<br>• Data were analyzed by ANOVA, *t*-test, and *F*-test using SPSS. | • Time taken for physical performance (1000 m cycling TT) was significantly less in the evening than morning (88.2 ± 8.7 s and 94.7 ± 10.9 s, respectively).<br>• Diurnal variations in $VO_2$, PPO, and HR were not statistically significant. | Fernandes et al. (2014) (Brazil) |
| 63. | Effect of time of day on weightlifting performance | Snatch, clean and jerk (weightlifting-specific performance), and oral temperature | 9 male elite weightlifters<br>Age: 21 ± 0.5 y | • All the subjects performed snatch, clean, and jerk (weightlifting-specific performance) at 08:00 h, 14:00 h and 18:00 h.<br>• Blood samples were collected before and after each training session and the rating of perceived exertion (RPE) was assessed.<br>• ANOVA was used for data analysis. | • RPE was the lowest at 14:00 h as compared to morning and evening sessions.<br>• The highest oral temperature was observed at 18:00 h.<br>• It was concluded that afternoon training is more effective than morning and evening. | Ammar, Chtourou, Trabelsi et al. (2015) (Tunisia) |
| 64. | Effect time of day on peak athletic performance | Speed, agility, pulse rate, skin temperature, stress, and anxiety | 60 female athletes<br>Age range: 16–17 y | • Sprinters, shot-put throwers, jumpers, and long-distance runners were selected in the same numbers; and speed, agility, pulse rate, skin temperature, stress, and anxiety were measured at 06:00 h, 10:00 h, 14:00 h, and 18:00 h. | • Peak performance of sprint, jump, and shot-put throw was found at 18:00 h; whereas in long-distance running 06:00 h was recorded as the time of the peak performance.<br>• Anxiety and stress levels remained unchanged but significant diurnal variation was found in speed, pulse rate, and skin temperature among all the athletes. | Kalaiselvi (2009) (India) |
| 65. | Effect of time of day on peak performance | Peak power ($P_{peak}$), mean power ($P_{mean}$) fatigue index, medical stress | 12 male students in physical education<br>Age: 23.5 ± 3.1 y | • 4 Wingate tests; peak power ($P_{peak}$), mean power ($P_{mean}$) fatigue index, and medical stress test measured during 30 s cycling exercise at 08:00 h and 18.00 h on different days separated by 36 h.<br>• After 5 min warmup or 15 min warmup, rectal temperature was measured.<br>• Two-way ANOVA was used for data analysis. | • The effect of time of day upon $P_{peak}$ and $P_{mean}$ was found more significant in contrast with the effect of warmup duration.<br>• $P_{peak}$ and $P_{mean}$ were significantly improved from morning to afternoon. | Souissi et al. (2010) (Tunisia) |

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**Table 1.** (Continued).

| S. No. | Areas of study | Variable | Sample structure and size | Methodology | Outcome | Reference |
|---|---|---|---|---|---|---|
| 66. | Time of day effect on static and dynamic balance | lower quarter Y-balance, and upper quarter Y-balance | 34 athletes (16 males and 18 females)<br>Age: 23.4 ± 3.7 y | • Subjects had performed single-leg stance tests with and without their eye open, landing lower quarter Y-balance test and upper quarter Y-balance test.<br>• All the tests were performed in the morning (07:00 h to 10:00 h) and in the afternoon (15:00 h to 18:00 h) for two consecutive days. | • It was found that; the effect of time of day was not found to be statistically significant in dynamic balance.<br>• There is a significant effect of time of day on static balance. | Heinbaugh et al. (2015) (USA) |
| 67. | Effect of time of the day on static and dynamic balance | Oral temperature, static and dynamic postural balance | 40 female subjects (20 rhythmic gymnasts (Age: 13.2 ± 0.5 y) and 20 healthy students (Age: 12.9 ± 0.6 y) | • Horne and Östberg Morningness-Eveningness Questionnaire used, static and dynamic balance measured and oral temperature measured in morning and evening. Both trials were separated by one week.<br>• Repeated measure MANOVA, repeated measure two-way ANOVA, and one-way ANOVA were employed for data analysis in SPSS. | • No significant difference was found in the balance test as a function of time of day in athletes but there is a significant time of day effect found in the balance test in non-players.<br>• Untrained students show better results in the morning than evening. | di Cagno et al. (2014) (Greece) |
| 68. | Effect of time of day on static and dynamic balance | Static and dynamic postural balance | 24 healthy students (10 males and 14 females)<br>Age: 22.17 ± 1.61 y | • Static and dynamic postural balance tests were conducted during three sessions, at 09:00 h, 13:00 h, and 17:00 h.<br>• Counterbalanced order for prevention (COP) velocity and distance were measured at each test session. | • Static as well as dynamic balance was influenced by the time of the day.<br>• COP velocity was slower and COP distance was shorter significantly at 09:00 h as compared to 13:00 h and 17:00 h.<br>• The study suggests that static as well as dynamic postural balance abilities were greater in the morning and worse at noon. | Kwon et al. (2014) (Korea) |
| 69. | Benefits of physical training in the morning | Physical performance, and salivary testosterone concentration | 18 male Rugby players<br>Age: 22 ± 1 y | • Saliva samples were collected twice a day at 09:00 h (before performance) and 15:00 h (after performance).<br>• Physical performance 5×40 m sprint and countermovement jump were performed by players, and time and accuracy were measured. | • Salivary testosterone concentration significantly declined from am to pm (ΔT= −10.9 ± 2.4 pm/ml) and salivary cortisol concentration increased from am to pm.<br>• It was found that morning training is associated with improved physical performance in the afternoon.<br>• The association of salivary testosterone with physical performance was unclear. | Cook et al. (2014) (UK) |

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| S. No. | Areas of study | Variable | Sample structure and size | Methodology | Outcome | Reference |
|---|---|---|---|---|---|---|
| 70. | Circadian rhythm in swimming performance | Sleep-wake cycle, and swimming performance | 25 swimmers (12 males and 13 females)<br>Age: 20.7 ± 0.6 y | • All subjects followed an ultra-short sleep-wake cycle of 3 h consisting of 2 h of wakefulness in dim light and 1 h of sleep under darkness. This protocol was repeated multiple times throughout the study.<br>• All subjects were assessed for 50–55 hours in the laboratory for equal distribution of behavior and environmental masking factors.<br>• Swimmers performed 200 m swimming across 8 times per day and each performance was separated by 9 h.<br>• Cosinor and ANOVA were used to analyze the data. | • Performance peaked at approximately 23:00h (5–7 h before lowest body temperature and worse at 05:00h (approximately 1 h before and 1 h after lowest body temperature).<br>• Mean swim performance 169.5 s/200 m, during worse performance swimmers take- 5.8 s extra.<br>• The results of this study suggest that the circadian rhythm in swimming performance was statistically significant and independent of environmental and behavioral masking effects. | Kline et al. (2007) (USA) |
| 71. | Effect of time of the day on swimming performance | Swimming performance and performance time | $N = 144$ Olympic swimmers (72 males and 72 females) | • Swimmers who qualified for the heats, semifinal, and final were included only.<br>• All data for this study likewise; swim schedules and pertinent finish times of Olympic venues of Athens, Beijing, London, and Rio de Janeiro were obtained from https://www.olympic.org/<br>• Nine different combinations of swimming performance were taken for the analysis. backstroke (100 and 200 m), breaststroke (100 and 200 m), butterfly (100 and 200 m), and freestyle (50, 100, and 200 m). | • The physical performance assessed was significantly affected by time of day. The best performance was determined in the late afternoon around 17:12 h, which was approximately 0.32% improved than 08:00 h.<br>• Peak physical performance is not only determined by training but also by the endogenous circadian system. | Lok et al. (2020) (USA) |
| 72. | Diurnal variation in performance of power output | Body temperature, jump performance, and warm-up timings | 8 male athletes<br>Age: 29.8 ± 5.2 y | • Subjects performed warm-ups at 08:00 h and 16:00 h (control warm-up) and 08:00 h and 16:00 h (extended warm-up) increased 0.3 ± 0.2°C body temperature. | • Performance was 2–6% higher at 16:00h than at 08:00h of control warm-up; whereas no significant difference was found for extended warm-up at 08:00 h and 16:00 h.<br>• It was concluded that to reduce diurnal differences in jump performance, warm-up is beneficial. | Taylor et al. (2011) (Australia) |
| 73. | Diurnal variation in jump performance | Squad jump (SJ) and counter-movement jump (CMJ) | 20 male athletes<br>Age: 18.6 ± 1.3 y | • Subjects performed warm-up by either static stretching or dynamic stretching or no warm-up before performing SJ and CMJ at 07:00 h and 17:00 h.<br>• Data were analyzed using two-way ANOVA, Turkey post hoc test, and partial etas square ($\eta P^2$) using STATISTICA software. | • Both the SJ and CMJ performed significantly higher at 17:00 h than at 07:00 h.<br>• Subjects performed better after no stretching as compared to any kind of warm-up protocol.<br>• Dynamic stretching was more beneficial than static stretching concerning jump performance. | Chtourou et al. (2013) (Tunisia) |

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**Table 1.** (Continued).

| S. No. | Areas of study | Variable | Sample structure and size | Methodology | Outcome | Reference |
|---|---|---|---|---|---|---|
| 74. | Diurnal variation of fatigue on performance | Fatigue, and cycling performance | 20 male cyclists<br>Age: 21.2 ± 1.4 y | • Subjects performed a 60 s Wingate test at 06:00 h and 18:00 h and fatigue index and power output were assessed. | • Fatigue index and power output were higher at 18:00 h (71.4%) than at 06:00 h (69.2%).<br>• Diurnal variation in performance and fatigue were significantly associated with diurnal changes in cycling kinematic parameters. | Lericollais et al. (2011) (France) |
| 75. | Diurnal variation in cardiovascular endurance and performance | Maximum oxygen uptake ($VO_2$ max), percentage of maximal heart rate, body temperature, and blood lactic acid level. | 35 male athletes<br>Age: 15.17 ± 1.62 y | • All the participants performed cardiovascular endurance exercises in the morning (09:00 h- 10:00 h) at noon (12:00 h-13:00 h) and in the afternoon (16:00 h- 17:00 h) on three nonconsecutive days.<br>• Maximum oxygen uptake ($VO_2$ max), post-exercise percentage of maximal heart rate, post-exercise body temperature, and blood lactic acid level were measured. | • $VO_2$ max was found significantly higher at noon as compared with the afternoon.<br>• Other parameters do not show any significant difference concerning the time of the day.<br>• For young athletes' noon training appears to be productive. | Chin et al. (2015) (Hong-Kong) |
| 76. | A. study – 1<br>Diurnal variation in mental and physical performance | Intra-aural temperature (a marker of the body clock), grip strength, reaction time, flexibility (physical performance), juggling, dribbling and wall volley test (soccer-specific skills), alertness, and fatigue | 8 male soccer players<br>Age: 19.1 ± 1.9 y | • Intra-aural temperature (a marker of body clock), grip strength, reaction time, flexibility (physical performance), juggling, dribbling, and wall volley test (soccer-specific skills) were performed at 08:00 h, 12.00 h, 16:00 h, and 20:00 h on separate days and measured.<br>• Repeated measure ANOVA and ANOVA were used for data analysis. | • Alertness was the highest and fatigue was the lowest at 20:00 h.<br>• Juggling and wall volley performance peaked at 16.00 h and 20:00 h respectively but dribbling did not show diurnal variations. | Reilly et al. (2007) (UK) |
| 77. | B. study – 2<br>Diurnal variation of body temperature | Intra-aural temperature | 8 male football players<br>Age: 23.9 ± 0.7 y | • All the players completed five test sessions at 08:00 h, 12:00 h, 16:00 h, and 20:00 h, and intra-aural temperature was measured. | • The intra-aural temperature was higher at 16:00h (36.4°C) than at 08:00h (35.4°C).<br>• The effect of chronotype upon temperature acrophase was not statistically significant.<br>• Players performed optimistically between 16:00 h and 20:00 h; when body temperature was at its peak. | Reilly et al. (2007) (UK) |

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**Table 1.** (Continued).

| S. No. | Areas of study | Variable | Sample structure and size | Methodology | Outcome | Reference |
|---|---|---|---|---|---|---|
| 78. | Diurnal variation in sprint ability | Rectal temperature (Trec) and muscle temperature (TM), heart rate, thermal comfort and rating of perceived exertion, distance covered, peak power, peak velocity, and average velocity | 20 active males<br>Age: 21.0 ± 2.2 y | • All the participants performed 10×35 repeated sprints with 30 s recovery on the non-motorized treadmill in the morning (07:30 h) and in the evening (17:30 h).<br>• Rectal temperature and muscle temperature, heart rate, thermal comfort, and rating of perceived exertion were measured during both trials. | • Trec and TM values were higher at rest in the evening than in the morning (0.46°C and 0.57°C respectively).<br>• Distance covered, peak power, peak velocity, and average velocity were significantly higher in the evening.<br>• A significant positive correlation between thermal comfort and repeated sprint ability (RSA) was found.<br>• The diurnal variation in Trec and TM cannot fully explain, time of day oscillation in RSA on a non-motorized treadmill. | Pullinger et al. (2014)<br>(UK) |
| 79. | Diurnal variation and day-to-day variations of $VO_2$ max among athletes | Maximum oxygen uptake ($VO_2$ max) | 17 (10 males and 7 females)<br>Age range: 18–40 y | • All participants performed a cardiopulmonary exercise test (CPET) at six different times of the day at 07:00 h, 10:00 h, 13:00 h, 16:00 h, 19:00 h and 21:00 h.<br>• $VO_2$ max was measured breath by breath for 30 s during each CPET.<br>• Day-to-day variation and diurnal variation of $VO_2$ max were analyzed. | • Diurnal variation was significantly higher than the day-to-day variation of $VO_2$max.<br>• The time of the day effect on $VO_2$ max was not statistically significant.<br>• Diurnal variations have meaningful implications for competitive sports and need to be considered by athletes. | Knaier, Infanger, Niemeyer, et al. (2019)<br>(Switzerland) |
| 80. | Diurnal and day-to-day variation in strength | Isometric and isokinetic leg, arm, and trunk strengths | 19 male athletes<br>Age: 24.1 ± 2.5 y | • Isometric and isokinetic leg, arm, and trunk strength were measured at 07:00 h, 10:00 h, 13:00 h, 16:00 h, 19:00 h, and 21:00 h with an isokinetic dynamometer.<br>• Day-to-day variation and diurnal variation in the isometric and isokinetic leg, arm, and trunk strength were analyzed. | • Diurnal variation in strength was observed without a significant time-of-the-day effect, which clarified that individuals achieve their peak performance at different times of the day.<br>• Diurnal variations in leg and arm strength were nearly three times higher than the day-to-day variation. | Knaier, Infanger, Cajochen, et al. 2019<br>(Switzerland) |
| 81. | *PERIOD 3* Gene and chronotype distribution among athletes | Morningness-eveningness preference | 390 males (125 Cyclists (CYC), 120 Runner (RUN), 49 Ironman Triathletes (IM), and 96 Controls (CON)<br>Age range: 25–50 y | • Chronotype was determined using the Horne and Östberg Morningness-Eveningness Questionnaire.<br>• *PER3* gene (*PER3*$^5$ and *PER3*$^4$), *VNTR* genotypes were assessed and analyzed. | • Significantly more individuals from the athlete group were found to be morning type than the control individuals, CON (CYC = 72%, RUN = 67%, IM = 59%, and CON = 41%).<br>• Athletes have more PER3$^5$/PER3$^5$ homozygous dominant genotype (responsible for morningness) than the CON.<br>• The PER3 and VNTR may be one of the factors that could be ascribed to this phenomenon. | Kunorozva et al. (2012)<br>(South Africa) |

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| S. No. | Areas of study | Variable | Sample structure and size | Methodology | Outcome | Reference |
|---|---|---|---|---|---|---|
| 82. | Effect of time of day, chronotype, and PER3 genotype on the performance of swimmers | Swimming performance, salivary α amylase, chronotype, and period gene (PER 3 gene) | 27 swimmers (8 males and 19 females)<br>Age range: 18–22 y | • All participants performed a 200-m time trial swimming performance at 07:00 h and 19:00 h. Salivary α-amylase level was evaluated as a physiological effort from the saliva sample collected at pre- and post-performance.<br>• Hair samples were collected for the analysis of genotype; circadian clock gene- PER3. | • Self-report evening-type elite swimmers, swim up to 6% slower and expend 50–70% more effort in the morning (50% more α-amylase level). Similarly, the morning-type swimmer required 5–7 times more effort than the evening-type.<br>• Participants homozygous for the $PER3^{4,4}$ performed 3–6% slower in the morning.<br>• The results indicate that the players' circadian phenotype significantly influences swim performance and effort. | Anderson et al. (2018) (US) |
| 83. | Chronotype distribution among marathon runners | Morningness-eveningness preference | 380 male marathon runners<br>Age range: 25–50 y | • Marathon runner (South Africa = 95, Netherlands = 90), control (South Africa = 97, Netherlands = 98).<br>• Demographics, training, and race history were assessed, and chronotype was determined using the Horne and Östberg Morningness-Eveningness Questionnaire.<br>• Buccal cell samples were collected from each subject and DNA was amplified by PCR. PERIOD3 (PER3), Variable Number Tandem Repeat (VNTR) genotypes were assessed and analyzed. | • It was found that South African runners were significantly more morning type than Dutch runners and morningness yielded better performance in the morning.<br>• Runners of both countries were earlier chronotypes than controls.<br>• PER3 and VNTR polymorphisms were similar in each group and it was not associated with chronotype. | Henst et al. (2015) (South Africa) |
| 84. | Chronotype distribution among cyclists | Morningness-eveningness preference | 20 male trained cyclists<br>Age: 39.8 ± 7.7 y | • All these subjects were morning type (mean Horne-Östberg score 68.3 ± 5.5) and were carrying the $PER\text{-}3^5$ allele.<br>• The cycling test was performed at 06:00 h, 10:00 h, 14:00 h, 18:00 h and 22:00 h. | • Rating of perceived exertion was the maximum found at 18:00h and 22:00h as compared to morning and afternoon.<br>• The Chronotype of the players must be considered in the training and competition schedule. | Kunorozva et al. (2014) (South-Africa) |
| 85. | Aural temperature, sleep, mood, and diurnal performance | Aural temperature, fatigue, drowsiness, and sleep duration | 130 (61 male gymnasts, 69 female gymnasts)<br>Age range: 6–11 y | • Gymnastics were performed at the gym at 09:00 h, 11:00 h, 14:00 h, and 16:00 h and saliva samples were collected and cortisol levels were measured.<br>• Applied t-tests and ANOVA were employed to analyze data. | • Aural temperature, fatigue, drowsiness, and sleep duration did not differ significantly between morning (at 09:00 h to 10:00 h) and afternoon (at 14:00 h to 15:00 h).<br>• Gymnasts performed better in June than in the winter season. | Huguet et al. (1997) (France) |

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| S. No. | Areas of study | Variable | Sample structure and size | Methodology | Outcome | Reference |
|---|---|---|---|---|---|---|
| 86. | Chronotype, mood, and swimming performance | Morningness-eveningness preference, mood, and swimming performance | 26 swimmers (18 males and 8 females)<br>Age: 32.6 ± 5.7 y | • Swimmers were examined once in a randomized order as a single group and at another time they were categorized into 2 groups and swam at 06:30 h and 18:30 h for 200 m time trials (TT). | • No significant difference in performance was found when morning and evening groups were compared (158.8 ± 22.7 s and 158.5 ± 22.05 s, respectively), but when the morning type performer performed in the morning and the evening type swimmers performed in the evening, then significant diurnal variation in performance was observed. | Rae et al. (2015) (South Africa) |
| 87. | Chronotype effect on rowing crew performance | Standing broad jump performance | 16 (8 males, 8 females)<br>Age: 19.6 ± 1.5 y | • 2000 m Rowing Crew sprint and standing broad jump test were performed by subjects in the early morning (05:00 h to 07:00 h) and the late afternoon (16:30 h to 18:00 h).<br>• Chronotype was determined by standard self-rating chronotype scale. | • Chronotype estimation resulted in 8 E-type, 4 M-type, and 4 N-type subjects.<br>• Rowing Crew sprint performance was significantly faster in M-type in the morning than in E-type and N-type; whereas no significant difference was found in standing broad jump performance among various chronotype groups. | Brown et al. (2008) (USA) |
| 88. | Chronotype and peak physical performance | Morningness-eveningness preference, light exposure, sleep duration, sleep quality | 216 (114 females and 102 males)<br>Age: 21.5 ± 3.96 y | • RB-UB chronometric test based on a questionnaire was employed to assess wake-up and sleep time, light exposure, sleep duration, sleep quality, and information about diet and its time of intake.<br>• Physical performance consisting of the sprint, accuracy test, and BLEEP test to estimate athletes' maximum oxygen uptake was performed from 07:00 h to 22:00 h (6 times/d). | • With the help of the RU-BP questionnaire, all the participants were categorized into Early Chronotype (ECT, $n$ = 32), Intermediate Chronotype (ICT, $n$ = 111), and Late Chronotype (LCT, $n$ = 73).<br>• Significant differences were found in wake-up time and sleep onset time among ECT, ICT, and LCT.<br>• A significant difference in peak performance time was observed as ECT at 13:52 h and LCT at 20:59 h.<br>• A significantly positive correlation was detected between ECT and age in males. | Facer-Childs and Brandstaetter (2015a) (UK) |

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| S. No. | Areas of study | Variable | Sample structure and size | Methodology | Outcome | Reference |
|---|---|---|---|---|---|---|
| 89. | Exercise and circadian phase shifting | Chronotype, habitual bedtime, sleep, rest-activity, peak oxygen consumption, and dim light melatonin onset | 52 young, sedentary adults (16 males and 36 females)<br>Age: 24.77 ± 1.20 y | • All participants completed the Morningness-Eveningness Questionnaire (for the assessment of chronotype preference) and the Munich Chronotype Questionnaire (for the assessment of habitual bedtime).<br>• Participants wore actigraphy devices for the duration of the study to measure activity and sleep. Cardiorespiratory fitness was determined by measuring peak oxygen consumption ($VO_2$ peak).<br>• Dim light melatonin onset (DLMO) was measured before and after 5 d of exercise.<br>• All participants were divided into two exercising groups; morning (10 h after DLMO; $n$ = 26) and evening (20 h after DLMO; $n$ = 26). | • Morning as well as evening exercise-induced phase advancement in late chronotypes but in contrast, earlier chronotypes had phase advances from morning exercise but had phase delays from evening exercise.<br>• Morning exercise is more helpful in phase-shifting as morning exercise-induced phase advance shifts (0.62 ± 0.18 h) significantly greater than phase shifts from evening exercise (−0.02 ± 0.18 h).<br>• Exercise is a beneficial method to get rid of severe circadian misalignment. | Thomas et al. (2020) (USA) |
| 90. | Travelling direction and Jet lag in athletes | BP, HR, salivary cortisol, melatonin, and body temperature | 19 male athletes<br>(Westward Flight group, $N$ = 13; Age: 24.6 ± 2.0 y and Eastward Flight group, $N$ = 6; Age: 23.0 ± 2.3 y) | • 13 athletes traveled 6 time zones toward the West and 6 athletes traveled 8 time zones toward the East and performed exercises $1^{st}$, $4^{th}$, $6^{th,}$ and $11^{th}$ d in the morning and evening after travel.<br>• Blood pressure (BP), heart rate (HR), salivary cortisol, and melatonin were measured in all the participants. | • Jet lag symptoms were seen on Westward traveled players for 5–6 d; whereas symptoms were found in Eastward players for 7 d.<br>• BP and HR were significantly affected due to transmeridian flight but in a different manner.<br>• BP increased in Westward travel, while decreased in Eastward travel.<br>• Synchronization or entrainment in body temperature rhythm is needed for 1 day for 1-time zone after the travel. | Lemmer et al. (2002) (Germany) |
| 91. | Sun exposure, exercise, and sleep | Physical status and quality of life, and melatonin | 10 male Subjects<br>Age: ~ 20 y | • Subjects performed 4 experimental protocols; 1. Only sun exposure for 30 min (EG-1), 2. Only aerobic exercise for 30 min (EG-2), 3. Aerobic exercise with sun exposure (EG-3), 4. Control (EG-4).<br>• Each protocol was repeated 5 times a week and there is a 1-week gap between each protocol.<br>• Pittsburgh Sleep Quality Index was filled before and after each protocol and sleep-related hormones like melatonin, cortisol, epinephrine, and nor-epinephrine were measured.<br>• One-way ANOVA was used for data analysis. | • Bedtime and wake-up time of EG-4 were significantly later than EG-1 and EG-3 and the sleep cycle of EG-4 was also found shorter than other experimental groups.<br>• Melatonin in the blood of EG-3 was significantly higher than EG-4 but no other hormones.<br>• The result suggests that sun exposure (EG-1) and sun exposure with exercise (EG-3) improve physical status and quality of life. | Lee et al. (2014) (Korea) |

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| S. No. | Areas of study | Variable | Sample structure and size | Methodology | Outcome | Reference |
|---|---|---|---|---|---|---|
| 92. | Effect of bright light therapy on the sleep-wake cycle of Olympic swimmers | Sleep-wake cycle, and reaction time | 22 Brazilian Olympic swimmers (11 males and 11 females)<br>Age: 24.8 ± 3.4 y | • All players reached 10 d before the competition to acclimatize according to the new time zone (Brazil to Rio) and this study was performed during the acclimatization period.<br>• The sleep-wake cycle was assessed for 8 d by actigraphy and treated with bright light using artificial light emanating glasses for 30–45 min between 18:00 h to 20:00 h from the third day.<br>• Reaction time was assessed before (day 1) and after (day 8) following the bright light therapy. | • Bright light therapy in the evening hours delayed the sleep-wake cycle and improved the reaction time of athletes.<br>• Artificial light-emanating glass is a useful tool for athletes who go to compete in different time zones. | Rosa et al. (2018) (Brazil and Rio) |
| 93. | Effect of bright light on cycling exercise | Core body temperature, and cycling ability | 8 male cyclists<br>Age: 22 ± 2 y | • Subjects were exposed to either bright light (BL), 2500 Lux from a 50 cm distance, or no light (NL) for 30 min in the evening one day before the commencement of the experiment.<br>• 10 km time trial cycling was performed the next day morning at 35°C, 60% humidity.<br>• Core body temperature was measured after cycling. | • 10 km cycling was completed in 1.43 ± 0.63 min faster after BL exposure as compared to NL exposure.<br>• Core body temperature in BL was 38.21 ± 0.56°C while in NL it was 38.64 ± 0.42°C. A statistically significant difference was not found.<br>• The result shows that 30 min BL exposure before sleep can induce exercise the next morning in hot conditions. | Thompson et al. (2015) (UK) |
| 94. | Light exposure and cycling performance | Cycling performance | 41 male cyclists<br>Age: 25.1 ± 3.1 y | • All participants were divided into 3 groups: 2HEX (light exposure 120 min before and during exercise), $n$ = 16; 1HEX (light exposure 60 min before and during exercise), $n$=10; and 1H (light exposure 60 min only before exercise), $n$=15.<br>• 40-min time-trial cycling performed by the subjects. | • The work performance of the 2HEX group was significantly higher than the other 2 groups.<br>• Light intensity and duration of exposure were significantly associated with cycling performance. | Knaier et al. (2016) (Switzerland) |
| 95. | Effect of light therapy and sleep hygiene on swimming performance | Reaction time, and competition time | 14 (10 males and 4 females)<br>Age: 27.3 ± 2.4 y | • The morningness-eveningness preference of all swimmers was monitored by Horne and Östberg´s Questionnaire. The sleep-wake cycle was measured by actigraphy.<br>• During the swimming competition, each athlete's reaction time and competition time were recorded in three phases (Elimination, Semifinals, and Finals).<br>• Light therapy and sleep hygiene were used as intervention strategies. | • Results revealed that the light therapy and sleep hygiene intervention effectively minimized any effect of the time of competition upon the performance of reaction time and competition time of elite athletes.<br>• The findings could be of significance to the planners of sporting events. | Mello et al. (2020) (Brazil) |

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| S. No. | Areas of study | Variable | Sample structure and size | Methodology | Outcome | Reference |
|---|---|---|---|---|---|---|
| 96. | Time of the effect on psychomotor and physical performances | Physical performances, and psychomotor performances | 14 male cyclists<br>Age: 17.3 ± 1.6 y | • 2×10 s sprint presented by subjects at 6 different times of day at 08:30 h, 10:30 h, 12:30 h, 14:30 h,16:30 h, 18:30 h.<br>• Attentional/psychomotor performance test performed in every 2 h. | • Psychomotor and physical performance depended on the time of day; hence, cycling competition couldn't be programmed throughout the day.<br>• Daily variations in physical performances were reflected in psychomotor performances. | Petit et al. (2013) (France) |
| 97. | Circadian rhythm of mood disturbance among volleyball players | Mood disturbance | 30 volleyball players (15 males and 15 females)<br>Age range: 19–22 y | • The Profile of Mood States questionnaire was used to assess mood disturbance.<br>• The circadian rhythm of mood disturbance in male and female were measured.<br>• Data were collected at 02:00h, 06:00 h, 10:00 h, 14:00 h, 18:00 h, and 22:00 h. Data were subjected to ANOVA and Cosinor. | • Circadian rhythm of total mood disturbance was not found in males but was significantly reported in females.<br>• Significant differences in mood disturbance were found between the genders. | Rajagopal (2012) (India) |
| 98. | Stress, mood, and DHEA/C ratio in female cyclists | Stress level and cortisol concentration | 12 female cyclists<br>Age: 21.7 ± 5.5 y | • 2 ml saliva was collected from each subject from 07:30 h to 08:00 h just after waking up without breakfast and urine samples were collected before ($T_1$) and after ($T_2$) of the training camp.<br>• Cortisol in saliva and DHEA-S in urine were analyzed using radioimmunoassay.<br>• Subjects filled Recovery Stress questionnaire (RESTQ- sports) at $T_1$ and $T_2$.<br>• Paired sample *t*-test was used to analyze the data. | • Stress level and cortisol concentration significantly increased from $T_1$ to $T_2$; whereas the DHEA-S/C ratio remained unchanged, but DHEA-S/C significantly decreased and was negatively correlated with stress ($r = -0.7$). | Bouget et al. (2006) (France) |
| 99. | Eating behavior, stress hormones, and α-amylase among tennis players. | Body mass index, salivary α-amylase, higher anxiety level, and salivary cortisol | 26 female tennis players<br>Age: 19.6 ± 2.1 y | • Eating behavior, nutritional patterns, dieting and training diet training history, weight fluctuation history, menstrual history, type, and frequency of musculoskeletal injuries were collected using Eating Attitudes Test-26, Eating Disorders Inventory 2, and Body Shape Questionnaire. Diet records for 7 d were collected.<br>• Saliva samples were collected at awakening, 30 min, 60 min, and 12 hours after awakening. | • 12 players had a Disordered Eating attitude (DE).<br>• Players with DE had lower body mass index, lower concentration of salivary α-amylase, higher anxiety levels, and higher salivary cortisol as compared to the players without DE.<br>• Salivary α-amylase level was low within 30 min. of awakening and progressively increased toward the afternoon. | Filaire et al. (2015) (France) |

(*Continued*)

**Table 1.** (Continued).

| S. No. | Areas of study | Variable | Sample structure and size | Methodology | Outcome | Reference |
|---|---|---|---|---|---|---|
| 100. | Reactive oxygen species, antioxidant marker's concentration at different times of the day in weightlifters | C-reactive protein, rate of lipid peroxidation, and antioxidant activity | 9 male weightlifters<br>Age: 21 ± 0.5 y | • Weightlifters performed snatch, clean, and jerk at 08:00 h, 14:00 h and 18:00 h.<br>• Blood samples were collected at rest, 3 min after, and 48 h after their performance.<br>• C-reactive protein, rate of lipid peroxidation, and antioxidant activity were assessed.<br>• ANOVA was used for data analysis. | • Antioxidants were present in higher concentrations in blood at 14:00 h and 18:00 h as compared to 08:00 h.<br>• Levels of lipid peroxidation and enzymatic defense remained elevated 48 hours after the morning training session.<br>• It was concluded that weightlifting coaches should avoid scheduling their training sessions in the morning hours. | Ammar, Chtourou, Trabelsi et al. (2015) (Tunisia) |
| 101. | Antioxidants, rhythm, and sports performance | Core body temperature, perceived exertion, homocysteine concentration, and physical performance | 12 male football players<br>Age: 17.4 ± 0.4 y | • All the subjects performed repeated sprint ability tests (cycling sprint) at 07:00 h to 08:00 h and 17:00 h to 18:30 h.<br>• Blood samples were collected before and 3–5 min after each test. Core body temperature, perceived exertion, and performance were measured in both trials. | • The diurnal variation was observed in homocysteine (a biological marker) with a peak in the evening.<br>• Higher performance as well as higher muscle fatigue were observed in the evening due to higher levels of biological markers. | Hammouda et al. (2011) (Tunisia) |
| 102. | Altitude and running performance | Variables of running performance, including High-intensity running (HIR), Total distance capacity, and distance and velocity | 6 female soccer players<br>Age: 19.5 ± 1.0 y | • During the National Collegiate Athletic Association (NCAA) tournament, two soccer matches were played at sea level (SL) and one played at moderate altitude (MA).<br>• High-intensity running (HIR), total distance capacity, and distance and velocity were measured by A-10 HZ (a global positioning design) during each match.<br>• Data were analyzed and compared using ANOVA and post hoc tests. | • Distance rate decreased in MA group (SL = 120.55 ± 8.6 m/min and MA =105.77 ± 10.19 m/min)<br>• HIR decreased significantly in MA group (SL = 27.65 ± 9.25 m/min and MA = 25.05 ± 7.66 m/min)<br>• The players who were habituated to practice at SL had difficulties in MA condition and their performance decreased. | Bohner et al. (2015) (USA) |

**Table 2.** List of relevant reviews published in the domains of circadian rhythm and sports.

| S. No. | Author | Affiliation country | The main issues discussed in the review |
|---|---|---|---|
| 1. | Cook and Charest (2023) | USA, and Canada | Good sleep enhances performance by improving the quality of training, enhancing mental health, reducing the risk of injury, and decreasing the strength of the detrimental effects of travel. |
| 2. | Papanikolaou et al. (2022) | Greece | Athletes with inadequate sleep are more likely to suffer from hypoxia during practice. Having less than the recommended sleep alters multiple body functions (e.g., cardiovascular system, immunity, and cognition) of athletes during their performance. |
| 3. | Knaier et al. (2022) | Switzerland | Different sports have different peak performance times, for example, anaerobic power and jump height have a characteristic peak between 13:00 h and 20:00 h. There is some evidence that handgrip strength peaks between 14:00 h and 21:00 h, whereas maximum endurance does not have a definite peak performance time. |
| 4. | Cheng et al. (2022) | China | Exercise can be scheduled at the best circadian time to achieve health benefits. Exercise therapy is a noteworthy adjuvant treatment for metabolic diseases, and it synergistically affects cardiovascular health. |
| 5. | Ayala et al. (2021) | Spain | Practice sessions must be organized according to the athlete-specific best circadian time to achieve optimal performance because training time rather than the circadian peak time can cause a decline in physical performance. |
| 6. | Sabzevari Rad et al. (2021) | Iran | Components of physical performance (aerobic-anaerobic power, muscle endurance, and flexibility) and hormone secretion are considerably affected by circadian rhythm. For this reason, it is advised to competition organizers and trainers to consider the effects of circadian rhythm on sports performance. |
| 7. | Kusumoto et al. (2021) | Louisiana | Body temperature has a great role in the diurnal variation in athletic performance as poor performance is found generally at low body temperature. Therefore, morning warm-up is effective in reducing diurnal variation of performance. |
| 8. | Botonis et al. (2021) | Greece | Sleep loss results in poor performance but sleep loss at night followed by a mid-day nap may restore the physical performance, cognitive performance, and perceptual responses of an athlete. |
| 9. | Miles et al. (2022) | Australia | Most of the female players experience sleep disturbance on pre- and post- nights of the competition, while they achieve satisfactory sleep during the non-competition day. |
| 10. | Lastella et al. (2021) | Australia, Italy, and Pakistan | Athletes should be permitted to take ~30 minutes of napping before training and competition to reduce sleep inertia which may assist in obtaining better performance because napping increases athletic performance, cognitive performance, perceptual responses, and psychological mood state. |
| 11. | Wilkes et al. (2021) | USA | The association of athletic performance and injury rate with sleep is controversial but most of the studies in this review indicate that decreased sleep, both quality and quantity, resulting in poor cognitive performance is most likely to increase the chances of having an injury and might significantly induce a decline in physical performance. |
| 12. | Chennaoui et al. (2021) | France | Good sleep synergistically affects the different phases of muscle regeneration and repair and it is needed for a player's body after an intense training session. Deleterious effects of sleep deprivation on muscle tissue and biological responses are evident. |
| 13. | Freitas et al. (2020) | Brazil | Sleep debt increases catabolic pathway signaling and decreases anabolic pathway signaling resulting in decreased muscle integrity which eventually makes athletes more susceptible to musculoskeletal injuries accompanied by slowing down of the muscle recovery process. |
| 14. | Bellastella et al. (2019) | Italy | With the knowledge of general characteristics and parameters of biological rhythms on physical performance, an athlete and a sports physician can establish the best form of competitive activity. |
| 15. | Doherty et al. (2019) | Ireland | Sleep has an integral contribution to learning, memory, and synaptic plasticity. All these variables can impact athletic performance and physical/mental recovery. High physiological and psychological demands are placed on athletes during training and competition, so they need adequate sleep concerning duration and quality. |
| 16. | Vitale et al. (2019) | United States | Sleep deprivation retrogressively affects reaction time, accuracy, vigor, submaximal strength, endurance, and cognition, and sleep extension reverses results from sleep deprivation in all aspects. "Banking sleep (intentional sleep extension before the night of sleep deprivation before the sporting event) is a new concept that may also improve performance." |
| 17. | Gupta et al. (2017) | UK | Athletes have a high prevalence of insomnia due to poor night sleep and they experience excessive daytime fatigue. Therefore, daytime napping seems a good compensatory strategy used by athletes. |
| 18. | Facer-Childs and Brandstaetter (2015b) | UK | Time since entrained awakening appears to be a major predictor of peak performance times, rather than the time of the day. Therefore, to evaluate an athlete's personal best performance requires analysis of performance as a function of time since entrained awakening. |
| 19. | Thun et al. (2015) | Norway | The athletic performance is found at its peak along with the peak in core body temperature in the evening. Sleep extension improves whereas sleep deprivation is negatively associated with athletic performance. |
| 20. | Shibata and Tahara (2014) | Japan | The circadian clock regulates athletic performance by regulating sleep/wake patterns, hormonal secretion, and metabolism. |
| 21. | Lee and Galvez (2012) | USA | Jet lag adversely affects mood and cognition and thus negatively affects individual and team-based performance in a new destination. So, resynchronization after jet lag, strategic sleeping, napping, timed exposure to bright light, and the use of melatonin should be encouraged. |
| 22. | Teo, Newton et al. (2011) | New Zealand | Core body temperature and athletic performance are found to reach a peak approximately at the same time, i.e., in the early evening most possibly because increased core body temperature has been reported to increase energy metabolism and improve muscle compliance.<br>In addition, the circadian rhythm of the relative concentration of testosterone and cortisol hormones facilitates peak athletic performance in the early evening. |

(*Continued*)

**Table 2.** (Continued).

| S. No. | Author | Affiliation country | The main issues discussed in the review |
|---|---|---|---|
| 23. | Hayes et al. (2010) | UK | Testosterone levels are reported higher in the morning which is associated with higher physical performance but, an increased resistance exercise has been found in the late afternoon because morning elevated testosterone level may be counteracted by the morning elevated cortisol level, therefore the intensity of physical performance may be better clarified through cortisol/testosterone ratio due to their roles in protein degradation (catabolic) and protein synthesis (anabolic), respectively. |
| 24. | Davenne (2009) | France | Sleep quality and quantity affect the athletic performances that have been taken before the competition. Sleep deprivation results in decreased cognition, memory impairment, sustained attention, vigilance, and response capability and simultaneously increases lapsing. |
| 25. | Reilly and Edwards (2007) | UK | Sleep disturbance occurs due to rapid travel across multiple meridians which restricts normal sleep in an athletic endeavor. Prolonged reduction in sleep can lead to immune suppression and reduced athletic performance. |
| 26. | Waterhouse et al. (2005) | UK and Germany | There is an interaction between the circadian rhythm of core body temperature and thermoregulation during exercise. Body temperature rises more quickly, and the thermoregulatory mechanism responds less quickly around the trough of the circadian rhythm of core body temperature, so, warm up requires before strenuous physical activity to exercise maximally with minimal risk of muscle injury or heat exhaustion. |
| 27. | Drust et al. (2005) | UK | Morning hours are considered the best time for skill-based performance, whereas sports that require extensive physical effort should be completed later in the day. However, the best timing for sports that require skill and physical effort is unclear. |
| 28. | Pati (2001) | India | A biological phenomenon that takes approximately 24 hours to complete one cycle is known as circadian rhythm and it is endogenously regulated, as rhythmicity persists in the absence of zeitgeber also. Some nap-based studies reviewed indicated that a nap can improve alertness, performance, and mood. |
| 29. | Manfredini et al. (1998) | Italy | Jet lag retrogressively affects athletic performance mainly on account of the desynchronization of circadian rhythms. Preadaptation is hardly practicable due to social and behavioral constraints. The composition and timing of meals may be useful for accelerating resynchronization at the destination. Phototherapy is undeniably useful. Melatonin ingestion at a certain time and in a certain amount can be used but is illegal in some countries without a medical prescription. A combination of bright light and melatonin ingestion (with a medical prescription) is likely to produce satisfactory results. |

performance of athletes, and based on this finding, they concluded, that it is not admissible to plan training differently for the morning or afternoon periods.

Chronotype and sleep behavior are interconnected as sleep onset and offset timings are the perfect predictors of chronotype. However, Lastella et al. (2010) assigned 23 (7 females and 16 males) subjects to chronotype groups and measured their daytime sleepiness with sleep quality and sleep satisfaction and did not find significant differences in all these three parameters of sleep, when neither type (NT) and the MT groups were compared. They also did not find any changes in these parameters as a function of gender. In contrast to this finding, Lim et al. (2021) reported that sleep quality is much better in the early chronotype than in the late chronotype and Facer-Childs et al. (2018) found a significant difference in daytime sleepiness between the early and late chronotypes.

## Sleep and physical performance

### *Sleep – circadian rhythm and homeostasis*

Before summarizing the literature on the effects of sleep on physical performance, it is important to understand the regulatory mechanism of sleep. The regulation of sleep is very intricate and it involves a homeostatic and a circadian process (Deboer 2018). In a review by Deboer (2018), it has been mentioned that sleep and sleep-related variables, such as sleepiness and alertness are influenced by both processes independently. Borbély (1982) proposed a two-process model for sleep regulation. According to this model, a sleep-dependent process (Process S) and a sleep-independent circadian process (Process C) jointly regulate sleep and sleep-related variables. This model also explains how sleep propensity and the duration of sleep are determined by the combined action of the two processes. Thus, both the processes together and independently regulate sleep in humans. It is intriguing to understand if the two processes are directly influencing each other. More research is required to answer this conjecture (Deboer 2018). Undoubtedly, poor sleep (sleep disturbance, sleep deprivation, and sleep debt) elevates homeostatic sleep pressure that leads to decreased athletic performance. In the current review, we made an effort to summarize the effects of sleep on physical performance among athletes.

### *Effects of sleep on physical performance*

It has been unequivocally established that all attributes of all kinds of sports performances are always affected by sleep. There is ample literature to prove that poor sleep or sleep deprivation leads to poor performance in sports (Davenne 2009; Eagles and Lovell 2016; Lastella et al. 2015b; Matthews et al. 2012; Poussel et al. 2014; Sargent et al. 2014; Silva et al. 2012). Good sleep synergistically affects the different phases of muscle regeneration and repair (consisting of degeneration, inflammation, regeneration, remodeling, and maturation) and a player's body requires it after an intense training session (Chennaoui et al. 2021). Players generally have good sleep efficiency but they also experience short sleep duration and struggle with low sleep quality, insomnia, and daytime sleepiness (Khalladi et al. 2019). An online survey-based study revealed a significant positive effect of high sleep quality on physical performance (Klier et al. 2021). Sleep deprivation not only affects physical performance but also produces devastating effects on the alertness, and psychological, metabolic, and physiological functions of the athletes (Jones et al. 2009; Konishi et al. 2013; Lastella et al. 2014). The deleterious effects of sleep deprivation on muscle tissue and biological responses in athletes are well known (Chennaoui et al. 2021). Depression score strongly correlates with the number of awakenings, wake after sleep onset, and daily training time (Lee et al. 2021). Sleep deprivation has also been linked with fatigue, diminished vigor, depression, and reduced reaction time (Milewski et al. 2014; Scott et al. 2006); all these together linked to sleep deprivation are likely to enhance the risk of accident and injury during the sports event.

A study on rugby players revealed an association between late sleeping time and reduced sleep quality with reduced sports performance (Eagles and Lovell 2016). Both sleep duration and sleep quality have been reported to decrease on the previous night of the day of the sports competition (Lastella et al. 2015b). It was observed that the players go to bed later and wake up earlier during tournaments as compared to the control nights. With this regard, a study found that most of the players experience sleep disturbance on pre- and post-competition nights, while they achieve satisfactory sleep during the non-competition day (Miles et al. 2022). Athletes with a lack of sleep are more likely to suffer from hypoxia during practice. Having less than sufficient sleep alters multiple body functions (e.g., cardiovascular system, immunity, and cognition) more during their performance (Papanikolaou et al. 2022). This result found support from another study wherein poor sleep quality in athletes has been linked with their lower sleep efficiency and greater sleep latency usually noticed before the competition (Silva et al. 2012). These conditions antagonistically affect physical performance and additionally, it has been established that sleep not only affects physical performance but also modulates psychological behaviors among athletes (Silva et al. 2012). Later sleep onset and early wake-up among athletes lead to sleep debt, consequential fatigue, and poor performance (Matthews et al. 2012; Sargent et al. 2014). Detrimental effects of sleep deprivation have been observed on performance in both aerobic and anaerobic exercise (Davenne 2009). There is a significant adverse effect of poor sleep on the players' mean power and peak power performance (Lim et al. 2021). In another study, sailors who adopted the sleep strategy traveled significantly more miles offshore than sailors who did not adopt the sleep strategy, but the sleep strategy did not significantly influence the final arrival time (Filardi et al. 2020). All these studies collectively prove that sleep affects the entire physiology of an individual and therefore, sleep deprivation and sleep fragmentation lead to poor athletic performance.

Sleep debt associated with fatigue, depression, and higher reaction time reduces the capacity of athletes to respond instantaneously. This condition also increases the vulnerability of athletes to an accident during the competition (Scott et al. 2006). Good sleep not only reduces the chances of physical injury in professional athletes but also increases the ability to recover at the same time (Cook and Charest 2023). Clinically moderate-to-severe insomnia and excessive daytime sleepiness increase concussion risk in sportspersons (Raikes et al. 2019). Another review reveals that poor sleep quality and reduced total sleep time may increase catabolic pathway signalling, and decrease anabolic pathway signalling, compromising muscle integrity that eventually makes it more susceptible to musculoskeletal injury in sportspersons (Freitas et al. 2020). However, how much sleep is optimum is difficult to ascertain, because it may vary depending upon the chronotype of an individual sportsperson. Although Milewski et al. (2014) discovered that athletes, who slept $<8$ h per night, were 1.7 times more likely to have an injury during the performance as compared with athletes, who slept $\geq 8$ h per night. The association of athletic performance and injury rate with sleep is controversial but most of the studies in this review indicate that decreased sleep quality and quantity resulted in a negative cognitive performance which significantly affects physical performance (Wilkes et al. 2021).

Burke et al. (2020) reported a contradictory result as they found sleep metrics (quality and quantity) were not associated with an increased risk of injury in football players.

Most researchers have evaluated the effects of sleep deprivation on physical performance; however, there are limited studies on the effects of sleep quality and quantity on mood and reaction time along with physical performance. Sleep has an integral contribution to learning, memory, and synaptic plasticity. All these variables can impact athletic performance and physical/mental recovery. High physiological and psychological demands are placed on athletes during training and competition so they need adequate duration and quality of sleep (Doherty et al. 2019). Sleep deprivation retrogressively affects reaction time, accuracy, vigor, submaximal strength, endurance, and cognition and sleep extension just reverses results from sleep deprivation in all aspects. "Banking sleep (sleep extension before the night of intentional sleep deprivation before a sporting event) is a new concept that may also improve performance" (Vitale et al. 2019). Heart rate, circulating levels of serum cortisol, and adrenocorticotropic hormones have been reported to be significantly higher in sleep-deprived athletes, and these are the conditions that reflect a higher level of stress (Konishi et al. 2013). Further, it has been shown that sleep deprivation and sleep fragmentation together give rise to negative mood states, like fatigue and tension in athletes, which in turn significantly reduces athletic performance (Lastella et al. 2014). An experiment carried out on 11 basketball players at Stanford showed that extended sleep up to about 10 h/night has been shown to improve reaction time, mood state, shooting accuracy (in Basketball), and other physical performance significantly (Mah et al. 2011). The results obtained by Thun et al. (2015) also corroborate the above findings by concluding that sleep extension improves whereas sleep deprivation is negatively associated with athletic performance. Longer total sleep times are associated with faster reaction times (Knufinke et al. 2018). Sleep quantity (total sleep time, sleep onset latency) and sleep staging (light sleep) affected gross motor performance but produced no effects on motor skill performance (Knufinke et al. 2018). Athletes with clinically significant sleep problems had worse sleep hygiene, more general health complaints, and mood disturbance but a significant association was not reported among sleep problems, chronotype, and self-reported injury (Biggins et al. 2019).

## *Effect of exercise on sleep*

Sleep (deprivation and extension) has drastic effects on physical performance but the impact of exercise on sleep quality is not equivocal. While many authors reported a positive effect (Buman et al. 2014; Cook and Charest 2023; Reid et al. 2010), Robey et al. (2014) published contradictory findings. Yet there is another report that produced a neutral effect (Petit et al. 2014). Various factors of sports training, such as time and intensity of training and training load can potentially impact the sleep of athletes (Cook and Charest 2023). A cross-sectional study on 1000 individuals in the United States showed that the individuals who are habituated to exercise in the evening have 97% better sleep quality and 98% better sleep duration than the non-exercising persons (Buman et al. 2014). Persons having insomnia significantly improved their sleep quality, vitality, sleep duration, and sleep efficiency and reduced daytime sleepiness and depression as compared to baseline after exercising over a period of 16 weeks (Reid et al. 2010). Along with the improvement in physical performance, exercise can improve psychological mood as well. All mood components; anger, depression, confusion, fatigue, tension, and vigor, had a significant improvement following morning and evening exercise; however, exercise responses were not significantly different in the morning and evening groups (Irandoust et al. 2019). Sanz-Milone et al. (2021) studied athlete's subjective (using questionnaires) and objective (using Actigraphy) sleep data for 10 d of pre-season and 10 d of competition season and found that athletes had low sleep quality (sleep efficiency ˂85%, a high score in the Pittsburgh questionnaire, increase of sleep latency and increase wake after sleep onset) during the competitive season in both methods. This could be attributed to heavy training and exercise due to competitive sports tournaments.

Robey et al. (2014) studied 12 Australian male elite soccer players and concluded that high-intensity training in the early evening does not inversely impact sleep quality and quantity. Petit et al. (2014) studied 5 h of early phase shifting on male athletes and found that sleep efficiency and non-rapid eye movement decreased significantly but upgradation was seen in rapid eye movement after phase advancement but physical performance neither improved nor declined, i.e., there is no effect of phase advancement and sleep on physical performance capacity.

Gupta et al. (2017) concluded that elite athletes show a high overall prevalence of insomnia symptoms characterized by non-efficient sleep due to higher sleep fragmentation resulting in longer sleep latency and excessive daytime fatigue.

## *Effect of nap on athletic performance*

Sleeping for a short duration (nap), especially in the daytime is capable of restoring energy and stamina. Thus, a nap can be used as a recovery tool for the players (Daniel et al. 2010; Waterhouse et al. 2007).

Mid-day naps after sleep loss at night may restore the physical and cognitive performance along with the perceptual responses of an athlete (Botonis et al. 2021). Daniel et al. (2010) studied daytime nap patterns on 6 male subjects and demonstrated that a daytime nap after endurance exercise (approximately at 11:30 h) is a potential and valuable tool for recovery and restoring energy and stamina. Lastella et al. (2021) suggested that athletes should be permitted to take approximately 30 min of napping before training and competition to reduce sleep inertia, which may assist in obtaining better performance as napping increases athletic performance, cognitive performance, perceptual measures, and psychological mood state. Another study supported this result by demonstrating that daytime nap compensates for the effect of sleep deprivation; they concluded this by conducting an experiment in which sleep deprivation followed by 30-minute naps after lunch facilitated mental as well as physical performance, alertness, short-term memory, accuracy, sprint time, reaction time (Waterhouse et al. 2007).

## Effect of melatonin on physical performance

The secretion of melatonin is stimulated by ambient darkness and is a "sleep facilitator" in humans and it regulates the performance ability by regulating sleep and thus circadian rhythm of sportspersons (Atkinson et al. 2005; Ghattassi et al. 2016; Leonardo-Mendonça et al. 2015).

Melatonin treatment (100 mg/d) 30 min before bed for four weeks significantly improves sleep efficiency and beneficially modulates the sleep-wake cycle in athletes (Leonardo-Mendonça et al. 2015). Ghattassi et al. (2016) studied cognition and physical performance at 4 different time points after 5 mg melatonin or placebo ingestion and found that cognitive and physical performance were significantly higher at 16:00 h than at 08:00 h. But it has also been reported that melatonin ingestion at 11:45 h reduces body temperature, alertness, short-term memory, heart rate, and reaction time in the afternoon and evening (Atkinson et al. 2005) because it is a sleep-inducing hormone and therefore, the time of ingestion is crucial.

## Effect of time of the day on athletic performance

It has been unequivocally demonstrated that athletic performance varies as a function of the time of the day (Chtourou et al. 2013; Facer-Childs and Brandstaetter 2015b; Kline et al. 2007; Lericollais et al. 2009; Petit et al. 2013; Reilly et al. 2007; Smith et al. 1997; Souissi et al. 2004, 2010; Taylor et al. 2011). Practice sessions must be organized according to the best circadian time for each athlete to achieve optimal performance because training other than at circadian peak time can cause a decline in physical performance (Ayala et al. 2021). However, few papers do not support this generalization (Chtourou et al. 2012; di Cagno et al. 2014). A large body of literature in favor of the former concept outweighs a few papers that negate the involvement of the biological clock in the pattern of sports performance along a 24-hour time scale. Time-of-the-day-dependent variations in physical performance related to soccer, cycling, athletics, swimming, gymnastics, and weightlifting have been amply demonstrated.

Reilly et al. (2007) studied diurnal variation in the mental and physical performance of eight male soccer players and found out that the alertness of the players was the highest and fatigue was the lowest at 20:00 h. They also noticed that the peaks in juggling and wall volley performance (soccer-specific skills) were located between 16:00 h and 20:00 h. It has been noticed that during cycling performance, peak power (PP), mean power at 30 s (MP-30s), and mean power at 60 s (MP-60s) are significantly higher at 18:00 h than at 06:00 h (Lericollais et al. 2011). It has been found that the cyclists took less time to complete 1000-m cycling in the evening and took more time for the same task at the same place in the morning (Fernandes et al. 2014). The peak performance and the mean power in cycling performance are higher in the evening than morning (Lericollais et al. 2009). The best performance was determined in the late afternoon or early evening around 17:12 h, which was approximately 0.32% improved than 08:00 h (Lok et al. 2020). Kline et al. (2007) found that the best and the worst swimming performance peaked approximately at 23:00 h and 05:00 h, respectively.

It has been observed that squat jump and countermovement jump performances are significantly higher at 17:00 h than at 07:00 h (Chtourou et al. 2013). Different kinds of sports activities have different peak performance times. Between 13:00 h and 20:00 h, anaerobic power and jump height appear to be at their peak. There is some evidence that handgrip strength peaks between 14:00 h and 21:00 h, however, there is minimal evidence that maximum endurance has a peak performance time (Knaier et al. 2022). Heinbaugh et al. (2015) tested dynamic balance and static balance in 34 athletes in the morning and afternoon. They found out the time of the day affects only the static balance. However, the findings of a Korean study on 24 healthy students revealed time of the day effects on the dynamic and static balance (Kwon et al. 2014). They further added that the peaks in both the variables appear in the morning and the nadirs in the noon. Yet in another study, Taylor et al. (2011) reported that in recreationally trained males, athletic performance is better at 16:00 h than at 08:00 h. They attributed this difference to the variation in body temperature of the subjects which exhibited significant overlapping between the peaks of core temperature and the respective peaks in their athletic performance (Taylor et al. 2011).

Circadian rhythms in attention and physical performance have also been reported (Petit et al. 2013; Souissi et al. 2004). The authors opined that sports competitions should not be scheduled throughout the day.

Another study revealed that gymnastic performance also varies as a function of the time of the day. In a study on female gymnasts, it was observed that their performance is significantly better in the evening, but only in one component, i.e., in reactive strength. The performance in coordination tests remained the same, irrespective of the time of the day (di Cagno et al. 2013). Drust et al. (2005) reported that the morning is the peak performance time of skill-based performance, whereas the best time for highly physically demanding performance is the evening. Whereas, Souissi et al. (2010) studied physical performance, peak power, and mean power in athletes and reported that their performance significantly increased from morning to afternoon with a peak at noon. Anderson et al. (2018) reported time of the day definitely affects performance and there is a peak performance time also but that time can't be the same for all athletes, because it depends on their circadian typology. They found that ET elite swimmers, swim up to 6% slower and expend 50–70% more effort in the morning and similarly, MT swimmers required 5–7 times more effort in the evening than the evening chronotype swimmers.

Ammar et al. (2015) demonstrated that the afternoon is the more effective time for training as compared to either morning or evening times. Some reports rule out the effect of the time of the day on physical performance (Chtourou et al. 2012; di Cagno et al. 2014). The former group did not find any significant differences in balance tests as a function of the time of day in athletes, but non-athlete adolescents performed better in the morning. The latter group opined that training for physical performances can be carried out at any time of the day with the same benefit. Knaier, Infanger, Niemeyer, et al. (2019) and Knaier, Infanger, Cajochen, et al. (2019) reported a significant diurnal variation in $VO_2$ max and diurnal variation in leg and arm strength. Therefore, the time of the day effect needs to be considered by athletes for competitive sports. Knaier, Infanger, Niemeyer, et al. (2019) demonstrated a diurnal variation in strength but without a significant time-of-the-day effect, which clarified that individuals achieve their peak performance at different times of the day and that time depends upon their chronotype.

It has been demonstrated that morning training is associated with improved physical performance in the afternoon (Cook et al. 2014). However, in another cross-sectional study, statistically significant diurnal variation was not observed in the tympanic temperature and fatigue, drowsiness, and sleep duration of the subjects throughout the day in gymnasts (Huguet et al. 1997). In the same study, it was observed that on an annual time scale, gymnastic performance was found to be better in June as compared to winter months (Huguet et al. 1997). There are only a few studies on the circannual variation of physical performance; therefore, it would be too early to talk about the involvement of the circannual clock in the regulation of physical performance over a seasonal time scale.

## Effect of metabolism and physiology on peak performance time

Many researchers pursued molecular-level biochemical tests on various players and tried to investigate the association between various biochemical variables, metabolism, and physical performance as a function of the day in weightlifters, cyclists, and athletes (Ammar, Chtourou, Trabelsi et al. 2015; Chin et al. 2015; Hammouda et al. 2011). Exercise can be scheduled at the best circadian time to achieve health benefits and exercise therapy is an important adjuvant treatment for metabolic diseases and cardiovascular health (Cheng et al. 2022).

Ammar, Chtourou, Trabelsi et al. (2015) analyze the concentration of C-reactive protein, the rate of lipid peroxidation, and antioxidant activity on 9 weightlifters at three different time points of the day and concluded that weightlifting coaches should avoid scheduling the training sessions during the morning hours. Hammouda et al. (2011) studied core body temperature, and perceived exertion after cycling sprint test at two-time points of the day along with the concentration of homocysteine, total antioxidant status, and biological markers in the blood and demonstrated that higher performance, as well as higher muscle fatigue, showed in the evening due to higher level of biological markers. Chin et al. (2015) studied maximum oxygen uptake ($VO_2$ max), the post-exercise percentage of maximal heart rate, post-exercise body temperature, and blood lactic acid level in 35 male athletes in Hong Kong, in morning, noon, and afternoon and concluded that young athletes are recommended to training at noon for maximum result.

## Effect of core body temperature rhythm on sports performance

It is universally accepted that the core body temperature (T-core) depicts robust circadian rhythmicity. Therefore, it is considered an important marker of circadian rhythm, and it has been proven by several experiments that T-core affects performance ability in various sports, such as Rugby, soccer, dart throwing, cycling performance, and other athletics (Souissi et al. 2004; Edwards et al. 2007; Reilly et al. 2007; Hobson et al. 2009; Chtourou et al. 2011; Teo, Newton et al. 2011; Pullinger et al. 2014; West Cook et al. 2014; Thun et al. 2015). Most of these papers demonstrated that high T-core was synergistically associated with better performance in sports but few papers manifested contradiction as they found better performance in the morning when T-core was lower (Chtourou et al. 2011; Hobson et al. 2009).

The T-core significantly rises from morning to evening simultaneously with the increase in peak power output from AM to PM in Rugby players (West, Cook et al. 2014). Reilly et al. (2007) reported in soccer players that high intra-aural temperature and optimum performance of players were found simultaneously in evening hours (from 16:00 h to 20:00 h). The force and accuracy of Dart Throwing performance significantly increase with increasing intra-aural body temperature (Edwards et al. 2007). High body temperature is associated with improved athletic performance (Thun et al. 2015). Athletic performance is associated with diurnal variation of oral temperature in athletes (Souissi et al. 2004). High body temperature and peak exercise performance have been reported simultaneously in the late afternoon or early evening (Teo, Newton et al. 2011). Pullinger et al. (2014) performed a sprint test non-motorized treadmill along with measuring rectal temperature and muscle temperature, heart rate, thermal comfort, and rating of perceived exertion and researchers found distance covered, peak power, peak velocity, and average velocity are significantly higher in the evening but opposite of previous explained studies they reported that the diurnal variation in rectal temperature and muscle temperature cannot fully explain, time of day oscillation in Repeated Sprint Ability on a non-motorized treadmill.

Body temperature has a great role in the diurnal variation in athletic performance as poor performance is found generally at low body temperature. Therefore, morning warm-up is effective in reducing diurnal variation of performance (Kusumoto et al. 2021). Body temperature rises quickly and the thermoregulatory mechanism responds comparatively slowly around the trough of the circadian rhythm of T-core, so they suggested not to do exercise at the circadian nadir of T-core and also demonstrated that warm-up is essential before strenuous physical activity to exercise maximally with minimal risk of muscle injury or heat exhaustion (Waterhouse et al. 2005).

Notwithstanding contradictory reports that depict different results in cycling performance, although physiological phenomena, like body temperature and fatigue index, were significantly higher in the evening (17:00 h) than morning (07:00 h) no difference was found in cycling performance between 07:00 h and 17:00 h (Chtourou et al. 2011). Another study supported this contradictory result with similar findings in which, endurance exercise capacity in male cyclists was found significantly high in the morning when body temperature was reported low (Hobson et al. 2009).

## Effect of cortisol (stress marker) and testosterone hormones on diurnal athletic performance

Cortisol and testosterone are the hormones that exhibit a robust rhythmic pattern in their secretions and directly affect the diurnal athletic performance of elite athletes.

The effect of cortisol (stress marker) upon diurnal athletic performance has been studied extensively and now it has been confirmed that just after awakening in the morning, cortisol secretion suddenly increases showing increased physical as well as mental stress in morning hours and cortisol secretion manifests rhythmicity in the 24-hour day-night cycle and as it is a stress marker, the secreting onset of stress causing psychological bad feelings and negatively affects physical performance along with cortisol, testosterone, and testosterone to cortisol ratio (T/C) also affect sports performance (Bouget et al. 2006; Díaz et al. 2013; Filaire et al. 2015; Teo, McGuigan et al. 2011; West, Finn et al. 2014). Although the secretion of these hormones in response to stress during sports competition has been confirmed, it has been observed that the cortisol concentration significantly varies in saliva between, before, and after the competition in players (Doan et al. 2007; West et al. 2014). The adverse impact of these hormones on physical performance is well established but some contrasting results in the literature depict no association between these hormones and sports performance ability (Georgopoulos et al. 2011; Papadopoulos et al. 2014; Teo, Newton et al. 2011). The above articles demonstrated the impact of diurnal secretion of cortisol and testosterone on sports performance. However, the study in the reverse direction, i.e., the effect of exercise on the diurnal secretion of these hormones has been rarely carried out. The result of a few works on it depicts that there is no effect of exercise on the diurnal secretion of these two hormones (Kraemer et al. 2001; Labsy et al. 2013; Shariat et al. 2015).

It is slightly difficult to make the human subjects agree to blood sample collection several times a day for cortisol rhythm-related research work but the problem has been solved now as research pursued on 25 male players in Italy showed that salivary cortisol concentration is significantly positively correlated with the cortisol in the circulating blood. Therefore, the impact of cortisol on diurnal athletic performance or any other psychological function can be assayed by measuring, salivary cortisol (Lippi et al. 2009), so the saliva sample is widely used to assess the circadian rhythm of cortisol and testosterone and its impacts on the various phenomenon. Teo, McGuigan et al. (2011) concluded that the rhythmic release of salivary cortisol and testosterone could be attributed to peak performance. It has been demonstrated that the concentration of high salivary cortisol before the competition has a negative association with psychological feelings, such as tension, anxiety, and hostility (Díaz et al. 2013). However, the salivary testosterone levels remained unchanged before and after the match (West, Finnet al. 2014) while salivary cortisol concentration gradually increased from pre-training to post-training indicating an increase in stress level during the training and competition (Bouget et al. 2006). A study conducted on 26 female tennis players in France concluded that the players with a Disordered Eating attitude (DE) had lower body mass index, lower concentration, higher anxiety levels, and higher salivary cortisol levels (Filaire et al. 2015) which decreased athletic performance.

Testosterone levels are higher in the morning which is associated with higher physical performance, but an increased resistance exercise has been found in the late afternoon because morning elevated testosterone levels may be counteracted by the morning elevated cortisol level, therefore the intensity of physical performance may be better clarified through T/C ratio due to their roles in protein synthesis (anabolism) and protein degradation (catabolism), respectively (Hayes et al. 2010). While a high concentration of salivary cortisol was observed after the match, no difference was found in the concentration of salivary testosterone and T/C before and after the match (West, Finn et al. 2014). In another study, it was found that salivary cortisol and ratio of salivary testosterone to salivary cortisol continuously declined with each round of game in the match, but salivary cortisol did not change significantly throughout the match (Doan et al. 2007) that indicates the salivary testosterone level decreases as match proceeds, hence T/C level decreases, normally salivary cortisol decreases with the progression of the day, but that is not happening here in this case because the players become more tensed and pressurized to win the match and consequently cortisol is released in response of negative feeling.

There are some contrasting results; no significant difference was found in salivary cortisol levels before and after the competition in elite Artistic Gymnasts of Greek, but females were reported with higher cortisol concentrations and simultaneously had higher stress levels than male gymnasts before and after the competition (Georgopoulos et al. 2011). Young swimmers in Canada also did not experience pre-competition stress (Papadopoulos et al. 2014). A study on male players demonstrated that maximal power production ($P_{max}$) and maximal force production exhibit robust diurnal variation. However, the phenomenon was not significantly associated with salivary testosterone, salivary cortisol, and T/C ratio (Teo, McGuigan et al. 2011). Therefore, they concluded that the diurnal variation in T-core is a more appropriate indicator of peak physical performance than the hormone.

The impacts of exercise on the diurnal secretion of cortisol and testosterone have been rarely studied, Labsy et al. (2013) concluded that intense aerobic exercise for 90 min does not show any impact on the diurnal secretion of cortisol. Kraemer et al. (2001) found no significant effect of resistance exercise on the diurnal secretion of salivary testosterone. Shariat et al. (2015) validated this finding by demonstrating an insignificant difference in the diurnal secretion of salivary testosterone between the exercising group and control, i.e., no effect of exercise was found on the diurnal secretion of testosterone in male players.

## Effect of light exposure on athletic performance

It has been unequivocally demonstrated that exposure to bright light (natural as well as artificial light) at a certain circadian time improves cycling performance (Knaier et al. 2016; Thompson et al. 2015) and provides better health with better quality of life (Lee et al. 2014).

An experiment carried out on 41 male cyclists in Switzerland revealed that light exposure of a certain intensity for a certain period at a certain time of the day might significantly improve cycling performance (Knaier et al. 2016). In another study, 8 male cyclists were exposed either to 2500 Lux bright light or exposed to no light for 30 min on the prior evening of the experiment day and researchers found that 30 min bright light exposure before sleep improved the cycling performance on the next morning (Thompson et al. 2015).

It has also been concluded that the players who are exposed to sunlight for 30 min have improved physical status and have a better quality of life (Lee et al. 2014).

## Effect of altitude/oxygen-deficient environment, humidity, and air pressure on physical performance

The effect of altitude/oxygen-deficient environment is an untouched area in sports chronobiology. To the best of our knowledge, no research articles are available on the effects of different oxygen-deficient geographical and environmental conditions on athletic performance, especially as a function of circadian rhythms. However, based on a well-designed study, Bohner et al. (2015) argued that sports training at different altitudes can alter athletic performance.

High-intensity running performance and distance covered capacity were studied on female soccer players at sea level and moderate altitude, it was discovered that players habituated to training at higher altitudes, perform better at both altitudes than players who trained at lower altitudes. Lower altitudes players encounter difficulties performing at higher altitudes (Bohner et al. 2015). It has been established that high altitude training improves the endurance of sportspersons and athletes by increasing aerobic capacity (Bahenský et al. 2020), lactic acid tolerance (Saunders et al. 2013), and oxygen flow to the muscles (Park et al. 2016) of the trainees. However, information is lacking on the effect of circadian rhythm/time of the day on the performance of sportspersons and athletes while training at high altitudes/oxygen-deficient environments.

Both relative humidity and air pressure change as a function of the altitude of a place. Humidity and atmospheric pressure remain low at higher altitudes as compared with places at lower altitudes. There are many studies on the effects of humidity and air pressure on physical performance of sportspersons and athletes. However, the findings are mostly interpreted as the effects of altitudes. A PubMed search using the keywords "circadian rhythm," "humidity" OR "air pressure," and "athletic performance" did not reveal any results.

## Effects of other circadian-related factors on athletic performance in sportspersons

### *Food intake time and calorie-restricted feeding*

Sports nutrition is a specialized branch of science that brings into its fold studies to determine the effects of food intake time, quality of diet, and calorie-restricted feeding regime on the physical performance of athletes. In the SCOPUS database using the search keys "food intake time" and "athletic performance," we found as many as 22 reviews limited to humans that summarized the scientific data on how choices of food and nutrients, and timing of food intake influence athletic performance in sports persons (Kerksick et al. 2017; Kloby Nielsen et al. 2020; Malsagova et al. 2021; Manore et al. 2000). It has also been reported that nutritional interventions improve sleep quality and quantity in athletes (Doherty et al. 2019; Gratwicke et al. 2021). These authors opined that further research is needed to understand the relationship between sleep and nutrition. There are also many studies on the effects of Ramadan intermittent fasting on athletic performance (Chaouachi et al. 2012; Hakoumi 2016; Shephard 2012,2013). However, information is lacking on the effects of food intake time and calorie-restricted/time-restricted feeding on athletic performance along a circadian time scale. In the present context, it is important to ascertain if food intake time and calorie-restricted/time-restricted feeding regimen could act as a synchronizer of physiological circadian rhythms in sportspersons. Further research is warranted to resolve this possibility. However, many studies report food intake time as a powerful synchronizer of circadian rhythms in animal models.

### *Aging and sleep-related neurological disorders*

Aging has a profound effect on physical capacities. Therefore, it is not unusual to find impaired sports performance in elderly athletes (Reaburn and Fernandes 2023). Although there are many studies on the relationship between aging and athletic performance in sportspersons, there is a complete lack of information about the status of circadian rhythms in performance, and physiological and metabolic variables in aged sportspersons as compared with their younger counterparts. A SCOPUS database search using key terms "aging" within the article title and "athletic performance" and "circadian rhythm" within the article title, abstracts, and keywords did not reveal a single study on this topic.

There are several types of sleep-related neurological and psychiatric disorders, such as (1) chronic insomnia, (2) obstructive sleep apnea syndrome (OSAS), (3) narcolepsy, (4) somnambulism, (5) restless legs syndrome, and (6) circadian rhythm sleep disorders. The latter is more prevalent among shift workers and intercontinental travelers with jetlag (Rémi et al. 2019). These disorders individually would certainly impair athletic performance in sportspersons. However, a SCOPUS database search using key terms "athletic performance," "sleep-related neurological disorders" and "circadian rhythm" within the article title, abstracts, and keywords did not detect a single article on this topic. In this review, we have discussed the effects of jetlag separately in the following section.

## Effect of jetlag on sports performance

International players often visit several countries to participate in tournaments. During transmeridian flight, players rapidly cross several time zones, but their internal body clock runs according to their home time zone, such desynchronization in circadian rhythm is termed jetlag and the transmeridian flight towards the East direction is more hazardous than travel towards the West direction with the reference of jetlag symptoms and sports performance (Lastella et al. 2015a; Lee and Galvez 2012; Lemmer et al. 2002; Manfredini et al. 1998; Reilly and Edwards 2007; Smith et al. 1997).

Jetlag causes irritability, sleep irregularity, lack of concentration, lack of coordination of muscles with time, depression, fatigue, loss of appetite, and gastrointestinal disturbance collectively thereby lowering the physical performance of competitive athletes (Manfredini et al. 1998). Mood and cognition are negatively affected after long-haul transmeridian travel. Therefore, individual as well as team performance are significantly adversely affected by jetlag (Lee and Galvez 2012). In another study on heart rate, blood pressure, jetlag symptoms, and training performance along with coordination were measured on 13 westward and 6 eastward traveling athletes after their transmeridian travel for several days and reported that increased blood pressure after westward and a decreased blood pressure after the eastward journey and jetlag symptoms along with decreased athletic performance were seen on westward traveled players till 5–6 d; whereas symptoms were found in the Eastward players until 7 d (Lemmer et al. 2002). Rapid travel across multiple meridians leads to sleep restriction or chronic sleep deprivation, which causes immune suppression, and ultimately inversely affects the behavior and performance of athletes (Reilly and Edwards 2007). In another study in the USA, the West Coast (WC) team won most of the matches for 25 y during the National Football League tournament (Smith et al. 1997), this was explained as the WC team and the East Coast (EC) team crossed 3 time zones from their home time zone, WC team traveled eastward while EC team traveled westward so their body clock differs from destination time of about −3 h for WC team and +3 h for EC team, the matches were played at 21:00 h, the point is, the WC team played at 18:00 h whereas EC team played at 00:00 h (Mid-night) according to their internal body clock time. It has been reported that evening is the best performance time and midnight or early morning is the worst performance time of any athletic event, i.e., the schedule of matches was the main determining factor or main reason behind the result of matches (Smith et al. 1997). Lastella et al. (2015a) concluded that the amount and quality of sleep significantly declined during and after the simulated tour according to wrist activity data that caused declining mood and well-being and ultimately physical performance.

Although the entrainment occurs with time after a transmeridian flight, the process of natural entrainment is a time-consuming phenomenon. Therefore, knowledge of treatments, exercises, or other ways to overcome jetlag is mandatory for players and their coaches. Some potential jetlag alleviation strategies are melatonin treatment, preadaptation, strategic sleeping, napping, timed exposure to bright light or bright light therapy/treatment, and exercise at a particular time according to the direction of transmeridian travel (Atkinson et al. 2005; Knaier et al. 2016; Lee and Galvez 2012). Some remarkable measures for jetlag alleviation are as follows:

### *Melatonin treatment*

Melatonin ingestion is a helpful method to get rid of severe circadian misalignment but the direction of transmeridian travel, amount of dose, and timing of ingestion are very crucial for the treatment of jetlag by melatonin. Melatonin contributes to phase advancement when taken in the evening. It is useful in jetlag treatment after eastward travel and phase delay when taken in the very late evening or morning. Therefore, it is useful in the treatment of circadian misalignment due to transmeridian travel (Lemmer et al. 2002). Melatonin ingestion (100 mg/d) 30 min before bed to four weeks significantly improves sleep efficiency and beneficially modulates the sleep-wake cycle in athletes (Leonardo-Mendonça et al. 2015). Ghattassi et al. (2016) studied cognition and physical performance after 5 mg melatonin or placebo ingestion in the morning and found that cognitive and physical performance significantly improved at 16:00 h than at 08:00 h.

### Preadaptation

Generally, it has been recommended that players shift their time of sleep and awake according to the destination a few days before the departure. Reilly et al. (2007) concluded that to shorten the duration of jetlag, travelers can pre-habituate their circadian rhythm by shifting (early or delayed) sleep schedule toward the destination time zone a few days before departure.

### Bright light therapy

Bright light therapy is also useful for athletes who are competing in different time zones for re-entrainment and improvement of their performance (Rosa et al. 2018). Bright light exposure in the morning advances the body clock, while exposure in the late evening delays it. Therefore, it can be used according to the requirements of entrainment direction for resetting the circadian clock (Mello et al. 2020). They also concluded that the light therapy intervention effectively minimizes the adverse effect of the time of competition on the performance of reaction time in elite athletes (Mello et al. 2020).

The use of artificial light-emitting glasses might be a useful procedure for athletes who are competing at unusual times and need to adjust their sleep-wake cycles to conform to the competition timetables.

### Exercise

It has been shown that while evening exercise induces sleep at night, exercise performed at night inhibits sleep and modulates early morning awaking. The concept of chrono-exercise has emerged based on the above and similar other studies. It has been argued that metabolic disorder-induced circadian desynchronizations can be re-entrained through the practice of chrono-exercise (Shibata and Tahara 2014). Exercise is a beneficial and helpful method to get rid of severe circadian misalignment because morning, as well as evening exercise, induces phase advancement in persons with late circadian phenotype but morning exercise phase advances and evening exercise phase delays in persons having earlier chronotypes (Thomas et al. 2020). It has been reported that the morning exercise-induced phase shift ($0.62 \pm 0.18$ h) is reported significantly greater than the phase shift from evening exercise ($-0.02 \pm 0.18$ h).

## Circadian rhythm studies in sportsperson: Indian scenario

During the literature survey, it was discovered that few centers in India carried out studies on circadian rhythms in sportspersons. Precisely we came across only four notable studies in recent times.

In a Ph.D. thesis submitted to Alagappa University, Tamil Nadu, India, Kalaiselvi (2009) included in her study of 60 female adolescent athletes regarding circadian rhythms in their speed, agility, pulse rate, stress, anxiety, and skin temperature. The author validated circadian rhythm in all these variables and related those to the motor ability components of the athletes (Kalaiselvi 2009). The second study was also conducted in Tamil Nadu at AVT Municipal High School, Sivakasi. In this study, the effect of the factor, "gender" on circadian rhythm in total mood disturbance (TMD) of volleyball players was evaluated. The author reported significant variability in mood, irrespective of gender, as a function of the time of the day (Rajagopal 2012). The third center is located on the campus of Pandit Ravishankar Shukla University, Raipur, India which awarded Ph.D. degrees to two students based on their work on circadian rhythms in sportspersons (Gupta 2008; Patel 2011). The former (Gupta 2008) related physiological rhythms with the performance among sportspersons, while the latter (Patel 2011) focused on circadian rhythm in heart rate, energy expenditure, physical activity, and activity intensity of sportspersons. Studies on circadian rhythms in sportspersons are still in progress under the joint initiatives of the School of Studies in Physical Education and the School of Studies in Life Science.

One can come across thousands of published papers in this important domain; but most of the studies have been carried out in European countries, the USA, South Africa, and Australia. The results of those studies, therefore, cannot be extended to Indian sportspersons as they have different food habits and are exposed to different climatic and geographical conditions. It is desirable therefore to carry out research on the sportspersons of Asia as a whole to underscore the importance and role of circadian rhythms on the performance of sportspersons. This will also make the general public of this region of the world aware of the significance of circadian rhythms in sports.

## Circadian rhythm-dependent sports/athletic performance

From the preceding review of literature, it is evident that the performance of sportspersons and athletes depends on the functional status of their circadian clocks. Integration of physiological, psychological, and metabolic rhythms together enhances performance significantly (Nobari et al. 2023). In addition, peaks in circadian rhythms of various cardiovascular variables in the early afternoon augment sports performance in the afternoon considerably (Bellastella et al. 2019; Kantermann et al. 2012; Nobari et al. 2023). Receiving photic and non-photic signals from the environment circadian rhythm regulates cycles of alertness and sleepiness in humans (Reddy et al. 2023). The endogenous circadian clock enables athletes and sportspersons to optimize energy expenditure and physiological functions of the body that are essential for the maximization of physical performance (Reddy et al. 2023; Riede et al. 2017). In addition, there are numerous peripheral clocks in nearly all vital organs, for example, the heart, liver, kidneys, lungs, esophagus, adrenal gland, etc., that play a significant role in maintaining the physiological functioning of the body congenial for physical performance (Guo et al. 2014; Reddy et al. 2023). Although these peripheral clocks have the ability to function independently, they remain synchronized with the master circadian clock located at the SCN. In a nutshell, the performance of sportspersons and athletes is associated with synchronized circadian rhythms in physiological, metabolic, and psychological variables.

## Conclusion

The circadian rhythms in all physiological, metabolic, and psychological variables in players are modulated by several factors, such as the sleep-wake cycle and its attributes (sleep duration, sleep quality, and efficiency), mood states, jetlag, light exposure (time, duration, and intensity of light in which players are exposed), core body temperature and chronotype. Therefore, it is very likely that the physical performance of sportspersons and athletes would vary rhythmically keeping the internal phase relationship with the circadian rhythms in numerous biological variables. This is an important area of research that has been largely neglected by sports administrators and researchers worldwide. Research work in this domain, therefore, is mandatory and its promotion is highly recommended.

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