RUTKOWSKA, Marta, BIEŃKO, Mateusz, KRÓL, Tomasz, TOBOREK, Michalina, MARCHAJ, Magdalena, KORTA, Karolina, PUTRA, Anna, NIEDZIELA, Natalia, MARGAS, Mikołaj and BEDNARZ, Karolina. Sleep Cycles and Health: Role of Sleep Stages, Circadian Rhythms, and Lifestyle Factors on Optimizing Physical Performance and Mental Well-Being – a literature review. Quality in Sport. 2024;18:53393. eISSN 2450-3118.
https://dx.doi.org/10.12775/QS.2024.18.53393
https://apcz.umk.pl/QS/article/view/53393

The journal has been 20 points in the Ministry of Higher Education and Science of Poland parametric evaluation. Annex to the announcement of the Minister of Higher Education and Science of 05.01.2024. No. 32553.
Has a Journal's Unique Identifier: 201398. Scientific disciplines assigned: Economics and finance (Field of social sciences); Management and Quality Sciences (Field of social sciences).
Punkty Ministerialne z 2019 - aktualny rok 20 punktów. Załącznik do komunikatu Ministra Szkolnictwa Wyższego i Nauki z dnia 05.01.2024 r. Lp. 32553. Posiada Unikatowy Identyfikator Czasopisma: 201398.
Przypisane dyscypliny naukowe: Ekonomia i finanse (Dziedzina nauk społecznych); Nauki o zarządzaniu i jakości (Dziedzina nauk społecznych).

The authors declare that there is no conflict of interests regarding the publication of this paper.
Received: 11.07.2024. Revised: 08.08.2024. Accepted: 05.08.2024. Published: 15.08.2024.

Sleep Cycles and Health: Role of Sleep Stages, Circadian Rhythms, and Lifestyle Factors on Optimizing Physical Performance and Mental Well-Being – a literature review

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Abstract

Introduction:

Sleep is a crucial physiological process impacting cognitive function, emotional resilience, and physical health. It is fundamental to overall physical and mental well-being and understanding its nuances is imperative for unraveling the secrets of restorative sleep.

Purpose:

This review explores sleep cycles, synthesizing research on physiology, variability, and Non-Rapid Eye Movement (NREM) / Rapid Eye Movement (REM) dynamics to understand optimal rest. It assesses how disruptions, from lifestyle or sleep disorders, affect physical performance, mental well-being and overall health.

State of Knowledge:

Sleep behaviors vary among individuals, influenced by factors like age, environment, health and lifestyle. Aging leads to changes in sleep patterns, impacting sleep quality. Sleep disorders, such as epilepsy and apnea, significantly alter sleep architecture, illustrating the close link between health and sleep. Deprivation of sleep has been shown to impair motor skills, reaction times, and cognitive functions, which are critical for athletic performance. Lifestyle factors, including diet, physical activity and drug use, affect sleep quality, emphasizing the need for promoting healthy habits.

Conclusion:

The comprehensive exploration of sleep architecture, individual variability in sleep patterns, circadian rhythms, age-related changes, impact of drugs and sleep disorders, sleep hygiene, and associations with mental health underscores the intricate relationship between sleep and physical performance. Sleep disorders pose an increased risk for mental health disorders, such as anxiety, stress, depression and ADHD. Conversely, mental health issues can significantly affect sleep quality and patterns. Finally, sleep is crucial for physical health and athletic performance - it supports muscle recovery, tissue repair, and cognitive functions, while sleep deprivation can impair motor skills, reaction times, and increase the risk of injury. Prioritizing sleep is essential for achieving optimal health and performance among athletes. Developing strategies to promote healthy sleep hygiene and lifestyle habits is crucial in improving sleep quality, ultimately contributing to enhanced physical performance, mental health, and general well-being.

Key words: sleep; insomnia; apnea; epilepsy; physical activity; autism;

1. Introduction

In the realm of human physiology, few processes are so essential and enigmatic as the sleep cycle. The intricate dance of neural and physiological events that unfold during sleep is fundamental to overall well-being and impacts cognitive function, emotional resilience, and physical health. As the importance of sleep increases, understanding the nuances of sleep cycles becomes imperative for unraveling the secrets of restorative sleep.

2. Purpose of the Review:

This review explores sleep cycles, synthesizing research on physiology, variability, and Non-Rapid Eye Movement (NREM) / Rapid Eye Movement (REM) dynamics to understand optimal rest. It assesses how disruptions, from lifestyle or sleep disorders, affect physical performance, mental well-being and overall health.

3. Description of the State of Knowledge:

Sleep behaviors vary among individuals, influenced by factors like age, environment, health and lifestyle. Aging leads to changes in sleep patterns, impacting sleep quality. Sleep disorders, such as epilepsy and apnea, significantly alter sleep architecture, illustrating the close link between health and sleep. Lifestyle factors, including diet, physical activity and drug use, affect sleep quality, emphasizing the need for promoting healthy habits.

3.1. Understanding Sleep Architecture:

Research has revealed the intricate architecture of sleep, with distinct stages such as NREM and REM sleep, each serving specific functions and alternate throughout the night [1,2,4,5]. NREM and REM sleep have distinct and complementary functions. NREM and REM sleep have distinct and complementary functions. NREM sleep facilitates information processing and synaptic plasticity, while REM sleep performs brain network selection [1,2]. The non-uniform nature of sleep, with different stages affecting various areas of the brain and body, is influenced by the impact of circadian rhythms on sleep and wakefulness [6].

3.1.1 Non-Rapid Eye Movement Sleep Stage

The Non-Rapid Eye Movement (NREM) Sleep can be referred to as The Foundation of Restoration. It is essential for overall health and well-being [10]. It is characterized by synchronized EEG patterns and it is crucial for physical and intellectual performance [7]. It is generated by neurons in the preoptic region of the hypothalamus and adjacent basal forebrain[8]. NREM sleep, encompassing three subsequent stages, is crucial for physical restoration and maintenance, with each stage playing a specific role. The first stage is a transitional phase, the second stage involves the onset of true sleep, and the third stage represents deep- or slow-wave sleep. During deep sleep, the body engages in critical processes such as cellular repair, growth hormone release, and immune system strengthening [11]. This is facilitated by a shift in monocyte function towards cellular immunity, with increased type 1 cytokine activity [12]. The release of proinflammatory cytokines, such as interleukin-1 and tumor necrosis factor-α, during deep NREM sleep also plays a role in normal sleep regulation [13]. These cytokines can influence the intrinsic properties of neurons, leading to changes in the local network's input-output properties [14]. The cytokines' effects on sleep are mediated through various mechanisms, including direct receptor-mediated effects on neurons and the synthesis and release of transmitters, peptides, and hormones [15]. These processes are part of the somatic and autonomic physiological regulation that occurs during NREM sleep, which helps maintain the body's homeostasis at a lower energy expenditure compared to wakefulness [16]. Moreover, the NREM sleep stage is particularly important for the brain, as it enables information processing, synaptic plasticity, and cellular maintenance [2,3]. It is the state of vigilance that best identifies the epileptogenic zone in the interictal electroencephalogram [9].

3.1.2. Rapid Eye Movement Sleep Stage

The REM Sleep can be referred to as The Realm of Dreams and Cognitive Rejuvenation. REM sleep, characterized by vivid dreaming and rapid eye movements, plays a crucial role in cognitive processes and emotional regulation [17]. During this stage, the brain consolidates memory, processes emotions, and engages in neural plasticity, all of which are essential for learning, creativity, and maintaining optimal cognitive function [3,18]. This is further supported by the finding that long temporal sequences of patterned multineuronal activity, reflecting episodic memory traces, are reactivated during REM sleep [19]. This sleep phase is also associated with maintaining catecholamine systems in the central nervous system. These systems are involved in various physiological processes, including motor control, cognition, emotion, memory processing, and endocrine regulation [20]. However, the exact role of catecholamines in REM sleep and the locus coeruleus, the primary source of brain noradrenergic neurons, is still debated and unclear [21,22].

3.2. Individual Variability in Sleep Patterns: Unraveling the Mysteries

Individual variability in sleep patterns is a complex phenomenon influenced by various factors, and there is diversity in sleep behavior and neurophysiology across different species [26]. This diversity is shaped by ecological factors such as predation risk and light pollution and can result in species that can forgo sleep for extended periods of time [27]. Human sleep duration and organization are influenced by the circadian phase, resulting in variations in sleep length and other sleep characteristics [28]. Sleep duration varies significantly and is correlated with the circadian phase of the body temperature rhythm [28,29].

Research consistently shows a high prevalence of sleep problems in children with autism, including difficulty initiating and maintaining sleep [30,31,32]. These issues are not significantly related to age, IQ, or other demographic factors, but are associated with the severity of autism symptoms, particularly hyperactivity, mood variability, and aggression [31]. The dysregulation of melatonin synthesis, sensitization to environmental stimuli, and comorbid conditions like anxiety and depression are common factors contributing to these sleep problems [32]. Genetics, age, and environmental factors contribute to differences in the duration and composition of sleep cycles. Research has identified genetic markers associated with sleep traits, highlighting the personalized nature of sleep requirements. Understanding individual variability provides a nuanced perspective on sleep needs and challenges the notion of a one-size-fits-all approach to achieving well-rested states.

3.3. Circadian Rhythms and Chronotype:

Individuals with different chronotypes, such as morning types and evening types, have distinct sleep patterns and durations, which are influenced by social schedules [33,45]. These differences in sleep behavior can impact mood, with eveningness potentially being a risk factor for depression [34]. Furthermore, the evening chronotype is associated with various psychiatric disorders, including depressive disorders, substance use disorders, and eating disorders [35]. The circadian and homeostatic modulation of sleep pressure also differs between morning and evening chronotypes, with evening types showing a slower increase in sleep pressure during extended wakefulness [36].
Circadian rhythms, which are approximately 24-hour cycles of behavior and physiology, play a crucial role in regulating the sleep-wake cycle [37]. This cycle is influenced by both internal and external factors, including the body's internal clock and the light-dark cycle [22]. The interaction between these factors can be disrupted by various conditions, such as aging and changes in the environment, leading to sleep disturbances [38].
Sleep is regulated by complex neuronal networks and neurotransmitters, with the circadian pacemaker playing a key role in sleep consolidation and electroencephalographic activities [39, 43]. It is a complex network of individual clocks that must be synchronized by a central pacemaker [40]. This central pacemaker, located in the suprachiasmatic nucleus (SCN), interacts with other pacemakers, such as the one responsible for visual sensitivity [41]. The circadian pacemaker is regulated by a time-delayed negative feedback mechanism, which is essential for sustaining stable oscillations [42, 44]. The cardiac pacemaker's time-delayed negative feedback mechanism involves a complex interplay of various proteins and ion channels.

3.4. Age-Related Changes in Sleep Architecture:

Normal aging is associated with changes in sleep architecture, including a decrease in slow-wave and rapid eye movement sleep, and an increase in sleep fragmentation [46].
Older adults tend to nap more in the evening, leading to earlier wake-up times and decreased nocturnal sleep duration [24]. However, the maximal capacity for sleep is reduced in older individuals, indicating a decreased ability to rest during sleep [25].
Melatonin, a hormone that regulates sleep, decreases in concentration and is secreted later in old age [49]. This is further compounded by age-related changes in the brain, including cortical thinning, white matter degeneration, and neurotransmitter dysregulation, all of which disrupt the sleep-wake cycle [50]. The suprachiasmatic nucleus, the brain's biological clock, also experiences age-related decline, leading to changes in sleep duration and quality [51].
These changes can result in difficulties initiating and maintaining sleep, along with an increased incidence of insomnia [47]. They are believed to be influenced by various factors,

including age-related changes in circadian modulation, homeostatic factors, cardiopulmonary function, and endocrine function [46]. Furthermore, sleep fragmentation has been linked to delayed changes in hippocampal-dependent cognitive function, potentially due to its suppressive effect on adult hippocampal dentate gyrus neurogenesis [52]. Despite these changes, older adults may exhibit greater resistance to the cognitive effects of sleep deprivation, restriction, and fragmentation compared to younger adults [48].

3.5. Impact of Drugs and Sleep Disorders on Sleep Architecture:

Research has shown that sleep disorders, such as epilepsy and sleep apnea, can significantly impact sleep architecture. For example, antiepileptic drugs can alter sleep architecture [53], while there are multifactorial causes of sleep disturbance in intensive care patients [54]. Obstructive sleep apnea can lead to a decrease in deep sleep and an increase in light sleep[55]. Anticonvulsant medication could have an impact on EEG sleep architecture, but there is need for further research in this area [56]. Phenytoin and valproic acid disrupted sleep by decreasing slow wave and REM sleep, and increasing the first stage of sleep [57]. On the other hand, gabapentin improved sleep by increasing slow wave sleep [57]. Oxcarbazepine increases total sleep time, slow wave sleep, and REM sleep, indicating potential hypnotic properties [58]. Moreover, AEDs can also cause sleep disturbances, such as drowsiness, which may negatively impact sleep architecture [59].
In the case of sleep apnea, nasal obstruction, a common cause of sleep apnea, led to a decrease in deep sleep and an increase in light sleep [60]. This was associated with an increase in sleep arousals and awakenings. The severity of apnea increased as the night progressed, leading to a decrease in deep sleep [61]. However, obstructive sleep apnea severity is markedly reduced during slow-wave sleep, a stage of NREM deep sleep[62]. These findings collectively suggest that obstructive sleep apnea can disrupt the normal sleep cycle, leading to a decrease in deep sleep and an increase in light sleep.

3.6. The Role of Sleep Hygiene and Lifestyle Factors:

A variety of lifestyle factors, including excessive stimulant consumption, late-night electronic media usage, smoking, obesity, alcohol consumption, lack of physical exercise, and an unhealthy diet, can significantly impact sleep quality and duration [74]. Among office workers, irregular meal times, lack of vegetable consumption, nightcaps, weight gain, lack of morning sunlight exposure, and caffeine intake were found to be associated with sleep disturbance [75]. For children and adolescents, exposure to modern technologies, consumption of wake-promoting substances, late-evening meals, and cultural norms that devalue sleep can negatively affect sleep [74]. Furthermore, a sleep hygiene education program has proven effective in improving sleep irregularity and latency in adolescents [63]. These findings underscore the importance of promoting healthy sleep hygiene and lifestyle habits to improve sleep quality and duration.

3.7. Associations Between Sleep and Mental Health:

A growing body of research underscores the bidirectional relationship between sleep and mental health. Sleep disorders, such as insomnia, sleep-disordered breathing, and narcolepsy, are associated with an increased risk of mental health disorders [64]. Conversely, mental health issues, including anxiety, stress, depression, and bipolar disorder, can significantly impact sleep quality and patterns [77]. This relationship is particularly important in adolescents, where poor sleep duration and subjective sleep assessment are linked to poorer mental health [65]. Adolescents with sleep problems, particularly delayed sleep phases, are at a higher risk for mental health issues such as depression, anxiety, and ADHD [66]. These sleep problems are also associated with a range of mental disorders, including mood, anxiety, substance use, and behavioral disorders, as well as suicidality [67]. Sleep disorders are common in this age group, affecting 25-40% of adolescents, and can significantly impact their daytime functioning and development [68]. The prevalence of sleep disorders is higher when diagnosed using the International Classification of Sleep Disorders (ICSD) compared to the Diagnostic and Statistical Manual of Mental Disorders (DSM) [69].About 31.3% of adolescents in specialty mental health care had sleep problems, with a higher prevalence than in the general community [70]. There is also an association between delayed sleep phase and mental health problems, with 3.3% of adolescents experiencing this sleep disorder [66]. Furthermore, 88% of youth with anxiety disorders experienced sleep-related problems [71,73]. Specific sleep behaviors, such as later bedtime during weekdays, maintaining sleep difficulties, disorders of arousal, poor emotion at bedtime, and an unstable sleep schedule, are associated with mental health problems in the adolescent age group [72].

3.8. Associations Between Sleep and Physical Health and Performance

Sleep plays a vital role in maintaining physical health and optimizing athletic performance [78]. Adequate sleep is crucial for muscle recovery, tissue repair, and the release of growth hormones, all of which are essential for athletes' performance and recovery. During deep NREM sleep, the body engages in restorative processes that help in muscle repair, protein synthesis, and immune system enhancement [79]. Lack of sleep, on the other hand, can lead to increased levels of cortisol, a stress hormone that can impede muscle recovery and increase the risk of injury. Furthermore, sleep deprivation has been shown to impair motor skills, reaction times, and cognitive functions, which are critical for athletic performance [80]. Athletes who do not get enough sleep may experience decreased endurance, slower reaction times, and reduced accuracy, all of which can negatively impact their performance [81]. Therefore, understanding and prioritizing sleep is essential for athletes to achieve peak physical performance and reduce the risk of injury.

4. Summary:

Sleep plays a critical role in maintaining both physical and mental health, as well as optimizing performance. The Non-Rapid Eye Movement (NREM) sleep stage, known as the foundation of restoration, is essential for physical and intellectual performance, supporting processes such as cellular repair, immune function, and homeostasis. The Rapid Eye Movement (REM) sleep stage, characterized by vivid dreaming, is vital for cognitive processes, emotional regulation, and memory consolidation. Individual variability in sleep patterns is influenced by factors like circadian rhythms, chronotype, and age. Morning and evening chronotypes exhibit different sleep behaviors, affecting mood and cognitive function. Age-related changes in sleep architecture, such as reduced slow-wave and REM sleep, and increased sleep fragmentation, are common in older adults and can lead to difficulties in maintaining sleep.

Sleep disorders and the use of certain medications can disrupt normal sleep architecture, leading to reduced deep sleep and increased light sleep. Lifestyle factors, such as diet, exercise, and exposure to electronic media, also significantly impact sleep quality and duration. There is a strong bidirectional relationship between sleep and mental health, with sleep disorders linked to an increased risk of mental health issues, and vice versa. In adolescents, poor sleep is closely associated with mental health problems, including depression and anxiety.

Finally, adequate sleep is crucial for physical health and athletic performance. It supports muscle recovery, tissue repair, and cognitive functions, while sleep deprivation can impair motor skills, reaction times, and increase the risk of injury. Prioritizing sleep is essential for achieving optimal health and performance.

Disclosure:

Authors' contribution:

Conceptualization: Marta Rutkowska, Mateusz Bieńko, Mikołaj Margas, Magdalena Marchaj. Formal Analysis: Michalina Toborek, Tomasz Król, Natalia Niedziela, Karolina Bednarz. Investigation: Marta Rutkowska, Mateusz Bieńko, Mikołaj Margas, Magdalena Marchaj. Supervision: Michalina Toborek, Anna Putra, Natalia Niedziela, Karolina Korta. Validation: Michalina Toborek, Anna Putra, Karolina Korta, Natalia Niedziela, Karolina Bednarz.
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All authors have read and agreed with the published version of the manuscript.

Funding statement: No funding was received.
Conflict of interest: The authors declare no conflict of interest.
Statement of institutional review board: Not applicable.
Statement of informed consent: Not applicable.
Data availability statement: Not applicable.

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