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UNDERSTANDING THE RELATIONSHIP BETWEEN CAFFEINE AND SLEEP - A REVIEW

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ABSTRACT

Research objectives: Sleep is a fundamental physiological process essential for the proper functioning of the body and mind. It supports physical restoration, emotional regulation, cognitive performance, and overall health. Due to its complexity, even slight disruptions in sleep patterns can significantly affect well-being. Caffeine is the most widely consumed psychoactive substance worldwide. Found in coffee, tea, energy drinks, and various medications, it is used daily by the majority of the population to enhance alertness and reduce fatigue. Given its popularity and stimulating properties, it is important to examine how caffeine consumption affects sleep.
Methods: A comprehensive literature review was conducted, analyzing 44 studies from the PubMed database (English-language, up to 2025) that assess the relationship between caffeine and sleep.
Key findings: This work reviews existing research on how caffeine intake, particularly in moderate to high doses, influences sleep timing, duration, architecture, and recovery, with a focus on timing of consumption and habitual use.
Conclusions: Caffeine disrupts sleep by reducing total sleep time and altering key sleep stages, impairing recovery and daytime functioning. Even caffeine consumed hours before bedtime affects sleep quality. Limiting afternoon and evening intake is important to maintain healthy sleep. Further research is needed on individual sensitivity and long-term effects.

KEYWORDS

Lack Of Sleep, Daytime Sleepiness, Caffeine Sleep, Caffeine, Sleep Disorders

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Introduction

Sleep is a natural physiological condition characterized by reduced consciousness, lowered motor activity, and diminished responsiveness to external stimuli. It plays a vital role in restoring both the body and the mind, and is essential for maintaining mental and physical well-being. Sleep consists of multiple stages, each serving distinct purposes in the processes of recovery and the preservation of the body's internal balance.[1] On average, adults require between 7 and 9 hours of sleep per night, though individual needs may vary. Sleep is divided into two main phases: non-rapid eye movement (NREM) sleep and rapid eye movement (REM) sleep. NREM sleep, which constitutes approximately 75–80% of total sleep, includes stages of light and deep (slow-wave) sleep that are vital for physical recovery. REM sleep, accounting for 20–25% of total sleep, is associated with vivid dreaming and cognitive restoration.[2,3] Sleep plays a vital role in maintaining overall health: it enables the body to heal tissues, boost the immune system, and regulate hormone levels.[4] Additionally, sleep facilitates emotional processing, supports learning, and aids memory retention.[5] Adequate sleep contributes to mood stability and effective stress management, which are important for mental well-being.[6] Furthermore, sleep helps keep neurotransmitter levels balanced and removes toxins from the brain.[7]

Caffeine is the most commonly used psychoactive compound globally. Around 80% of people worldwide consume caffeine-containing products on a daily basis.[8] Caffeine is a xanthine alkaloid present in many foods and drinks, including chocolate, coffee, and tea. In Western Europe and the United States, coffee serves as the main source of dietary caffeine [9], however, among teenagers, soda seems to have become the favored caffeinated beverage. [10] Caffeine is widely recognized as a mild stimulant. It is inexpensive, readily accessible worldwide, and present in numerous products. [11] Caffeine is employed in the treatment of apnea of prematurity [12] and it is also present in various over-the-counter medications for headaches or appetite suppression. [13] Following oral consumption of caffeine, primarily through coffee or tea, approximately 99% is absorbed from the gastrointestinal tract into the bloodstream, reaching peak levels within 30–60 minutes. Caffeine absorption occurs more rapidly when delivered via chewing gum, with maximum concentrations

reached between 45 and 80 minutes after administration. In contrast, caffeine capsules have a slower absorption rate, with peak levels occurring between 85 and 120 minutes post-ingestion. [14] At the levels typically consumed by humans, caffeine's primary biological effects result from its ability to block adenosine receptors — mainly the A1 and A2A types, and to a lesser extent, A2B and A3 receptors. These A1 and A2A receptors are found in various regions of the brain and play a key role in regulating sleep, alertness, and cognitive function.[15]

Consequently, it is unsurprising that caffeine, acting as an adenosine receptor antagonist, can influence both physiological and cognitive functions. [16] Caffeine's influence on the homeostatic regulation of the sleep–wake cycle is thought to underlie both its stimulating effects and its tendency to interfere with sleep. It is well established that lack of sleep results in notable impairments in cognitive functioning, such as reduced attention, lowered alertness and vigilance, as well as slower mental and motor responses.

This is confirmed by research showing that caffeine effectively reduces the accumulation of sleep pressure linked to prolonged wakefulness. [17] Research has shown that caffeine delays sleep onset, reduces deep sleep and REM duration, and increases sleep fragmentation - especially when consumed close to bedtime or during periods of elevated sleep pressure, such as after sleep deprivation.

Caffeine and Sleep: How Timing Matters

In 2013, researchers investigated the possible impact on sleep of a fixed 400 mg caffeine dose given 0, 3, or 6 hours before usual bedtime, compared to a placebo, based on participants' self-reported sleep at home. [18] Objective measurements of sleep disruption were also collected using a validated portable sleep tracking device.

The findings of this study indicate that consuming 400 mg of caffeine 0, 3, or even 6 hours before bedtime substantially impairs sleep. Notably, caffeine intake as early as 6 hours before sleep reduced total sleep time by over one hour. Such a level of sleep deprivation, if sustained across several nights, could negatively affect daytime performance. [19-21] Therefore, the current findings imply that afternoon caffeine intake should ideally be limited to before 5 PM, especially when consuming moderate to large amounts typically found in popular premium coffees and energy drinks. Further studies are necessary to assess how afternoon caffeine affects sleep in individuals with insomnia compared to those without sleep disorders.

Sleep disturbances caused by caffeine were identified through both self-reported diaries and objective sleep assessments when caffeine was consumed at bedtime and 3 hours before bedtime. However, when caffeine was taken 6 hours before bedtime, only the objective measurements revealed differences. This discrepancy between subjective and objective assessments is especially noticeable in instances of brief awakenings, such as those seen with sleep fragmentation. [22] Sleep fragmentation is commonly observed following caffeine intake at night. [23]

Previous studies have reported that caffeine given in divided doses within 3 hours of bedtime causes disturbed sleep, including reductions in total sleep time and stages 1 and 2 sleep. [24] The observation that sleep disruption occurs even when caffeine is consumed 6 hours before bedtime expands our understanding of caffeine's impact on sleep, indicating that higher doses can significantly affect sleep even during the day. Importantly, future research should measure blood caffeine levels to investigate whether individual variations in absorption or elimination during afternoon intake correlate with the extent of nighttime sleep disturbance. Tolerance to caffeine's stimulating effects on alertness develops rapidly, and the use of high caffeine doses to boost alertness is becoming increasingly widespread among both adults and teenagers. [25-27] However, the risks of caffeine use in terms of sleep disturbance are underestimated by both the general population and physicians. These results showed that high doses of caffeine have a significant negative impact on sleep duration in the home environment, even when consumed in the early evening hours.

Caffeine's Role in Sleep Disruption and Recovery

In a study conducted in 2021, twenty male caffeine consumers (26.4 ± 4 years old) completed a double-blind crossover study with caffeine, withdrawal, and placebo conditions.. After 10 days of controlled intake, EEG was recorded for 8 hours starting 5 hours after usual bedtime, following a 60-minute nap to reduce sleep pressure. While total sleep time and architecture were similar across conditions, caffeine intake delayed REM sleep onset and its accumulation. Participants in the caffeine condition showed a delayed onset of REM sleep and a slower accumulation of REM sleep throughout the night compared to the placebo condition. These effects were observed during an early morning sleep period, corresponding to the circadian peak of REM sleep promotion, and were not seen during regular nighttime sleep at different circadian phases. This suggests that caffeine may influence the circadian regulation of REM sleep. Despite the last caffeine dose being

administered 13.5 hours before sleep onset, REM sleep features remained sensitive to caffeine intake. Additionally, participants reported greater difficulties waking and increased tiredness after caffeine consumption compared to placebo, indicating that subtle declines in subjective sleep quality may promote continued caffeine use, especially when sleep timing is delayed or shifted. [28]

In another study conducted in 2024, forty-one participants underwent total sleep deprivation (38 hours) in a double-blind, crossover design, receiving either caffeine (2.5 mg/kg) or a placebo twice, with the last dose administered 6.5 hours before the recovery sleep.. Sleep was monitored using a wearable polysomnographic device. After deprivation, participants experienced a significant rebound in total sleep time (+110.2 minutes). However, caffeine reduced recovery sleep by about 30 minutes and notably decreased deep sleep (N3). It also impaired sleep quality by increasing long awakenings, stage transitions, and sleep fragmentation, while reducing delta wave activity during NREM sleep. Regular caffeine consumption was associated with shorter total sleep time and more awakenings during recovery sleep, especially when caffeine was consumed acutely after deprivation. Habitual caffeine use may alter the adenosine receptor system, diminishing sleep's restorative effects and exacerbating caffeine's negative impact after sleep loss.[29]

The Relationship Between Caffeine Intake and Sleep Health

There is widespread agreement among both the general public and health professionals regarding the vital role of sufficient, restorative sleep in maintaining physical and mental health. Ensuring good sleep quality requires avoiding substances that stimulate the mind and body and disrupt normal sleep patterns. Caffeine, well-known for its ability to reduce sleepiness, is one such stimulant that can negatively affect subsequent sleep, especially when sleep occurs at a time when the biological clock strongly signals wakefulness, such as during the daytime. Therefore, caffeine should be consumed judiciously. In other words, caffeine intake should be avoided during periods when increased mental alertness and physical activation can impair sleep quality, particularly in the hours just before bedtime.

For individuals working shifts, sleep patterns must be adjusted to accommodate their irregular schedules, which can lead to particular challenges when combined with caffeine consumption. A 2008 study investigated sleep habits and the influence of caffeine consumption among 130 medical students, 68 postgraduate physicians, 162 specialists, and 93 nurses. The findings revealed that the amount of sleep required to feel well-rested varied depending on factors such as age, gender, work demands, and work schedules. However, participants who consumed caffeine reported greater difficulty staying awake during lectures, study sessions, and while driving. Based on these observations, the authors concluded that caffeine intake may negatively affect sleep habits and sleep quality, consequently impairing cognitive function and alertness during waking hours. [30]

How Caffeine Affects Sleep: Timing and Dosage Considerations

The negative impact of caffeine consumption at bedtime on sleep quality is well established. [23] In fact, caffeine administration has been utilized as a model to study insomnia. [31]

Dose-response studies show that higher amounts of caffeine taken at or close to bedtime lead to considerable disruptions in sleep. [32-34]

One limitation of these recommendations is the scarcity of studies directly comparing the sleep-disrupting effects of caffeine consumed at various times before bedtime. Therefore, it is still unclear how much caffeine intake in the afternoon affects nighttime sleep compared to doses taken closer to bedtime.

One study investigating the effects of 400 mg of caffeine taken 30 minutes before bedtime found significant sleep disturbances as well as notable cardiovascular changes during sleep, likely due to increased sympathetic nervous system activity. [35]

In one of the rare studies examining the effects of caffeine taken in the evening, participants received a total dose of 200 mg, split into 100 mg administered 3 hours before bedtime and another 100 mg 1 hour before sleep. Compared to placebo, caffeine intake led to a 5% decrease in sleep efficiency, an increase in the time it took to fall asleep by 12-16 minutes, and a reduction in total sleep duration by 25-30 minutes. [24]

However, since this study examined the combined impact of both doses, it was not possible to distinguish the effects of the timing of administration. Another study that gave a 200 mg dose of caffeine 16 hours before bedtime showed only minimal changes in typical sleep measures compared to a dose taken closer to bedtime, probably because caffeine levels in the blood were low at the time of sleep. [36] Still, despite the low doses and the long interval before bedtime, caffeine's impact on sleep measures was noticeable.

Discussion

Caffeine is one of the most widely consumed psychoactive substances, primarily used for its ability to reduce subjective sleepiness and enhance alertness. [37] Caffeine is a powerful modulator of the sleep-wake cycle. [38] The presented studies clearly demonstrate that caffeine significantly affects sleep quality and architecture, confirming previous findings on the negative impact of this widely used stimulant on the body's restorative processes.

The 2013 study by Drake et al. revealed that 400 mg of caffeine taken even six hours before bedtime reduced total sleep time by over one hour. Importantly, objective measures detected disturbances not always perceived by participants, emphasizing the risk of underestimating caffeine's impact on sleep.

The studies mentioned above, in line with previous research showing a reduction in REM sleep after caffeine consumption right before bedtime [39-41] indicate that certain aspects of REM sleep—such as its onset and accumulation—may be sensitive to caffeine intake, even when it is consumed only during the day and the final dose is taken 13.5 hours before going to sleep. These effects appear linked to disruptions in circadian regulation, suggesting that caffeine interferes with the mechanisms controlling sleep-wake cycles, particularly the REM phase, which plays a crucial role in cognitive and emotional processing.

Moreover, findings from the 2024 study highlight caffeine's impact on recovery sleep following total sleep deprivation. Despite the natural rebound effect, where the body attempts to compensate for lost sleep, caffeine reduced total recovery sleep time and notably shortened deep sleep (N3), which is essential for physiological restoration. This was accompanied by impaired sleep continuity, reflected by increased long awakenings, more frequent stage transitions, and reduced delta wave activity during NREM sleep. These results indicate that caffeine not only delays sleep onset but also diminishes sleep quality, potentially impairing cognitive function and overall well-being.

Additionally, regular caffeine consumption appears to alter the body's response to the stimulant, possibly through modifications in adenosine receptor functioning. Habituation may mask caffeine's stimulating effects in habitual users but could also exacerbate sleep disturbances following periods of sleep deprivation or acute caffeine intake. This underscores the importance of individualized recommendations for caffeine consumption, taking into account habitual use and circadian factors. Current data indicate that a study is needed to distinguish between innate insensitivity and habituation to the stimulant's effects [42] due to a potential adaptation to the continuous availability of caffeine. [43]

In summary, while caffeine effectively reduces subjective sleepiness and enhances alertness, its detrimental effects on sleep quality and architecture—especially on restorative sleep after deprivation—are evident. Therefore, caution is advised regarding caffeine intake, particularly in the afternoon and evening, to avoid disrupting the body's natural restorative processes. Future research should focus on better understanding the timing effects of caffeine on various sleep stages and the adaptive mechanisms involved in chronic caffeine use. The relationship between caffeine's effects and sleep highlights the substantial impact of poor sleep quality on global health and points to a clear opportunity for public health initiatives. [44]

Conclusions

Caffeine significantly affects sleep by reducing total sleep time, delaying sleep onset, and disrupting important stages like REM and deep sleep. These effects impair sleep's restorative functions and can lead to daytime sleepiness and cognitive issues. Both acute and habitual caffeine use influence sleep, with tolerance potentially masking some effects but worsening disturbances after sleep loss. Given its widespread consumption, limiting caffeine intake in the afternoon and evening is crucial to protect sleep quality, especially for those with sleep problems or irregular schedules. Future research should focus on individual differences in caffeine sensitivity and long-term impacts on sleep to better balance caffeine's alertness benefits with its effects on sleep health.

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