# Effect of Sleep Deprivation on the Performance of Pilots: A Systematic Review

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**Abstract-** Sleep deprivation negatively affects a person's emotions, cognition, and performance and ultimately reduces safety. The main purpose of this systematic review is to study and report the evidence on the effect of sleep deprivation on the performance of pilots. This systematic review was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses. International databases including PubMed, Web of Science (WOS) and Scopus were considered for the search of English articles up to April of 2023. Keywords were sleep deprivation, pilot, flight, performance, airline, air force, flight safety, fatigue, pilot performance, flight performance, eye movement, workload, motion, visual, attention, errors, cognition, sleep quality, and circadian rhythm. In this systematic review, 12 studies consisting of 259 subjects remained. Most of the studies have reported the negative effects of sleep deprivation in a different way, and the decrease in performance was expressed as one of the important issues following sleep deprivation. As various studies show, any type of sleep deprivation in pilots can have negative effects on their performance, and this decrease in performance can have irreparable consequences.



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**Keywords:** Sleep; Deprivation; Pilot; Performance

## Introduction

Sleep is essential for maintaining physical and mental health. Research has shown that sleep, through its effect on the activity of the hypothalamus-pituitary-adrenal axis (1), enhances memory (2), regulates emotions (3), increases metabolic functions (4), improves energy balance, and modulates the immune system (5). Sleep loss or sleep deprivation can significantly interfere with and impair cognitive, motor, and physiological performance (6). Sleep deprivation can also negatively affect a person's emotions and moods. Sleep deprivation and subsequent fatigue are associated with reduced cognition (7), impaired workplace performance (8), higher error rates (9) and ultimately reduced safety (10). Inadequate sleep can lead to significant personal and societal burden, including adverse effects on well-being (11), productivity (12), and safety (13). The consequences of sleep loss have multiple causes. Negative consequences may result from decreased muscle strength (14) and endurance (15), changes in mood (e.g., decreased motivation) (16), increased perceived effort (17), changes in cognitive processing ability (e.g., decision-making, executive function) and decreased fine motor skills (18), or a combination of these factors. Sleep has two distinct dimensions: quantity and quality. However, given the challenges associated with accurately determining sleep quality in most situations, sleep loss is often measured in terms of duration (19). Sleep deprivation is a general term used to describe a period of prolonged wakefulness, which often refers to a condition in which a person is unable to sleep for a period of more than 24 hours (20). Sleep-restricted (also known as termed "relative sleep deprivation") occurs when a person has the opportunity to sleep, but the duration is limited

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relative to their normal sleep patterns (20) and is often the result of delayed sleep onset (21). Sleep deprivation affects physical performance, daily activities and increase the likelihood of accidents related to human error (22). Occupations such as nursing, medicine, mining, maritime, and transportation that perform 24-hour activities are highly susceptible to human error as a result of sleep deprivation (23). One industry that has received relatively little attention despite its high risks is the commercial aviation industry. Commercial airline pilots are exposed to highly demanding, complex, and stressful work environments as a result of full-time activities, long work periods, and disrupted circadian rhythms so these all key factors contribute to fatigue of the airline operator (24). Furthermore, sleep deprivation and fatigue are common among the commercial pilot population and more than 50% of pilots reported experiencing levels of fatigue affecting their abilities while on duty (25). Sleep deprivation and fatigue are the main causes of pilot error (26). The popularity of air travel is increasing annually, resulting in today's flight operations and pilots working under pressure on a 24-hour schedule. However, despite being considered the "gold standard" for measuring fatigue in aviation, much remains unknown (27). The main purpose of this systematic review is to study and report the evidence on the effect of sleep deprivation on the performance of pilots.

## Materials and Methods

This systematic review was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (28). International databases including PubMed, Web of Science (WOS) and Scopus were considered for the search of English articles up to April of 2023.

Inclusion criteria were studies discussing the effect of sleep deprivation on pilots. Exclusion criteria were studies as case reports, animal studies, and studies with the incorrect values of the selected index (Figure 1). Keywords were sleep deprivation, pilot, flight, performance, airline, air force, flight safety, fatigue, pilot performance, flight performance, eye movement, workload, motion, visual, attention, errors, cognition, sleep quality, and circadian rhythm. Here is the search syntax for PubMed:

((Sleep Deprivation [Title])) AND (pilot [Title/Abstract] or flight [Title] or performance [Title] or airline [Title] or air force [Title] or flight safety [Title] or fatigue [Title] or pilot performance [Title] or flight performance [Title] or eye movement [Title] or workload [Title] or motion [Title] or visual [Title] [Title] or Attention [Title] or Errors [Title] or cognition [Title] or Sleep quality [Title] or Circadian rhythm [Title])).

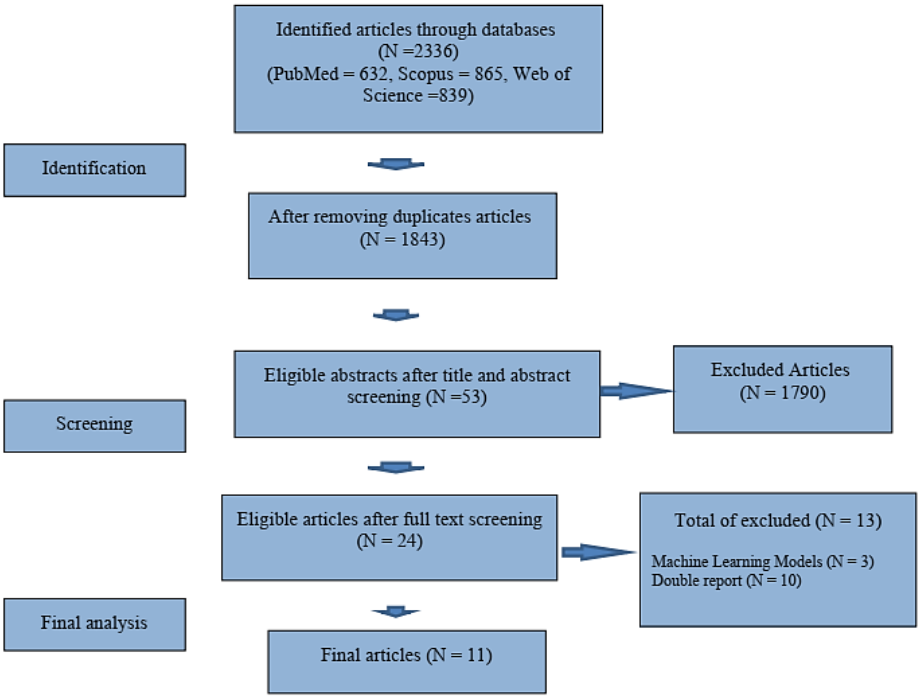


**Figure 1.** PRISMA flowchart

## Results

In this systematic review, 12 studies consisting of 259 subjects remained as presented in figure 1. In table 1, author, year, country, participants, periods of sleep deprivation, used performance test and main findings were presented for each study.

**Table 1. Features of selected studies in the systematic review**

| First author, Year | Country | Sample | Periods of Sleep Deprivation | Performance test | Main findings | Description |
|---|---|---|---|---|---|---|
| **Dowd, 1974 (29)** | USA | 143 experienced pilots | (24-30 hours) or rest (6 hours) | Two Coriolis test periods were given to all subjects; 48 hours after the initial period all subjects received the repeat test | a) Increased sensitivity to Coriolis excitation. (b) Decreased recovery rate and (c) interference with the vestibular habituation process | Subjected to two Coriolis acceleration experiments |
| **Miszczak, 1977 (30)** | Poland | 20 pilots (aged 20 to 40 Years) | 24 hours | - | Sleep deprivation disrupts the balance between the processes of stimulation and inhibition of non-specific structures (with increased stimulation) | Studying the effects of sleep deprivation on visual evoked potentials |
| **Chelette, 1998 (31)** | USA | 16 active personnel (8 men and 8 women) | 24 hours | - | Sleep deprivation (24 hours) caused feelings of fatigue and frustration, but overall performance did not decrease. The desire for a complex defensive maneuver was reduced when they were sleep-deprived | Conducted on the centrifuge Dynamic Environment Simulator (F-16) |
| **Previc, 2007 (32)** | USA | 10 pilots, mean age: 34.2 years | 36 hours of continuous wakefulness in the laboratory | Subjective fatigue, using two scales: 1) the Profile of Mood States (POMS), a 65-question survey and 2) the Visual Analog Scale (VAS), a computerized scale involving ratings of various dimensions (alertness, anxiety, energy, confidence, irritability, jittery, sleepy, and talkative) with a line and pointer | Despite clear signs of fatigue in our pilots, the overall effects of these conflicts on cognition and performance are generally not altered by sleep deprivation. | Investigating the ability to understand and be affected by physiologically simulated sleep conflicts |
| **Elmenhorst, 2008 (33)** | Germany | 16 healthy volunteers, mean age: 27 years | 280.8 ± 8.5 min on average of the maximum possible 300 min | Performance data collected five times a day will be reported later | Relative sleep deprivation alters daily sleep and alertness. The results show that not only slow wave sleep (SWS) but also REM is important for sleep. | This plan corresponds to the service conditions and sleeping rhythm of rescue helicopter pilots in Germany. |
| **Elmenhorst, 2009 (34)** | Germany | 16 healthy volunteers | Subjects spent 5 hours of night restriction daily for four consecutive days | Performance was tested five (or six) times per day with reaction time task (SRT) and unstable tracking task (UTT) | Sleeping 5 hours a night for four consecutive days impairs performance in a way that compromises traffic safety. | The deprivation pattern of this study was chosen due to its similarity with the work schedule and rest time of helicopter pilots in air medical rescue services in Germany. |

**Cont. table 1**

| | | | | | | |
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| **Previc, 2009 (35)** | USA | Ten pilots from the United States Air Force (USAF), average age of the pilots was 34.2 years (range = 23–46 years) | 34 hours of continuous wakefulness | Root mean squared error (RMSE) was used as the measure of flight performance. fatigue surveys: the Profile of Mood States (POMS) (McNair, Lorr, & Droppleman, 1981), a 65-question survey that scales on six dimensions (tension-anxiety, depression-dejection, anger-hostility, vigor-activity, fatigue-inertia, and confusion-bewilderment), and the Visual Analog Scale (VAS) | Flight hours peaked after about 24 to 28 hours of continuous wakefulness in line with the peak of mental fatigue and theta electroencephalogram activity. | This study was carried out in a stable operation simulator. |
| **Lopez, 2012 (36)** | USA | Ten pilots from the United States Air Force (USAF), mean age of the pilots was 34 years (ranging from 23 to 46 years) | 35 hours of continuous wakefulness | Variance of optimal flight performance was predicted by the Psychomotor Vigilance Task (PVT), and the Operation Span Task (OSPAN), but each measure added incremental validity to the prediction. | Performance on all tests decreased after about 18 to 20 hours of continuous sleep deprivation, although the degree of performance reduction varied. | They simulated flight at 3-hour intervals during a 35-hour sleep deprivation period |
| **LIU, 2013 (37)** | China | Four young healthy male, age range 18–22 years, mean age=20 | 32 continuous hours of sleep deprivation | Eye movement data and flight performance data were measured at the following times: 11:00, 15:00, 04:00, 11:00, 15:00. The workload and fatigue of the subjects were evaluated with NASA-TLX (national aeronautics and space administration-task load index) and RPE (rating of perceived exertion.( | Average pupillary area eye movement indices, mean saccade amplitude and mean saccade speed decreased during the 32-hour standard deviation and all showed a significant change in the final standard deviation, while the mean fixation time index increased in the final standard deviation. Flight performance worsened during 32 hours of sleep deprivation, but not significantly. | The study was conducted in fixed-base flight simulators, the prototype of which was a high-fidelity military aircraft |
| **O'Hagan , 2018 (27)** | Ireland | Seven male university level subjects, mean age: 21 years | 24 continuous hours of sleep deprivation | Working memory was determined using the Auditory Digit Span (Forward & Backward) Test (ADS) of the Wechsler Adult Intelligence Scale—Fourth Edition | Certain pilot task-specific factors such as mental fatigue, cognitive flexibility, and working memory are particularly vulnerable to sleep loss, with significant declines in performance after 16 hours of continuous wakefulness, suggesting a decrease in optimal performance after this period. . | Subjects were asked to complete a battery of mood, fatigue, and pilot competency task analog measures every 8 h (0 h, 8 h, 16 h, 24 h) during each test period. |

**Cont. table 1**

| | | | | | | |
|---|---|---|---|---|---|---|
| **O'Hagan, 2020 (25)** | Ireland | Five male and two female commercial airline pilots, mean age:35 years | 24 continuous hours of sleep deprivation | Pilots completed the Samn-Perelli Crew Status Check (SPC), Profile of Mood States (POMS), Psychomotor Vigilance Task (PVT), Dual-N-Back, Rapid Visual Information Processing Task (RVP), NASA Task Load Index (NASA-TLX) and aviation-specific mathematical calculations as well as a computerised flight simulator task, during which participants were required to answer mid-flight fuel calculations and situational awareness questions (SA) | Significant fluctuations in performance were observed in almost all tests after 20 hours of continuous wakefulness. Flight performance was not significantly impaired. Changes in flight performance are consistent with changes in situational awareness. Overall findings showed impaired mood, cognition and flight performance after 20 hours of continuous wakefulness | Testing was performed at 3-hour intervals during the final 12 hours of a 24-hour continuous wakefulness period. |

## Discussion

The maximum physical and hormonal dysfunction in sleep deprivation was observed from 2 to 6 am, and employment in sensitive and military affairs will not be suitable for people who are deprived of sleep in these time periods (38). Sleep deprivation may cause social costs in two ways, directly and indirectly, which direct costs include the cost of diagnostic measures, treatment, and doctor visits and indirect costs include disabilities related to medical conditions following sleep deprivation, reduced production, and accidents caused by sleep deprivation (39). About one third of adults experience some kind of sleep disorder during their lifetime, among which sleep deprivation is the most common and well-known sleep disorder. Sleep deprivation is the feeling of insufficient sleep in terms of its quantity or quality, and it is not usually related to daytime sleepiness (40). Sleep has long been known as one of the physiological needs of humans, and this is a natural need to maintain balance and functional balance. Physical and psychological are important (11,40,41). This is despite the fact that interference in sleep and circadian rhythm and deprivation of sleep cause disorders such as fatigue, irritability, decrease in physical and mental performance, headache, forgetfulness, Disorders in metabolism, attention, concentration, changes in the capacity to react to stimuli, increase the possibility of obesity, diabetes, Alzheimer's and cardiovascular diseases (40,42,43). Physical performance following sleep deprivation is influenced by the severity and duration of sleep deprivation. A number of people such as military personnel, employees who have rotating shifts and athletes who travel to different regions with different time hours, and in addition any of these people who go to altitude, report poor quality sleep with an increase in the number of awakenings (44). It is widely accepted that sleep deprivation can have a negative effect on human performance. Complete sleep deprivation has a negative effect on attention, psycho-motor performance, physical performance (strength and power), reaction time, short-term memory, agility, visual performance, fatigue, and secreted hormone levels, etc. (45). Rognum *et al.*, also conducted their research on a group of soldiers who were allowed to sleep for 2 hours during 4 days and finally came to the conclusion that accuracy in shooting and running 3 kilometers was negatively affected by sleep deprivation (46). Also, sleep deprivation with sleep disturbance affects the sleep-wake cycle and affects the secretion of some body hormones, including cortisol, testosterone, and melatonin affecting physical performance (47). Consistent with the above-mentioned, in this systematic review, study by Dowd (29) was the largest one performed on 143 experienced pilots in the US and showed that sleep deprivation decreases recovery rate so in the long-term can resulted in low performance that is why body must be recovered to the same performance. Miszczak (30) in its study revealed that sleep deprivation disrupts the balance between the processes of stimulation and inhibition of non-specific structures (with increased

stimulation). In contrast, Chelette reported that overall performance following 24 hours deprivation of sleep did not decrease (31). It should be noted that Chelette found that Sleep deprivation (24 hours) caused feelings of fatigue and frustration. In a study by O'Hagan *et al*., in 2020 highlighted that overall findings showed impaired mood, cognition and flight performance after 20 hours of continuous wakefulness (25). In another study by O'Hagan *et al*., they showed that certain pilot task-specific factors such as mental fatigue, cognitive flexibility, and working memory are particularly vulnerable to sleep loss, with significant declines in performance after 16 hours of continuous wakefulness, suggesting a decrease in optimal performance after this period (27) .O'Hagan *et al.*, checked both 16 and 24 hours sleep deprivation and even 16 hours sleep deprivation showed negative effect on performance. In addition, LIU *et al.*, (37) showed that flight performance worsened during 32 hours of sleep deprivation, but not significantly. The same effect of sleep deprivation is reported in the studies in different hours sleep deprivation. Even after about 18 to 20 hours of continuous sleep deprivation, performance on all tests decreased although the degree of performance reduction varied (36). Besides, Elmenhorst, *et al*., (34), reported that sleeping 5 hours a night for four consecutive days impairs performance in a way that compromises traffic safety.

As various studies show, any type of sleep deprivation can have negative effects on people's performance, and this decrease in performance can have irreparable consequences in high-risk jobs. Due to the fact that reduced performance is very important and vital in the job of a pilot, it is recommended to pay attention to sleep deprivation from different directions so that it does not have life-threatening consequences for the pilot and passengers.

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