Article Title: Sleep issues in aviation and space

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Abstract (50-100 words)

This article describes the factors that cause sleep issues in aviation and spaceflight. There are many causes of sleep disruption that are common to both domains, including, irregular schedules, circadian misalignment, and inadequate sleep environment. There are also factors that are unique to each type of operation that may lead to the manifestation of sleep disorders among these populations. Each of these factors, and their subsequent impact on sleep, are reviewed in this article.

Introduction

Individuals who work in aviation and spaceflight face numerous challenges that inhibit their ability to obtain adequate sleep. Most of the professionals working in these occupations are healthy and at low risk of sleep disorders; however, many elements of their work conditions can lead to significant sleep loss. In particular, issues facing these groups include circadian misalignment due to irregular work schedules and jet lag, poor quality sleep environment, and elevated workload. In addition, some aspects of these occupations can lead to the development of sleep disorders such as insomnia and sleep apnea.

The consequences of sleep loss among these groups pose a significant threat to safety and can even be catastrophic if left unmanaged. For example, tragic accidents such as the 2009 Colgan Air accident, which resulted in 50 fatalities (Spangler and Park, 2010), and the Space Shuttle *Challenger* disaster (Presedential Commission, Appendix G, 1986) were each preceded by significant work-related sleep disruption among key personnel. These tragedies prompted re-examination of working time requirements among these groups in the United States (US), ultimately eventuating in new rules to limit workload and protect time for sleep (Federal Aviation Administration, 14 CFR Part 117; NASA Technical Standard, STD-3001). Similar changes have been enacted in other countries (Commission Regulation (EU), No. 83/2014). Although there are now many mitigations in place to protect sleep opportunity for these populations, sleep issues persist due to the nature of 24-hour operations. This article reviews the causes and manifestations of sleep issues in aviation and spaceflight.

Sleep issues in aviation

Aviation operations present distinct challenges that often inhibit a pilot or flight attendant’s ability to obtain sufficient sleep. The timing, duration, and number of flights, coupled with circadian misalignment due to time zone crossings, consecutive days of work, schedule irregularity, and sleeping away from home on an aircraft or in a hotel can interfere with the opportunity to obtain good quality sleep. In addition, emerging evidence suggests that sleep disorders may be underdiagnosed among aviation personnel, despite a requirement for medical certification to fly.

Overview of aviation operations

The societal demand for air travel and rapid shipment of parcels necessitates 24-hour aviation operations. As a result, pilots and flight attendants (also known as crews) are required to work irregular schedules that can begin and end at any time of day or night. Pilots must pass a physical exam, including a minimal sleep disorders screening, at least annually to become certified. They then must achieve a rating (qualification) to operate specific types of aircraft and may be assigned to operate flights anywhere that aircraft is capable of going. As a result, some crews of pilots and flight attendants may only operate long-haul (8-16 hour flights) or ultra-long-haul flights (> 16 hour flights), while others will only operate short- or medium-haul flights (< 8 hour flights), and some operate a combination of these types of flights. Schedules are often generated on a weekly or monthly basis but can involve on-call work. Local regulations vary by country and limit how long a crewmember can work in a single day, which is called the flight duty period. The flight duty period may include multiple flights, especially for short-haul operations, but it also includes the time required to conduct pre-, between-, and post-flight duties. The sequence of flights, which normally includes at least one layover day (time spent at the final duty destination that includes enough time for at least a main sleep period; usually in a hotel but can be on the aircraft in some cases), that a crew operates from leaving the home base airport until return to the home base airport is known as a trip. For example, a long-haul trip might involve flying to a destination many time zones away from one's home base, spending a night or two in a hotel during a layover and then flying back to the home base. In contrast, a short-haul trip may involve making multiple short flights in a flight duty period for several days in a row, with layover sleep in a hotel between each flight duty period. Local regulations determine whether crews will be afforded a rest opportunity during a flight and how many crewmembers are required for a single flight. Typically, shorter flights are operated by fewer crewmembers while longer flights require larger crews in order to allow each crewmember to have a rest break.

Notably, the risk of sleep deficiency is well recognized in the aviation industry and many airlines have fatigue risk management programs (FRMP) to help minimize sleep loss among crews (Gander et al., 2011). Some elements of an FRMP include ongoing surveillance of the operation through the intake of voluntary reports of fatigue among personnel, optimization of schedules through the use of biomathematical models that minimize sleep disruption, education modules to teach crews about good sleep practices and sleep hygiene, and collection of sleep and performance data to assess the impact of certain types of operations (Gander et al., 2011). Despite these mitigations, many aspects of aviation operations still result in sleep issues.

Flight timing

Overnight flights

Overnight flights (often referred to as "back of clock") present a considerable challenge to obtaining sufficient sleep. When flights are scheduled during the night they often overlap with the time in which the body is promoting sleep (biological night). This not only means that pilots are flying during a period of low alertness, but they are then also required to obtain preparatory or recovery sleep during the daytime when the circadian rhythm is promoting wakefulness. Daytime sleep following short-haul overnight flights is approximately 40% shorter and of poorer self-rated quality compared to nighttime sleep opportunities (Gander et al., 1998a).

Some flight crews take naps before overnight flights in order to proactively alleviate the build-up of homeostatic sleep pressure and expression of sleepiness during a flight (Gander et al., 1998a). Studies have shown that a pre-flight nap reduces on-the-job sleepiness among pilots and flight attendants without inhibiting subsequent in-flight sleep opportunities during long-haul operations (Signal et al., 2014; van den Berg et al., 2015). Pre-flight napping is a particularly important strategy to combat in-flight sleepiness for short-haul overnight flights because, in contrast to long-haul night duties, short-haul operations rarely allow pilots the opportunity for scheduled rest in a designated bunk facility. As a result, there is often no opportunity to use napping as a sleepiness countermeasure mid-flight. However, in some countries, and on certain flights, there may be the opportunity for a nap on the flight deck using controlled rest procedures (Fatigue Countermeasures Working Group, 2018), but this is less available in short-haul operations due to shorter flight lengths.

Early starts

While overnight flights are perhaps obvious contributors to sleep loss, ‘daytime’ flights can also have a significant impact on sleep, even in short-haul operations. A large proportion of flights take off before 08:00 am (Rosekind et al., 2000; Spencer and Robertson, 2002; Åkerstedt et al., 2021), which means that crewmembers are likely required to get up earlier than 06:00 am. Despite being considered daytime work schedules, early starts mean that crewmembers are waking during their biological night (the time when their sleep drive is strong) and, therefore, reduce the opportunity for circadian-aligned sleep. Achieving sufficient sleep before the first early start after time off is especially difficult (Simons and Valk, 1997) as it typically requires individuals to go to bed a few hours earlier than they normally would. This requires sleeping at a time when the circadian rhythm is strongly promoting wakefulness (Lavie, 1986), resulting in a shortened opportunity for sleep (Bostock and Steptoe, 2013). Studies investigating early report times (e.g., before 6:30 am) confirm that sleep is significantly truncated relative to sleep on days off and when work starts later (Åkerstedt et al., 2021; Bostock and Steptoe, 2013; Bourgeois-Bougrine et al., 2018; Flynn-Evans et al., 2018; Gander and Graeber, 1987; Kecklund et al., 1997; Roach et al., 2012; Sallinen et al., 2017; Simons and Valk, 1997; Vejvoda et al., 2014). In fact, flight duties starting before 06:00 am are typically preceded by approximately 1-2 hours less sleep than duties starting after 09:00 am (Åkerstedt et al., 2021; Bourgeois-Bougrine et al., 2018; Flynn-Evans et al., 2018; Kecklund et al., 1997; Sallinen et al., 2017; Spencer and Robertson, 2002; Vejvoda et al., 2014), with a dose-dependent decrease in sleep duration occurring with every hour of earlier morning start time (Roach et al., 2012). The early wake time required for early work starts has also been associated with a reduction in rapid eye movement (REM) sleep compared to non-work days (Kecklund et al., 1997), a phenomenon that is likely due to the distribution of REM cycles in a typical nocturnal sleep period occurring towards the end of the night. The consequences of such sleep architecture changes are unclear.

Late finishes

In contrast to early starts, late finishes typically allow for sufficient sleep opportunity in short-haul operations (Åkerstedt et al., 2021; Bostock and Steptoe, 2013; Flynn-Evans et al., 2018; Sallinen et al., 2017; Vejvoda et al., 2014), but the duration of wakefulness at the end of a late duty can be extended to over 14 hours, leading to a strong expression of sleepiness at the end of a flight (Arsintescu et al., 2021; Sallinen et al., 2017; Vejvoda et al., 2014). In addition, late finishes often end after one's habitual bedtime and, therefore, also encroach on the biological night (Bostock and Steptoe, 2013; Flynn-Evans et al., 2018; Gander and Graeber, 1987). Late bedtimes can also lead to truncated sleep if there is not a sufficient opportunity to sleep-in the next day due to schedules, domestic responsibilities, or waking at habitual times in line with circadian pressures, ultimately leading to less sleep before subsequent duties (Flynn-Evans et al., 2018; Gander and Graeber, 1987). While overnight flights typically allow for a nap before the shift, late finishes often start in the early to mid afternoon, which allows less time to take a nap. Consequently, napping is significantly less common for late finishes compared to overnight duties (Sallinen et al., 2021; Sallinen et al., 2017).

Consecutive days of work

The influence of work schedules interfering with sleep can be exacerbated when combined in a block of consecutive days of work (i.e., a trip), especially if the daily flight duty periods vary between early and late flights or if the layover location alternates across multiple time zones in opposite directions. Sleep loss accumulates across consecutive duty days (Gander et al., 1998b), especially across early starts (Åkerstedt et al., 2021; Spencer and Robertson, 2002), late finishes (Flynn-Evans et al., 2018), and overnight duties (Gander et al., 1998a). One might expect that sleep between consecutive overnight flights should improve day to day due to adaptation to the daytime sleep schedule. In reality, however, only partial adaptation typically occurs, with an average circadian phase shift of 1-3 hours across several days of work (Gander et al., 1998a; Flynn-Evans et al., 2018). Furthermore, the magnitude and direction of the phase shifts varies between individuals, suggesting additional countermeasures or strategies may be needed to achieve complete circadian adaptation (Flynn-Evans et al., 2018).

On-call schedules

Other scheduling factors beyond duty timing can also contribute to sleep deficiency. For example, the predictability of schedules can be particularly problematic in short-haul operations, especially in the business (sometimes referred to as corporate or executive) aviation industry. Pilots in this industry are often on-call for varying blocks of time and do not know whether or when they will be scheduled to report for duty (Wollmuth, 2017). Not knowing if or when a duty will start makes it very difficult to plan sleep ahead of time. Similarly, the apprehension of being on-call, or having to wake for an early start, can lead to poor quality sleep (Avers et al., 2009; Kecklund et al., 1997; Sprajcer et al., 2018).

Jet lag and layovers

Jet lag is a common malady associated with trans-meridian travel. The circadian misalignment that occurs when one travels to a different time zone causes sleep disruption that can persist for many days, depending on the number of time zones crossed and timing of light exposure relative to one’s circadian phase. Both short- and long-haul pilots and flight attendants experience jet lag and sleep away from home during layovers, but there are few data examining the impact of jet lag on pilots flying short-haul operations over a few time zones. On average, the circadian rhythm shifts slightly over an hour per day after an eastward flight and a little faster after a westward flight (Aschoff et al., 1975; Takahashi et al., 1999). However, pilots and flight attendants rarely experience more than a few days of layover between flights, leaving insufficient time for adaptation, even in short-haul operations.

Although the human phase response curve to light is well characterized in carefully controlled laboratory studies (Minors et al., 1991), erratic light exposure and sleep patterns (Sallinen et al., 2017), inter-individual differences in response to light (Stone et al., 2020), and use of countermeasures like caffeine (Burke et al., 2015) by pilots and flight attendants makes it difficult to predict how phase shifts may occur in practice. For example, long-haul flights can involve north/south directionality over the poles, leading to constant light or constant dark exposure during a flight. Similarly, depending on the timing of the flight and direction of travel, pilots may even see two sunsets in one flight. In studies examining flights lasting eight hours or more, participants adjusted in the expected direction of shift, shifted in the opposite direction, or did not shift at all (Arendt et al., 1987; Gundel and Spencer, 1999; Klein et al., 1977; Takahashi et al., 2001).

These findings highlight the challenges that crews face in trying to determine when to sleep during a layover.

Pilots employ a variety of strategies to achieve sufficient sleep on layovers. Factors such as the arrival and departure time at the layover location influence when pilots will sleep and how much sleep they will achieve. Some regulations allow for short layover periods between flights. While some studies have found that short layovers can be optimized to allow for sufficient sleep (Powell et al., 2010), any source of sleep disruption could result in insufficient sleep during a short layover (Lamond et al., 2006). The timing of when a flight arrives in a destination relative to a crewmember's circadian phase and the local night can also influence how much sleep one can achieve. For example, one study found that layover sleep duration was greatest on layovers ending between 12:00-03:59 pm home base time (Cosgrave et al., 2018), which is not surprising as it allows for a full physiological night's sleep opportunity prior to the return flight. On layovers, pilots tend to use one of two sleep strategies for their main sleep period: try to remain on their home base nighttime or shift to sleeping during the local night (Zaslona et al., 2018), even though the latter is associated with less total sleep due to circadian misalignment (i.e., the pilot or flight attendant's circadian phase is not aligned with the local night). Interestingly, pilots and flight attendants tend to sleep on local time even when they have been asked to sleep during their home base nighttime (Holmes et al., 2012; Lowden and Akerstedt, 1998; Lowden and Akerstedt, 1999), suggesting social timing of events influences when pilots will choose to sleep on a layover (Kandelaars et al., 2006). Some evidence suggests that pilots use strategic napping on layovers (Holmes et al., 2012), particularly after eastbound flights (Lowden and Akerstedt, 1999), which may mitigate some of the sleep deficiency that occurs from sleeping in a circadian misaligned state.

Sleep duration and quality is also influenced by the sleep environment, which can vary considerably during both short- and long-haul operations. Sleep away from home is often shorter and of poorer quality relative to home sleep (Avers et al., 2009; Chidester, 1990; Gander et al., 1998b), with reports of noise at layover hotels as a common complaint (Avers et al., 2009; Houston et al., 2012). Pilots and flight attendants report spending over one-third of each month away from home (Avers et al., 2009; Wollmuth, 2017), highlighting the potential chronic sleep debt in these populations.

Pilots and flight attendants typically return to sleeping during the local night when they return home from trans-meridian travel, although there is some evidence to suggest that partial phase shifting occurs during trips requiring adjustment upon the return home (Lamp et al., 2019; van den Berg et al., 2015). Sleep timing and duration typically returns to baseline timing within one or two days even after trips involving many time zone crossings (Lamp et al., 2019; van den Berg et al., 2015).

In-flight sleep

As modern aircraft increase the capability of flying longer and farther, flights can last 18 hours or more. As a result, longer flights require larger crews of pilots and flight attendants in order to allow rotating rest breaks during a flight. For example, when one crew is flying the aircraft, the other crew are able to take a rest break. Longer flights allow crews to take longer rest breaks, and for each additional hour of flight time, pilots' in-flight sleep has been shown to increase by ~12 minutes (Gander et al., 2013). Rest facilities vary and the type of rest facility available to pilots and flight attendants varies by flight duration according to regulations established in the country where the flight originated. Ultra-long-haul flights typically require that rest opportunities occur in a bunk or other surface that allows for a lie-flat sleep position separated from the flight deck and the passenger cabin, with temperature, sound, and lighting control. Shorter long-haul flights may only require that a rest opportunity occur on a surface that is flat or near flat and separated from the passenger cabin by a curtain to provide some protection from noise and light pollution. Some flights only require that pilots have access to a seat in the passenger cabin or flight deck that reclines at a minimum by 40 degrees with leg and foot support (Federal Aviation Administration, 14 CFR Part 117.3 – rest facilities; Simons and Spencer, 2007).

The quality of sleep that a crewmember obtains varies by rest facility and by the degree of seat recline (Simons and Spencer, 2007; Roach et al., 2018), but studies demonstrate that it can be difficult to sleep on an aircraft even in the best quality sleep environment. In-flight sleep is less efficient and lighter, with more fragmentation compared to sleep in a hotel or at home (Marqueze et al., 2017; Petrilli et al., 2006; Signal et al., 2013). This can be due to turbulence and/or the design and location of the rest facility. Pilots have noted that too much noise from the galley and flight deck and the sleeping surface being uncomfortable play major roles in reduced sleep duration and quality (Gregory et al., 2021). Practicing good sleep hygiene through use of ear plugs and eye masks has been shown to minimize in-flight sleep disruption (Zaslona et al., 2018). Despite the drawbacks, in-flight sleep has clear recuperative benefits and is considered the most effective in-flight fatigue countermeasure (Signal et al., 2005; Signal et al., 2013).

Although pilots are required to have access to some sort of rest facility on long-haul flights, many factors may prevent a pilot from achieving adequate sleep to suppress sleepiness. On short-haul flights, pilots do not typically have an opportunity to take a scheduled rest break. Another in-flight sleep opportunity that is legal in many countries, although not in the US except for in military operations, is controlled rest on the flight deck. Controlled rest is a practice that allows a pilot to take a short nap in his/her seat on the flight deck when unexpected fatigue or sleepiness arises that the pilot feels is adversely impacting alertness (Fatigue Countermeasures Working Group, 2018). Controlled rest allows for sleep to be achieved (Rosekind et al., 1994; Hilditch et al., 2020) and improves alertness and performance post-nap (Rosekind et al., 1994). Although controlled rest is a useful tool to help pilots relieve sleep pressure, it is only possible for pilots to take a nap on the flight deck when it is safe to do so. Proper use of controlled rest includes, but is not limited to, ensuring the pilot communicates with the rest of the crew about his/her intent to take a nap, only using controlled rest as a real-time fatigue countermeasure and not as a scheduled event, and ensuring the nap is kept fairly short with a “buffer zone” between waking and operating the aircraft. The buffer zone is used to allow for the dissipation of sleep inertia effects, which is the sensation of grogginess and reduced alertness upon waking that impacts cognition (Hilditch and McHill, 2019).

Sleep disorders

Professional pilots are required to be in good health and must undergo regular medical examinations with a designated medical examiner (DME) in order to maintain their certification. The medical requirements for pilots vary by country and by the type of aircraft that a pilot operates. While a review of sleep disorders screening by country is outside the scope of this article, the International Civil Aviation Organization (ICAO) provides guidance on what factors should be addressed during an air medical examination (ICAO, 2012). A number of sleep disorders are identified as potential causes of hypersomnolence, but only insomnia and sleep apnea have specific recommendations associated with their assessment and treatment. ICAO identifies that the risk of insomnia should be discussed and treated. Notably, long-term use of hypnotics is recommended to be disqualifying for pilots. However, if short-acting hypnotics are prescribed for transient insomnia, ICAO recommends that no flying activities occur from 8-12 hours after ingestion. ICAO also recommends that the DME review risk factors for sleep apnea, including history of snoring and excessive sleepiness, body mass index (BMI), and neck circumference, followed by administration of the Epworth Sleepiness Scale (ESS) if a pilot is positive for any risk factors. Those who score ≥ 10 on the ESS should be considered unfit for duty and referred to a sleep clinic for further screening. Once treatment (e.g., continuous positive airway pressure therapy, CPAP) is initiated, a pilot may return to work.

There is little research quantifying the prevalence of sleep disorders among pilots and flight attendants. Emerging evidence suggests that sleep apnea may be more prevalent among pilots than previously thought, although there appears to be a discrepancy between self-report and objective sleep assessment. Sleep apnea screening suggests that between 5% and 30% of pilots are at risk of sleep apnea (Alhejaili et al., 2021; Aljurf et al., 2018; Arora and Al-Houqani, 2021; Kim and Choi, 2021). However, in the three studies that have used polysomnography to assess obstructive sleep apnea (OSA) among pilots, one found that 26% of pilots screened positive for sleep apnea, while two others found that ~70% of the pilots evaluated had moderate to severe OSA. The disconnect between self-report and objective screening was particularly evident in one study that found that 69% of pilots screened positive for moderate to severe OSA, despite only 5% screening positive via questionnaire (Alhejaili et al., 2021). Collectively, these findings suggest that not all pilots recognize symptoms of sleep apnea or perhaps that they are not motivated to report symptoms of sleep disorders out of concern for their employment. It is also possible that the experience of flying in a pressurized environment may influence breathing during sleep as one study found that ~71% of pilots had moderate to severe OSA (apnea-hypopnea index, AHI ≥ 15) as assessed during a daytime sleep following an overnight flight (Han et al., 2021). Further research on the prevalence of sleep disorders among pilots and flight attendants is necessary to determine whether these occupations may be at greater risk relative to the general population.

Sleep issues in spaceflight

The spaceflight environment poses unique challenges that inhibit an individual's ability to obtain sleep of sufficient quality and quantity. Studies of sleep in space have demonstrated that individuals experience a transient insomnia, leading to less sleep in space relative to on Earth. The incidence of other sleep disorders during spaceflight is uncommon, although some studies have suggested that sleep architecture may be altered in space relative to on Earth. Living in microgravity or a partial gravity environment may have a direct influence on sleep outcomes, but there are also challenges to obtaining quality sleep that are consistent with terrestrial sleep disruptors. Each spaceflight mission and vehicle poses unique challenges, in most cases the sleep environment in space is sub-optimal, including noise pollution, temperature fluctuations, and irregular light-dark cycles. Circadian misalignment, which leads to further sleep disruption, is also common due to poor schedule design, high workload, and inappropriate timing of light. Numerous countermeasures have been developed to mitigate these issues, including use of hypnotics, scheduling adjustments, targeted lighting, and better-quality sleep quarters.

The astronauts and cosmonauts who have been to space thus far have typically been exceptionally healthy and free from medical conditions. There have been relatively few studies examining sleep during spaceflight. The studies that have been conducted have used a variety of measures to assess sleep quality and quantity, including polysomnography (PSG), actigraphy, and sleep logs. Although there are small differences between the data collection tools, collectively, these studies demonstrate that astronauts obtain significantly less sleep in space, averaging around six hours per night, compared to on Earth (Barger et al., 2014; Dijk et al., 2001; Frost et al., 1976; Gundel et al., 1993; Gundel et al., 1997; Monk et al., 1998; Santy et al., 1988; Stoilova et al., 2000). Although many spaceflight missions have involved high workload, the majority of missions and studies have afforded individuals at least eight hours of sleep opportunity per night, suggesting that the insomnia observed during spaceflight is not simply a function of overscheduling. Indeed, studies have shown that the duration of time awake increases in space relative to on Earth, via increased sleep latency, increased wake after sleep onset (WASO), or premature waking (Barger et al., 2014; Gundel et al., 1997; Maulsby, 1966; Monk et al., 1998; Stoilova et al., 2000). It appears that this sleep loss is consequential, as intrusions of local sleep-like events during waking increase during spaceflight, suggesting astronauts and cosmonauts experience elevated sleep pressure during wake episodes while in space (Petit et al., 2019).

Although the prevalence of insomnia is higher in space relative to on Earth, the studies that have utilized polysomnography during spaceflight have not identified any evidence of other sleep disorders appearing during spaceflight. Notably, one study found that the rate of sub-clinical apneas and arousals due to breathing events were *reduced* in space compared to on Earth, potentially due to lack of gravitational influence on the airway (Elliott et al., 2001). However, a different analysis of individuals in the same study showed that the microgravity environment alters the mechanical contribution to tidal breathing, with increased abdominal leading during REM sleep (Sá et al., 2009), confirming findings of an earlier study that found increased diaphragmatic electromyogram (EMG) activity during REM sleep in space (Takasaki et al., 1993). Together, these findings suggest that microgravity reduces upper airway resistance, but that breathing effort becomes less efficient, leading to a compensatory response in the absence of gravity. As the majority of individuals who have traveled to space thus far have been medically screened for good health, it remains unclear how the spaceflight environment might alter the incidence of sleep disorders in the general population.

Despite the low incidence of sleep disorders other than insomnia, some studies suggest that microgravity exposure alters brain activity during sleep. One study examining the microarchitecture of sleep in space found that fast spindle density and slow spindle frequency increased, while slow wave amplitude decreased compared to sleep on Earth

(Koller et al., 2021). The results of studies examining sleep stage differences in space compared to on Earth have been mixed, with one study showing increased REM sleep during spaceflight (Frost et al., 1976), two showing increased slow wave sleep (SWS) (Frost et al., 1976; Monk et al., 1998), three demonstrating a redistribution of REM and/or SWS (Dijk et al., 2001; Gundel et al., 1993; Gundel et al., 1997; Stoilova et al., 2000), and two showing decreased SWS (Dijk et al., 2001; Monk et al., 1998). Another study found that the frequency of eye movements dramatically increased during REM for the first sleep episode in space but returned to the Earth-based baseline during the second sleep episode. The disparity in these studies makes it difficult to interpret the potential for functional consequences of altered sleep architecture. Each of these assessments were case studies or only included a few participants and were conducted under different environmental conditions and schedules. Hence, more research is needed to understand how the spaceflight environment may impact sleep architecture and subsequent consequences.

There are several potential causes of altered sleep architecture and short sleep duration in space that are unrelated to the specific conditions of spaceflight. The sleep environment has varied dramatically by mission and in many cases has been quite poor. For example, during Gemini missions, where two astronauts orbited the Earth in a small capsule, crewmembers slept in their seats in alternating shifts. As a result, there was significant light and noise disruption as one astronaut communicated with mission control while the other attempted to sleep (Maulsby, 1966). Similarly, during the Apollo 11 moon landing, the lunar crew did not have any sleep accommodation and reported achieving fragmented sleeping on the floor of the lunar lander and being disrupted by light, noise, temperature, and lunar dust (Apollo 11 Mission Report, 1969). Subsequently, all missions have included sleep accommodations in some form, but in small space vehicles such as Apollo and Space Shuttle, most individuals were required to sleep in the same module in hammocks or sleeping bags attached to the wall. As a result, these astronauts were subject to light and noise pollution and also to disruption from other crewmembers (Imhof et al., 2010). Space station missions, such as Skylab, Mir, and the International Space Station (ISS) have utilized individual sleep compartments for crewmembers, intended to provide a better sleep environment and privacy (Imhof et al., 2010). However, some of these sleep quarters, such as the Russian Kayuta and the Temporary Sleep Station (TeSS) on the ISS were unable to provide an optimal sleep environment due to inadequate size, poor temperature regulation, noise pollution, and sub-optimal ventilation (Flynn-Evans et al., 2016b; Imhof et al., 2010). Although the habitable volume in some space vehicles, such as lunar landers, is not sufficient to accommodate individualized sleep quarters, the parameters necessary for an optimal sleep environment, including lighting, temperature, noise limits, air quality, and comfort have been incorporated into NASA engineering standards to help minimize sleep disruption due to environmental factors (Flynn-Evans et al., 2016b).

Light pollution in the sleep environment is associated with poor sleep hygiene and, during a Gemini mission, resulted in fragmented sleep (Maulsby, 1966). However, inappropriately timed light can also cause circadian misalignment, which leads to further sleep loss (Flynn-Evans et al., 2016a). In low Earth orbit, spacecraft circle the Earth every 90 minutes, which leads to an approximately 45-minute solar day and a 45-minute night. Forced desynchrony studies on Earth have demonstrated that a 90-minute ‘day’ is far too short for human circadian adaptation, resulting in an individual's endogenous circadian rhythm becoming misaligned from the imposed sleep-wake schedule (Wright et al., 2001). Space vehicles typically have interior lighting and window shades to dampen the influence of the orbital light-dark cycle, but some studies have found that astronauts and cosmonauts still experienced a drift in their circadian rhythms relative to the imposed schedule (Flynn-Evans et al., 2016a; Gundel et al., 1993; Gundel et al., 1997; Wright et al., 2001). These findings suggest that in some cases the interior lighting on space vehicles and/or window shades to block sunlight during sleep times has not been sufficient to enable crews to maintain circadian alignment (Dijk et al., 2001).

Circadian misalignment has also been shown to be associated with non-24-hour work schedules during some missions (Dijk et al., 2001; Flynn-Evans et al., 2016a). These issues can begin before a flight because launch timing could occur at any time of day or night. As a result, astronauts and cosmonauts have often been required to shift their sleep out of phase relative to their local time on Earth prior to launch (Santy et al., 1994; Whitson et al., 1995), likely contributing to the short sleep duration that has been observed in the days immediately preceding a space launch (Barger et al., 2014). Similarly, upon arrival in space, mission demands have sometimes required crews to adopt non-24-hour schedules in order to be awake during landing activities (Dijk et al., 2001). Long-duration missions, such as on Mir or the ISS, have typically imposed a 24-hour schedule, but mission activities, such as conducting experiments, preparing for spacewalks and coordinating with visiting vehicles have led to substantial variation in day-to-day sleep scheduling (Flynn-Evans et al., 2016a). These missions have also involved ‘slam shifts’ which have required astronauts and cosmonauts to abruptly shift their sleep timing to accommodate mission activities. Collectively, this type of circadian misalignment accounts for approximately one hour of sleep loss per night during spaceflight (Flynn-Evans et al., 2016a).

Although some of the causes of the short sleep duration observed during spaceflight may relate to poor sleep hygiene, many astronauts use hypnotics during spaceflight.

Survey studies have consistently demonstrated that hypnotic use is widespread, with hypnotics being the most frequent or second most frequent class of medications used by astronauts, and with up to 50% of astronauts using hypnotics during spaceflight (Barger et al., 2014; Putcha et al., 1999; Santy et al., 1988; Wotring, 2015; Wotring and Smith, 2020). Despite the high prevalence, the efficacy of these medications is questionable. One study found that astronauts who took temazepam the night before landing had orthostatic hypotension upon landing (Shi et al., 2003), raising the concern that some medications taken for sleep could compromise an individual's ability to readjust to a gravity environment. Another study demonstrated that the only improvement to sleep outcomes on nights where astronauts took hypnotics was a reduction in sleep onset latency (Flynn-Evans et al., 2016a). It is likely that the perceived benefit that the crewmembers experience in falling asleep faster drives ongoing hypnotic use. Studies examining how the pharmacokinetics and pharmacodynamics of drug action during spaceflight have yet to be completed.

Despite over 50 years of human spaceflight, it is still unclear whether the absence of gravity itself is responsible for sleep disruption. It will be necessary to provide individuals living and working in space with stable schedules and an optimized sleep environment before it will be possible to determine whether the unique aspects of spaceflight influence sleep duration and quality. Several unexplored facets of spaceflight have the potential to influence sleep quantity and quality. Phosphenes (perceived light flashes experienced due to radiation) have been reported during sleep and it is unclear whether these perceived light flashes activate retinal photoreceptors in a manner that could influence sleep or circadian timing (Fuglesang et al., 2006). It is possible that gravity itself influences one's ability to obtain normal sleep, particularly due to the fluid shift that occurs when an individual enters a weightless environment. It is also possible that the elevated radiation exposure experienced during spaceflight may influence sleep. In addition, future missions to Mars will require circadian adaptation to the Martian daylength of 24 hours and 39 minutes (Barger et al., 2012). As commercial space tourism evolves, more data will be needed to understand how individuals with existing sleep disorders may be affected by the experience of spaceflight. Future studies are needed to disentangle potential terrestrial contributors of sleep loss in space to the unique aspects of spaceflight that could influence an individual's ability to obtain adequate sleep in space.

Conclusions

In summary, the sleep issues that individuals encounter in aviation and spaceflight share many common origins, including schedule disruption, circadian misalignment, and inadequate sleep environment. In aviation, sleep issues also arise from frequent trans-meridian travel, irregular schedules, and sleeping away from home. In space, irregular schedules and a sub-optimal sleep environment contribute to sleep deficiency; however, there may be other aspects of the spaceflight environment that influence sleep beyond terrestrial sources of sleep disruption. More research is needed in both of these areas to develop and refine new countermeasures to facilitate adequate sleep.

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