Focus Questions
Article 2: "Crew Schedules, Sleep Deprivation, and Aviation Performance"
By J.A. Caldwell

In order to get full credit for reading each REP article, keep in mind you will need to complete an essay quiz in which you write (1) a brief summary of the article and (2) a paragraph describing how the article applies to the material you are learning in Psych 1100. The following guiding questions will help keep you focused on the most important aspects of the article.

Remember: You do not have to answer all of these questions in your summary and application essays. An understanding of these focus questions will help you synthesize your responses to the essay questions in the essay quiz.

As you read the **Caldwell** article and write your **summary** consider:

- What is the main point of the article?
- Briefly describe the research findings Caldwell reviews. What are some specific effects that fatigue has on pilots?
- Flight duty regulations have focused on limiting the number of hours pilots work. However, Caldwell argues that several other actors are important determinants of fatigue's effect on performance. Identify these factors.
- What are some of the strategies that the article suggests for countering aviation fatigue?

As you read the **Caldwell** article and write your **application** consider:

- What research methods are commonly used to study aviation fatigue?
- What does the research presented in this article reveal about the importance of adequate sleep? In particular, how do disruptions in the circadian rhythm affect people?
- How can the research reviewed in this article be used to address real world problems or create policies?
- What other aspects of this article remind you of topics addressed (or to be addressed) in class? (Tip: you may want to review Chapter 2:The Measure of Mind: Methods of Psychology and Chapter 6: The Aware Mind: Elements of Consciousness.

Please note: References to chapter numbers above are specific to the OSU custom edition of the Cacioppo & Freberg 2e (2015) textbook and may not correspond to the textbook used in the Honors sections of Psychology 1100.

Current Directions in Psychological Science
21(2) 85–89

DOI: 10.1177/0963721411435842
http://cdps.sagepub.com

Crew Schedules, Sleep Deprivation, and Aviation Performance

John A. Caldwell
Fatigue Science, Honolulu, HI

Abstract

Recent events have highlighted the importance of pilot fatigue in aviation operations. Because of demanding flight schedules, crew members often suffer disrupted sleep and desynchronized circadian rhythms, the combination of which threatens alertness and performance. Unfortunately, market requirements for transcontinental and transoceanic routes, as well as for nighttime departures and early-morning arrivals, continue to pose challenges to human vigilance in flight. However, regulatory attention to the physiological causes of fatigue, new techniques for schedule optimization, advanced sleep-monitoring technology, and behavioral strategies to counter fatigue will go a long way toward managing fatigue-related risks in operational contexts.

Keywords

aviation, circadian rhythms, fatigue, sleep deprivation

Effects of Fatigue on Aviation Performance

Pilot fatigue has long been a safety issue (Caldwell & Caldwell, 2003). Flight crews are chronically challenged by schedules that are unpredictable, duty periods that often stretch beyond 10 or 12 hours, work periods that call for nighttime alertness, and layovers in new time zones that place sleep opportunities at inappropriate times. The performance of aviation personnel, like that of industrial shift workers, is chronically threatened by fatigue caused by schedule-driven sleep loss. However, in aviation, the stakes are often higher because they involve multimillion-dollar airframes and the lives of up to 555 passengers.

Recent events have highlighted fatigue-related safety issues in civil aviation. In 2004, Corporate Airlines Flight 5966 crashed on approach to Kirksville Regional Airport after its fatigued pilots, who were on their sixth flight of the day, had been on duty for 14 hours. Because they were tired, these pilots ignored published procedures, failed to respond to alerts that the aircraft was too close to the ground, and crashed into trees after losing awareness of the location of their aircraft with respect to the approaching airport location and its surroundings. In February 2008, the Honolulu-based pilots of Go! airline Flight 1002 overshot their destination by more than 30 miles because they fell asleep on the flight deck during a trip that was only 50 minutes long. In October 2009, a similar event occurred when the pilots of Northwest Airlines Flight 188 remained unresponsive to communications from air traffic control for almost 90 minutes and overflew their destination by 150 miles because they evidently had dozed off at the controls.

Such incidents are not surprising, given that pilot fatigue has been on the U.S. National Transportation Safety Board's (NTSB) Most Wanted List of safety-related priorities since 1990. The Federal Aviation Administration (FAA) sought to update limitations on flight times and duty hours a few times over the past decades, but the 2009 crash of Continental Connection Flight 3407, in which 50 people were killed, rekindled the agency's call to action. Crash investigators determined that before that fateful flight, one of the two pilots had been awake all night, and the other had reported for duty following a lengthy commute and a nonrestorative sleep period. The NTSB concluded that "the pilots' performance was likely impaired because of fatigue" (National Transportation Safety Board, 2010, p. 153), which led the FAA to charter an Aviation Rulemaking Committee (ARC) to update flight regulations for pilots. A primary charge of the ARC was to provide science-based recommendations for new flight-duty regulations; at present, however, the regulations continue to focus more on work-hour limits than on the sleep and circadian factors that are at the root of the problem of pilot fatigue.

Hours-of-Service Rules Versus a Valid Fatigue-Management Approach

Reliance on hours-of-service regulations to mitigate fatigue appears to be a function of convenience rather than science.

Corresponding Author:
John A. Caldwell, Fatigue Science, 700 Bishop St., Suite 2000, Honolulu, HI 96813
E-mail: john.caldwell@fatiguescience.com

Hours on duty are easy to regulate because accurate tracking of on-the-job time is essential for payroll purposes. However, time on duty is far less important than are (a) the timing of these work hours and (b) the number of hours slept prior to work. Research has illuminated the combined importance of the circadian and sleep processes on waking vigilance (Achermann, 2004; Dijk & Franken, 2005). People who work at times during which their bodies are typically asleep and who do not sleep enough to fulfill their daily sleep quota while off duty suffer from elevated sleep pressure and associated drowsiness and cognitive instability (Monk, 1994). Unfortunately, performance under such conditions of sleep deprivation and circadian desynchronization is often worse than performance under conditions of alcohol intoxication (Williamson & Feyer, 2000). Moreover, overly tired people are poor subjective judges of their own impairment.

Operational Impact of Fatigue

In operational contexts, the effects of fatigue pose real problems. It has been clearly established that sleep loss leads to impaired performance and accidents (Williamson et al., 2011). A report from an NTSB study of major accidents in domestic air carriers stated that "crews comprising captains and first officers whose time since awakening was above the median for their crew position made more errors overall, and significantly more procedural and tactical decision errors" (National Transportation Safety Board, 1994, p. 75). A Navy Safety Center study cited fatigue as the second-most problematic factor, after spatial disorientation, in aeromedically related mishaps and hazard reports (Command Flight Surgeon, 2005). Conservative estimates are that fatigue is responsible for 4 to 7 percent of civil aviation mishaps (Lyman & Orlady, 1981), 4 percent of Army aviation accidents, 12 percent of the Navy's most serious aviation mishaps, and almost 8 percent of the Air Force's Class A (most severe) aviation mishaps (Caldwell et al., 2009).

Causal Factors of Fatigue

Fatigue-related risks increase substantially when (a) the waking period is longer than 16 hours, (b) the preduty sleep period is shorter than 6 hours, or (c) the work period occurs during the pilot's usual sleep hours (National Research Council, 2011). In other words, it isn't so much the *time on task* that counts, but rather the time since the pilot last slept, the amount of his or her preduty sleep, and the timing of the duty period in relation to his or her circadian rhythm. The two primary drivers of alertness at any given point in time are *recent sleep* and the *body clock*. If recent sleep is insufficient or the body clock is at a "low point" (as is the case with night work) or desynchronized (as is the case with jet lag), fatigue will be exacerbated (Folkard & Åkerstedt, 1991).

Effects of Fatigue on Aviators

From the standpoint of performance, as fatigue increases, accuracy and timing degrade, lower standards of performance are accepted, the ability to integrate information from individual flight instruments into a meaningful overall pattern declines, and attention narrows (Caldwell & Caldwell, 2003). Important aspects of flight tasks are forgotten or ignored. In addition, fatigued pilots tend to decrease their physical activity, withdraw from social interactions, and lose the ability to effectively time-share mental resources. Severely fatigued pilots may even experience perceptual illusions because of brief, involuntary lapses into sleep. As sleepiness increases, performance becomes less consistent, especially at night, when there is often a fivefold increase in lapses in vigilance (Dinges, 1990). Task-related details are missed and response failures occur because of an increase in unpredictable and involuntary lapses into sleep. Problem solving and reasoning are slower than normal, psychomotor skill is degraded, and the rate of false responding is increased. Overall, fatigue impairs the aviator's ability to pay attention to flight instruments, radio communications, crew coordination, and navigational tasks.

Results From Controlled Aviation Studies

Studies of sleep-deprived military pilots have indicated that pilots' control of even the most basic flight parameters deteriorates significantly after 20 to 24 hours of continuous wakefulness (Caldwell et al., 2009; Previc et al., 2009). This deterioration results in part from the fact that sleepy pilots become less efficient at time-sharing attentional resources. They lose the ability to accurately attend to multiple parameters simultaneously and may therefore be unable to sustain a stable flight path. Furthermore, fatigue-related short-term memory problems may lead pilots to perform the wrong maneuver or forget instructions.

An example from the laboratory

A study of F-117 pilots illustrated the basic fatigue-related decrements in performance that can ultimately lead to significant operational problems (Caldwell, Caldwell, Brown, & Smith, 2004). In this study, control errors (e.g., airspeed and altitude deviations) on precision instrument maneuvers (e.g., straight and level flight, climbs, and descents) sometimes doubled after one night of sleep loss, and changes in performance were accompanied by mood disturbances that could affect the ability of air crews to work effectively as a team while in flight. In addition, the pilots experienced central-nervous-system alterations, which no doubt degraded information-processing capacity and reaction time. Within 24 hours of continuous wakefulness, levels of self-rated depression, confusion, and fatigue increased, and there were substantial elevations in slow-wave EEG activity (of the type usually associated with extreme drowsiness). On a secondary task in between simulator flights, there was a 20 percent lengthening of reaction time, a 100 percent increase in incorrect responses to warning signals, and a 60 percent reduction in basic psychomotor tracking ability.

Individual differences

Decrements in generalized performance and alertness were evident across the sample of pilots, but there also were significant individual differences in fatigue tolerance. Although in a subset of the F-117 pilots discussed above, flight-simulator performance declined by an average of 52% overall, individual impairments ranged from decreases of 135% in one case to only 0.6% in another (Caldwell et al., 2005). The precise reason for this discrepancy remains unclear, but subsequent analyses revealed that it was not due to differences in demographic characteristics, such as age, flight hours, or habitual sleep needs. Unfortunately, at this point, the only way to determine an individual's fatigue resistance is to deprive him or her of sleep under controlled conditions while collecting performance-related data, and this simply is not feasible for the majority of operational contexts. Thus, from a practical perspective, it is important to keep in mind that sleep loss has different effects on different people, that there is no way to predict in advance who will be most or least affected by sleep deprivation, and, because of this, that there is no counter-fatigue strategy that will universally solve everyone's fatigue-related problems in real-world operations.

Recommendations for Countering Fatigue in Aviation

Humans were not designed to operate effectively on the schedules that define today's flight operations. Because of this, aircrew fatigue will never be totally eliminated; however, it can be mitigated with science-based strategies. First-line strategies should focus on schedule optimization; secondary strategies should focus on sleep and fatigue monitoring; and finally, in-flight fatigue-mitigation strategies should be implemented.

Schedule optimization

As noted previously, crew-scheduling practices in aviation continue to focus more on hours-of-service regulations than on the sleep and circadian issues that are truly at the heart of aircrew fatigue. In other words, the full impact of work-shift changes and time-zone changes on sleep quality and quantity (and hence fatigue) is underappreciated. This type of thinking is counter to what science has taught us about the factors that underlie human vigilance, but there are solutions available.

At present, airlines can attempt to optimize duty schedules by using tools that predict the impact of scheduling factors on fatigue risk. Several fatigue-prediction models are available, and these models can help determine the impact of work/rest schedules on aviator performance. In addition, the models can be used to explore scheduling modifications that will mitigate fatigue risks at least to some extent.

One such model—the Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) model (Hursh et al., 2004)—has been instantiated in the Fatigue Avoidance Scheduling Tool (FAST) software. It mathematically simulates the primary physiological processes (sleep and the working of the body clock) that determine one's level of fatigue at any given point in time. The SAFTE model has been validated as the most accurate predictor of sleep restriction on performance (Van Dongen, 2004). In addition, it has been shown to accurately predict the impact of scheduling factors on accident risk (Hursh, Raslear, Kaye, & Fanzone, 2006). Although the accuracy of SAFTE fatigue predictions, as well as those from other available biomathematical models of fatigue and performance, is undermined by individual differences and uncertain preduty conditions (Van Dongen et al., 2007), the model-based optimization of crew schedules represents a step in the right direction toward mitigating operational fatigue risks.

Sleep and fatigue monitoring

One disadvantage of examining duty schedules by themselves is that the sleep expected to be gained by personnel must be estimated rather than actually measured—and, of course, the accuracy of these estimations directly influences the accuracy of fatigue-risk calculations. However, direct, empirical measurements of sleep and sleep/wake timing can be obtained using wrist actigraphs (Morgenthaler et al., 2007; Sadeh & Acebo, 2002) such as the Fatigue Science (Honolulu, HI) ReadiBand (see Fig. 1). The accuracy of ReadiBand sleep/wake classifications was verified in a study of 50 patients undergoing polysomnographic evaluation (Russell et al., 2010); results indicated 92% weighted accuracy of the agreement between ReadiBand actigraphic epoch-by-epoch sleep/wake calculations compared with gold-standard polysomnographic determinations of sleep/wake status. Although actigraphy is not fail-safe because it cannot accurately detect relaxed (movement-free) wakefulness or microsleeps (i.e., lapses into sleep that last for 30 seconds or less), it is far better at tracking bedtimes, wake-up times, and sleep times than are subjective sleep logs. Actigraphically measured sleep histories can provide a solid indication of risk levels for operational fatigue attributable to sleep loss and disrupted sleep/wake cycles.

In fact, actigraphs could be used to establish a conservative fitness-for-duty program even without submitting the recorded recent-sleep-history data to a model analysis. Since it is well known that the average adult needs a minimum of 8 hours of sleep in order to be fully rested (Van Dongen, Maislin, Mullington, & Dinges, 2003), the actigraphy record of pilots reporting to duty could be examined, and pilots shown to have had less than 8 hours of sleep in the preceding 24-hour period could be excluded from upcoming flights (or at least warned about their potential level of impairment).

Fig. 1. A wrist actigraph for sleep and fatigue monitoring.

In-flight fatigue mitigation

Other techniques can be implemented either before or during the duty period to address remaining fatigue issues. Crew members should be educated about proper sleep hygiene so that they can optimize the restorative nature of sleep before duty or during layovers (Caldwell, Caldwell, & Schmidt, 2008). Onboard cockpit napping should be authorized to allow pilots to temporarily compensate for any existing sleep debt and thereby attenuate in-flight lapses in vigilance (Rosekind et al., 1994). The use of short-acting hypnotics for the promotion of quality sleep should be allowed and even encouraged when the preduty or layover sleep period falls outside of the optimal circadian phase. Caffeine gum (which is presently being included in the Army's First Strike Rations) could be used to temporarily sustain in-flight alertness threatened by sleep debt or circadian desynchrony (Committee on Military Nutrition Research, 2001). Controlled in-flight rest breaks (currently not authorized under FAA regulations) should be provided to mitigate cockpit crews' fatigue and boredom (Neri et al., 2002).

Education about scientifically valid fatigue countermeasures, along with regulatory provisions for their use, will augment the fatigue-mitigating benefits of schedule optimization and fatigue tracking. Although there is no single magic bullet, a combination of available approaches will enhance alertness and improve aviation safety.

Conclusions

Sleep and circadian factors are the primary underpinnings of human fatigue, and aviation schedules exert a powerful influence on both. Unfortunately, the regulations designed to manage fatigue in operational environments have not sufficiently emphasized these factors. Thanks to technological advances such as computerized fatigue models and sleep-tracking actigraphy, we are now able to better consider the impact of scheduling factors on aircrews. These advances, when used in combination with behavioral counter-fatigue strategies, can significantly mitigate fatigue and improve operational safety.

Recommended Reading

Balkin, T. J., Rupp, T., Picchioni, D., & Wesensten, N. J. (2008). Sleep loss and sleepiness. *Chest, 124*, 653–660. A comprehensive overview of what is known about the effects of sleep loss on human performance.

Caldwell, J. A., & Caldwell, J. L. (2003). (See References). A comprehensive overview of the problem of fatigue in aviation as well as recommended countermeasures.

Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

References

Achermann, P. (2004). The two-process model of sleep regulation revisited. *Aviation, Space, and Environmental Medicine, 75*(Suppl. 3), A37–A43.

Caldwell, J. A., & Caldwell, J. L. (2003). *Fatigue in aviation: A guide to staying awake at the stick*. Burlington, VT: Ashgate Publishing Company.

Caldwell, J. A., Caldwell, J. L., Brown, D. L., & Smith, J. K. (2004). The effects of 37 hours without sleep on the performance of F-117 pilots. *Military Psychology, 16*, 163–181.

Caldwell, J. A., Caldwell, J. L., & Schmidt, R. M. (2008). Alertness management strategies for operational contexts. *Sleep Medicine Reviews, 12*, 257–273.

Caldwell, J. A., Mallis, M. M., Caldwell, J. L., Paul, M. A., Miller, J. C., & Neri, D. F. (2009). Fatigue countermeasures in aviation. *Aviation, Space, and Environmental Medicine, 80*, 29–59.

Caldwell, J. A., Mu, Q., Smith, J. K., Mishory, A., George, M., Caldwell, J. L., . . . Brown, D. L. (2005). Are individual differences in fatigue vulnerability related to baseline differences in cortical activation? *Behavioral Neuroscience, 119*, 694–707.

Command Flight Surgeon. (2005). *Fatigue in naval aviation*. Retrieved from https://www.netc.navy.mil/nascweb/sas/files/fatigue_in_naval_aviation.pdf

Committee on Military Nutrition Research. (2001). *Caffeine for the sustainment of mental task performance: Formulations for military operations*. Washington, DC: National Academies Press.

Dijk, D. J., & Franken, P. (2005). Interaction of sleep homeostasis and circadian rhythmicity: Dependent or independent systems? In M. A. Kryger, T. Roth, & W. C. Dement (Eds.), *Principles and practice of sleep medicine* (pp. 418–434). Philadelphia, PA: Elsevier Saunders.

Dinges, D. F. (1990). *The nature of subtle fatigue effects in long-haul crews.* Proceedings of the Flight Safety Foundation 43rd International Air Safety Seminar (pp. 258–267). Arlington, TX: Flight Safety Foundation.

Folkard, S., & Åkerstedt, T. (1991). A three-process model of the regulation of alertness and sleepiness. In R. Ogilvie & R. Broughton (Eds.), *Sleep, arousal and performance: Problems and promises* (pp. 11–26). Boston, MA: Birkhauser.

Hursh, S. R., Raslear, T. G., Kaye, A. S., & Fanzone, J. F. (2006). *Validation and calibration of a fatigue assessment tool for railroad work schedules, Summary Report* (Technical Report No. DOT/FRA/ORD-06/21). Washington, DC: U.S. Department of Transportation, Federal Railroad Administration, Office of Research and Development.

Hursh, S. R., Redmond, D. P., Johnson, M. L., Thorne, D. R., Belenky, G., Balkin, T. J., . . . Eddy, D. R. (2004). Fatigue models for applied research in warfighting. *Aviation, Space, and Environmental Medicine, 75*(Suppl. 3), A44–A53.

Lyman, E. G., & Orlady, H. W. (1981). *Fatigue and associated performance decrements in air transport operations* (NASA Contractor Report No. 166167). Moffett Field, CA: NASA Ames Research Center.

Monk, T. (1994). Shiftwork. In M. H. Kryger, T. Roth, & W. C. Dement (Eds.), *Principles and practice of sleep medicine* (pp. 471–476). Philadelphia, PA: Saunders.

Morgenthaler, T., Alessi, C., Friedman, L., Owens, J., Kapur, V., Boehlecke, B., . . . Swick, T. J. (2007). Practice parameters for the use of actigraphy in the assessment of sleep and sleep disorders: An update for 2007. *Sleep, 30*(4), 519–529.

National Research Council. (2011). *The effects of commuting on pilot fatigue*. Washington, DC: National Academies Press. Retrieved from http://www.nap.edu/catalog.php?record_id=13201

National Transportation Safety Board. (1994). *A review of flightcrew-involved, major accidents of U.S. air carriers, 1978 through 1990* (NTSB Safety Study No. SS-94–01). Washington, DC: Author.

National Transportation Safety Board (2010). *Aircraft accident report: Loss of control on approach, Colgan Air, Inc., operating as Continental Connection Flight 3407, Bombardier DHC-8-400, N200WQ*. (NTSB Report number NTSB/AAR-10/01, PB2010-910401). Washington, DC: Author.

Neri, D. F., Oyung, R. L., Colletti, L. M., Mallis, M. M., Tam, P. Y., & Dinges, D. F. (2002). Controlled activity as a fatigue countermeasure on the flight deck. *Aviation, Space, and Environmental Medicine, 73*(7), 654–664.

Previc, F. H., Lopez, N., Ercoline, W. R., Daluz, C. M., Workman, A. J., Evans, R. H., & Dillon, N. A. (2009). The effects of sleep deprivation on flight performance, instrument scanning, and physiological arousal in pilots. *International Journal of Aviation Psychology, 19*, 326–346.

Rosekind, M. R., Graeber, R. C., Dinges, D. F., Connell, L. J., Rountree, M. S., Spinweber, C. L., & Gillen, K. (1994). *Crew factors in flight operations IX. Effects of planned cockpit rest on crew performance and alertness in long-haul operations* (Report No. DOT/FAA/92/24). Moffett Field, CA: NASA Ames Research Center.

Russell, C. A., Caldwell, J. A., Arand, D., Myers, L. J., Wubbels, P., & Downs, H. (2010). *Validation of the Fatigue Science ReadiBand* [White Paper]. Honolulu, HI: Fatigue Science.

Sadeh, A., & Acebo, C. (2002). The role of actigraphy in sleep medicine. *Sleep Medicine Reviews, 6*, 113–124.

Van Dongen, H. (2004). Comparison of mathematical model predictions to experimental data of fatigue and performance. *Aviation, Space, and Environmental Medicine, 75*(Suppl. 3), A15–A36.

Van Dongen, H., Maislin, G., Mullington, J. M., & Dinges, D. F. (2003). The cumulative cost of additional wakefulness: Dose-response effects on neurobehavioral functions and sleep physiology from chronic sleep restriction and total sleep deprivation. *Sleep, 26*, 117–126.

Van Dongen, H. P., Mott, C. G., Huang, J. K., Mollicone, D. J., McKenzie, F. D., & Dinges, D. F. (2007). Optimization of biomathematical model predictions for cognitive performance impairment in individuals: accounting for unknown traits and uncertain states in homeostatic and circadian processes. *Sleep, 30*, 1129–1143.

Williamson, A. M., & Feyer, A. M. (2000). Moderate sleep deprivation produces impairments in cognitive and motor performance equivalent to legally prescribed levels of alcohol intoxication. *Occupational and Environmental Medicine, 57*, 649–655.

Williamson, A. M., Lombardi, D. A., Folkard, S., Stutts, J., Courtney, T. K., & Connor, J. L. (2011). The link between fatigue and safety. *Accident Analysis & Prevention, 43*, 498–515.


STUDYDADDY
Get Homework Help
From Expert Tutor
Get Help