Chapter 46. Fatigue, Sleepiness, and Medical Errors

Ashish K. Jha, MD
University of California, San Francisco School of Medicine
Bradford W. Duncan, MD
Stanford University School of Medicine
David W. Bates, MD, MSc
Harvard Medical School

Introduction

Fatigue may contribute to the human error component of medical errors.[1-3] Hospitals function around the clock, which necessitates shift work for many personnel. Physicians, especially those in training, typically work long hours and are often sleep deprived.[4] Personnel who work during evenings and at night experience disruptions in circadian rhythms, which may aggravate fatigue. Although little research has focused specifically on fatigue in hospital personnel and its relationship to medical error, studies outside the medical field demonstrate the intuitive link between fatigue and degradation in performance and suggest some safety practices that may be adopted in medicine. Although both acute and chronic fatigue may have detrimental effects on the health of medical practitioners,[5-7] this chapter focuses on fatigue's direct effects on patient safety. We review the literature on problem sleepiness among medical personnel, its impact on performance, and interventions to address sleep deprivation: limiting work hours, changes in shift scheduling, napping, and pharmaceutical aids. Although beyond the scope of this chapter, factors that contribute to fatigue beyond sleepiness, such as job stress and work load, should be considered as part of a multifaceted strategy to combat fatigue.

Background

Fatigue and sleepiness may affect patient safety in several ways. Physicians and nurses need good attention, sound judgment, and often quick reaction time, especially in emergency situations. Whether evaluating an electrocardiogram for signs of myocardial ischemia or monitoring a patient during general anesthesia, degradation of attention, memory, or coordination may affect performance and lead to adverse events. Research suggests that sleep requirements and patterns are idiosyncratic, with wide variation across populations. In order to design interventions that will effectively decrease or prevent these events, it is important to understand the signs, prevalence, and impact of sleep deprivation and problem sleepiness.

Sleep Deprivation

Individuals differ in their optimal sleep requirements. Most sleep experts agree that adults typically need between 6 and 10 hours of sleep per 24-hour period, with most people requiring approximately 8 hours of sleep per day.[8,9] When adults get less than 5 hours of sleep over a 24-hour period, peak mental abilities begin to decline.[2] For short periods of time (2-3 days), adult who get 4 hours of sleep can function reasonably well, but below peak levels.[2] However, even with sleep deprivation of just a couple of days, slower response times and decreased initiatives are observed.[10] After one night of missed sleep, cognitive performance may decrease 25% from baseline.[11,12] After the second night of missed sleep, cognitive performance can fall to nearly 40% of baseline.[12]

With ongoing sleep deprivation (getting 2 to 3 hours less sleep than optimal), people develop a *sleep debt*.[2] If the sleep debt continues over 5 to 10 days, they are rarely maximally alert and at some point general performance, and particularly cognitive performance, become verifiably worse. Sleep debt also leads to slower response times, altered mood and motivation, and reduced morale and initiative. A meta-analysis of the effect of sleep deprivation on performance by Pilcher et al found that humans who are chronically sleep deprived function at the 9th percentile of non-sleep-deprived subjects. Further, sleep deprivation affected mood more than it did cognitive function; both were more affected than motor function.[9]

Night-Shifts and Shift Rotation

Shift work usually refers to a schedule in which some employees begin work at times other than the morning. In hospitals, up to 35% of nurses may be required to work at times other than the day shift.[13] A report by the Association of Professional Sleep Societies concluded that night-time operators' fatigue contributed to 4 well known disasters: Exxon Valdez, Bhopal, Chernobyl, and Three Mile Island.[14] Fatigue has also been implicated in aircraft accidents[15] and in poor driving and accidents among truck drivers.[16] It is well documented that shift workers have disturbances in their circadian rhythm, as measured by changes in their melatonin and cortisol levels.[17] Sleep after night work tends to be shorter than sleep after day work, leading to greater cumulative sleep deprivation.[18-20] Shift workers have poorer quality of sleep, marked by less REM sleep, and are less likely to feel refreshed after awaking. Between 60 and 70 percent of shift workers complain of sleeping difficulties or problem sleepiness.[21] Several surveys of shift workers have found that those who work during night shifts are more likely to report sleepiness at work.[18,19,22,23] Alertness on the job is also affected, with employees showing less alertness during nighttime shifts.[24] In addition, shift workers tend to perform less well on reasoning and non-stimulating tasks than non-shift workers.[22,23]

Prevalence and Severity

Fatigue and sleep deprivation are common among medical personnel. Long work-hours are a tradition during residency,[25] with most interns and residents working 80 to 100 hours a week, often 36 hours at a time.[26] During these shifts their sleep is limited, and is usually interrupted.[27] In a 1991 national survey, second-year residents reported an average of 37.6 hours as the largest number of hours without sleep during their first postgraduate year and roughly 25% of the residents reported being on call in the hospital over 80 hours per week.[26] A movement in the late 1980s, prompted partly by the death of a young woman,[28] led to regulations in New York State dictating that residents could work a maximum of 80 hours per week, with a maximum of 24 consecutive hours of patient care, and a minimum of 8 hours off duty between shifts (see also chapter 55).[29] Despite these regulations, unannounced inspections of 12 teaching hospitals in New York State in March 1998 found 37% of all residents worked more than 85 hours per week, 20% of all residents and 60% of surgical residents worked more than 95 hours per week, and 38% of all residents and 67% of all surgical residents worked more than 24 consecutive hours.[30] In 2000, 8% of programs and institutions reviewed by the Accreditation Council for Graduate Medical Education were cited as being in violation of their work-hour requirements.[31] Work-hour violations were noted in general surgery (35%), pediatrics (16%), internal medicine (10%) and other training programs as well.[31]

Long hours and sleep deprivation continue after residency. Health care providers, particularly those still in training or who have recently completed training, occasionally work extra shifts to increase their income ("moonlighting"). One recent survey found that nearly half of all emergency medicine residents moonlight.[32] As many as 65% of internal medicine residents and fellows moonlight[33] and moonlighting is common among other residencies and fellowships.[34, 35] These shifts are often at odd hours, and therefore are disruptive to normal sleep patterns. Among surgical staff, fatigue is common, especially since surgical teams can be involved in long, complicated operative cases that can take 12 to 20 hours at a time.[36,37]

Multiple studies have documented the impact of fatigue on medical personnel performance.[38] However, these studies have been limited by poor study designs or outcomes that may not correlate well with medical error. One study of nursing fatigue suggests that it may play a role in increased error. Gold and colleagues administered a questionnaire to nurses at a large academic hospital and found that nurses who worked a rotating schedule, when compared with nurses who predominantly worked day shifts, were more likely to fall asleep at work and get less sleep over all, and were nearly twice as likely to report committing a medication error.[39]

Using standardized testing, investigators have found that after a night of call, sleep deprived physicians may have worse language and numeric skills,[40] retention of information,[41] short-term memory,[42] and concentration.[43] Performance on standardized tests may not reflect performance in medical situations. Taffinder et al studied the impact of sleep deprivation on surgical residents previously trained on a simulator and found that after a night without sleep, surgeons were slower and more prone to errors on the simulator than those who had a normal night of sleep.[44] Similarly, Denisco et al studied anesthesia residents after a night of sleep deprivation and found that those who had been on call and were sleep deprived scored less well on simulated critical events.[45] Smith-Coggins et al compared cognitive and motor performance of emergency physicians and found that, as the 24-hour study period progressed, physicians were more likely to make errors during a simulated triage test and while intubating a mannequin.[19] However, other studies have failed to find an effect of sleep deprivation on cognitive performance by resident physicians.[46-48] Simulators may not reflect actual medical performance (see chapter 45). Though psychomotor performance seems to be affected by sleep deprivation, data are inconsistent as to fatigue's impact on cognitive function and there are inadequate data assessing its impact on clinical performance.

Few studies have looked at the impact of fatigue in hospital personnel on adverse events. A retrospective study by Haynes et al of 6371 surgical cases, found that the risk of postoperative complications among patients undergoing surgery was not increased when the surgical resident was sleep deprived.[49] These results may not be surprising for several reasons. First, the authors did not measure the residents' error rate, which may have been higher with sleep deprivation. Second, the study did not measure the role attending physicians or other operating room personnel may have played in averting adverse events when residents erred. The supervisory aspect of system design can (and should) reduce both the frequency of individual mistakes (*error prevention*) and the likelihood of adverse events given that errors are inevitable (*error absorption*).[1] Finally, the rate of adverse events, including those that did not result in operative complications ("near misses"), may have been higher but under reported. Well-designed studies that evaluate the effects of fatigue among medical personnel on rates of medical errors or adverse events would be useful. In the meantime, the lack of convincing data linking fatigue with poor patient outcomes should not deter us from tackling the issue of fatigue among medical personnel.

Practice Descriptions

Hours of Service

We reviewed the evidence for 2 potential safety practices concerning hours of service: 8-hour versus 12-hour length shifts and regulations limiting maximum shift length and/or total hours worked. Most observational studies on optimal shift length to reduce fatigue and maximize performance are in non-medical settings and present inconsistent findings. In a study of work-place accidents in Germany, Hanecke et al found accident risk increased exponentially after the 9th hour at work and was highest among workers whose shift began in the evening or night.[50] The authors concluded that shifts that last longer than 8 hours might lead to more worker fatigue and higher risk of accidents. Axelsson and colleagues studied workers at a power plant and found no difference in sleepiness or performance between those who worked 8-hour shifts and those who worked 12-hour shifts.[51] Another group found that switching from 8- to 12-hour shifts led to increased alertness on the job and improved recovery time after night shifts.[52] Overland has proposed that work that requires complex cognitive tasks may be ill suited for longer shifts, whereas work with limited cognitive demands may be well suited for longer shifts.[53] Because the components of work vary dramatically within and across industries, shift durations that maintain performance in one setting may be ineffective in another.

We identified 9 observational studies comparing 8- versus 12-hour shifts for medical personnel. Two studies of nursing care on 10 wards found that quantity[54] and quality[55] of care were significantly lower with 12-hour shifts. Six studies of nurses[56-61] and one of physicians[62] measured outcomes including self-reported alertness, self-reported performance, and/or worker satisfaction. While 2 nurse studies found that self-reported alertness, performance, and satisfaction wane with longer shifts,[56,57] Urgovics and Wright found that ICU nurses reported higher job satisfaction and subjectively improved clinical performance with 12-hour shifts.[60] The 3 remaining studies in nurses found no difference in either satisfaction or self-reported performance between 8- and 12-hour shifts.[58,59,61] A survey of emergency department physicians found that those who worked 12-hour shifts were less likely to be satisfied than those who worked 8-hour shifts.[62] The relationship between these subjective outcomes measures and medical error is not clear.

Hours of service regulations as an effort to reduce errors due to fatigue are standard in some non-medical fields. Truck drivers are typically allowed to work no more than 10 hours at a time and no more than 60 hours in one week. Airline pilots and air traffic controllers work regulated hours and some data suggest waning performance as work-hours increase.[24,63-65] Although most health care personnel are not subject to work-hour standards, many physicians-in-training are, either by statutory regulations or by being in an accredited training program. In a retrospective cohort study, Laine and colleagues found the aforementioned New York State regulations limiting resident work-hours had no effect on patient outcomes such as mortality or transfers to the intensive care unit but were associated with increased rates of medical complications and delays in diagnostic tests.[66] These negative effects may have been related to discontinuity of care and/or fewer physician-hours per patient. As the authors noted, “better care may be provided by a tired physician who is familiar with the patient than by a rested physician who is less familiar with the patient.”[66] In a case-control study, Petersen and colleagues found that when patients were cared for by a physician other than their primary resident, they were 6 times as likely to suffer a preventable adverse event.[67] Thus, fewer physician work hours may lead to more physician discontinuity and potentially, more adverse events and poorer outcomes for patients.

On the other hand, Gottlieb studied changes in a medical service staffing schedule that allowed for reduced sleep deprivation, improved distribution of admissions throughout the week, and improved continuity of inpatient care.[68] After these changes were instituted, patients had shorter lengths of stay, fewer ancillary tests, and fewer medication errors. Although it is difficult to ascribe the improvements to changes in work-hours because several other changes were made as well, it does appear that changes in work-hours can be made without adversely affecting patient outcomes. Any effort to change duty hours for health care personnel in an effort to reduce fatigue should factor in and continuously monitor numerous variables, including the potential costs of discontinuity, medical complications and unnecessary hospital days, to ensure that the measures do not compromise patient care. The costs needed to maintain adequate staffing in face of lost physician work-hours has been estimated to be $360 million in New York State alone.[69] However, the difficult task of estimating other costs and potential savings from implementing these regulations has not been accomplished.

Finally, some authors have expressed concern that restriction of resident physician work-hours may lead to poorer quality training and decreased professionalism among doctors.[70] They argue that restricted working hours will decrease a sense of obligation to patients and will sanction self-interest over the well-being of patients. However, there are no data to substantiate these concerns.

Direction and Speed of Rotation of Shift Work

The direction of s*hift rotation* may impact worker fatigue. For workers who change from one shift to another, a forward rotation of shift work (morning shifts followed by evening shifts followed by night shifts) may lead to less fatigue on the job than backward rotation (day shift to night shift to evening shift).[71-74] Forward rotation appears easier to tolerate physiologically since the natural circadian rhythm tends to move forward and it is more difficult to fall asleep earlier than the normal bedtime. Several studies in non-medical personnel have shown that forward rotation allows for better acclimation of the circadian rhythm.[2,12,75] However, 2 other studies found no significant difference in forward versus backward shift rotation.[76,77] None of these studies measured worker performance or error rates and we found no studies that evaluated direction of shift work rotation among medical personnel.

Another variable in scheduling is the speed of shift work rotation. Studies suggest that slow rotation (eg, changing from one shift to another every one to two weeks) may allow for better adaptation of the circadian rhythm than fast rotation (eg, changing shifts every 2-3 days).[71,73,78,79] Slow shift rotation results in greater sleep length at home, less sleepiness on the job, better self-reported performance, and fewer errors.[74,79] In some cases, fast rotation may increase worker satisfaction[80] but the effects of such satisfaction on safety have not been assessed. Shift rotation at an extremely slow rate approximates fixed, non-rotating shifts (permanent night shifts, permanent day shifts). Permanent shifts are associated with better adaptation to changes in the circadian rhythm[78] and better performance than rotating shifts.[79] However, daytime commitments and social obligations often prevent workers from completely adapting to permanent night shifts and worker satisfaction is poor.[71]

Improving Sleep: Education about Sleep Hygiene

Good sleep hygiene, including the avoidance of alcohol and caffeine before bedtime, and maintaining a healthy sleep environment, may aid in decreasing sleep debt and fatigue. Studies of sleep hygiene have focused on treatment of persons with insomnia or other chronic sleep disorders.[81-83] We found no clinical studies that measure the efficacy of good sleep hygiene among shift workers. Generally, most employers cannot dictate how their workers spend their hours off-duty and compliance with recommendations may be poor. One study of law-enforcement officers working rotating shifts found significant increases in awareness and knowledge after a training session on sleep hygiene practices but no change on a post-sleep inventory assessed at one-month follow-up.[84] The effectiveness of educational programs about sleep hygiene to improve shift worker performance requires further study.

Lighting at Work

The body's regulation of circadian rhythm is mediated by the effects of light and darkness. A 1986 survey found that 7.3 million Americans work at night.[71] These employees, who work during dark hours and sleep during daylight hours, are often chronically sleep deprived and may suffer adverse health effects,[85] partially due to poor synchrony of circadian rhythm to work schedule. Since scheduled light exposure can produce a phase shift in the endogenous circadian rhythm,[71, 86] investigators have studied changes in lighting at work and home to improve adjustment to the shift cycle. Foret et al studied 8 young men in a sleep lab and found exposure to bright lights during the night produced a beneficial effect on subjective alertness.[87] Czeisler and colleagues found that subjects who were exposed to bright light at night and nearly complete darkness during the day had better cognitive performance and subjective alertness, and longer daytime sleep (7.7 vs. 5.7 hours, p=0.01).[88]

Manipulation of light and dark is much easier in sleep labs than in the field,[89] where unintended exposure to bright light is common and may adversely impact attempts to alter workers' circadian rhythm.[90] The National Aeronautics and Space Administration (NASA) has studied the efficacy of bright lights on shuttle astronauts. Their encouraging results suggest that alterations in circadian rhythm can be obtained upon on exposure to light at night.[89,91] The United States Nuclear Regulatory Commission has also implemented bright lighting for its night workers and found less fatigue and better alertness on the job.[92] Field studies are needed to determine how bright artificial light affects objective measures of performance in health care workers and medical error. Bright light may not be appropriate for all areas of the hospital. For example, Bullough and Rea have noted that while bright light might help workers in neonatal care units, it may also be detrimental to patients.[93]

Nonetheless, lighting can be a relatively inexpensive intervention using existing equipment. Keeping lights bright at night, and educating workers about using heavy shades at home may have an important impact on worker performance on night shifts.

Napping

Napping is common among shift workers and is perceived as a way to combat fatigue.[94,95] One study of shift workers in a steel plant found that over half reported napping at home either before or after their shifts.[94] The efficacy of naps has been studied in 3 settings: prior to periods of sleep deprivation (*prophylactic naps*), during periods of sleep deprivation (*therapeutic naps*) and during work hours (*maintenance naps*). Most studies have been conducted in sleep labs in healthy, young, male subjects.

A number of studies in the non-medical literature have studied the efficacy of prophylactic napping. Gillberg and colleagues studied 8 male subjects who were allowed only 4 hours of sleep at night. When subjects took a 30-minute nap in the middle of the prior day, they had better subjective alertness, 20% improvement in vigilance performance, and less overall sleepiness than when they had not been allowed to nap.[96] Others have also found benefits of prophylactic naps on subjective and objective measures of alertness and performance in healthy volunteers undergoing extended periods of sleep deprivation.[97-100] Bonnet and Arand studied prophylactic versus therapeutic naps in 12 healthy young men who underwent 24 hours of sleep deprivation to simulate sleep patterns of medical housestaff.[101] One group of subjects had a 4-

hour prophylactic nap in the evening and caffeine during the 24 hours, while the second group had four, 1-hour naps during the 24-hour work period and no caffeine. Those in the prophylactic nap and caffeine group had a 15% increase in reasoning and overall improved subjective alertness compared with the group that had only short naps. There was no impact on mood. We identified one study of napping by medical personnel. Harma and colleagues studied 146 female hospital nurses and nurses' aides and found that those who napped prior to their night shifts were less likely to report on the job fatigue.[95]

Most studies evaluating the efficacy of therapeutic napping during prolonged periods of sleep deprivation have found beneficial effects when compared with no napping.[102-108] On the other hand, Gillberg and colleagues found no difference in simulated driving between the 2 groups of sleep deprived truck drivers, one group having taken a 30-minute nap during the middle of the previous night.[109]

Maintenance naps are naps that occur on the job, during the shift. These naps could compensate for daytime sleep deprivation or could bridge the nighttime low point in circadian somnolence.[110] Many Japanese industries have provided their employees with the option of on the job napping and nearly half of nighttime shift workers take advantage of this opportunity.[111] Though no systematic studies of the impact of maintenance naps exist in shift workers, one investigation found that short naps in the middle of the night improved performance for the rest of the shift.[98] Napping over several successive shifts has not been studied.[110]

An important consideration in napping is the phenomena of *sleep inertia*, a period of transitory hypo-vigilance, confusion, disorientation of behavior and impaired cognitive performance that immediately follows awakening.[112] Sleep inertia is well documented[112-116] and lasts up to 30 minutes after awakening.[116-118] The duration of deep sleep and the time of the nap, relative to the circadian cycle, seem most related to the severity of sleep inertia.[8] Strategies for napping on the job to reduce fatigue should be designed to avoid possible detrimental effects of sleep inertia. Another potential negative effect of lengthy naps is that they can disrupt the quantity and quality of later sleep periods.[119]

In summary, there is strong evidence that therapeutic naps and maintenance naps combat the effects of fatigue and sleep loss. They can help subjects adapt better to circadian rhythm disturbances and perform better during acute sleep deprivation. Their application in the medical field is not well known. While prophylactic and therapeutic napping result in loss of social time at home, maintenance napping results in loss of work time. Costs associated with naps have not been reported. The financial impact of reduced worker fatigue due to napping has not been evaluated in medicine.

Medical Therapies

Melatonin is the major hormone responsible for circadian rhythm regulation. James et al studied the effect of oral melatonin supplementation on circadian rhythm and adaptation to night shifts among medical personnel.[120] They and others have found no effect among medical shift workers.[121-123] Though melatonin continues to be studied for chronic insomnia and other conditions, there currently is insufficient evidence to recommend its use to combat the fatigue associated with changing workshifts.

Some studies have looked at the potential benefits of benzodiazepines and other sedatives for short-term insomnia associated with shift work, but no data exist on long-term use. Stimulants and caffeine can boost performance acutely but do not address the underlying sleep deprivation,[124] and thus are not a viable long-term solution. Furthermore, concern over side effects, addiction, and performance degradation with current pharmacologic interventions makes their use as a safety practice unlikely.

Comment

Sleep deprivation and disturbances of circadian rhythm lead to fatigue, decreased alertness, and poor performance on standardized testing. Although data from non-medical fields suggest that sleep deprivation leads to poor job performance, this link has not yet been established in medicine. Although the link with fatigue seems intuitive, promoting interventions designed to combat medical errors should be evidence-based. Limits on physician duty hours must account for potentially detrimental effects of discontinuity in patient care. Forward rather than backward shift rotation, education about good sleep hygiene, and strategic napping before or during shifts may reduce fatigue and improve performance. High face validity, low likelihood of harm, and ease of implementation make these promising strategies, although more evidence of their effectiveness in medicine is warranted. Studies on the use of bright light in the medical workplace are needed before it can be embraced.

As Gaba points out,[125] in most high-hazard industries the assumption is that fatigue and long, aberrant work hours lead to poor performance, and the burden of proof is in the hands of those who believe that such work practices are safe. In medicine, concerns over discontinuity of care, and difficulties in changing medical culture have pushed the burden of proof into the hands of those who wish to change the *status quo*. Given that medical personnel, like all human beings, probably function suboptimally when fatigued, efforts to reduce fatigue and sleepiness should be undertaken, and the burden of proof should be in the hands of the advocates of the current system to demonstrate that it is safe.

Finally, fatigue among medical personnel may not be fully remediable and human errors are, in the end, inevitable. The ultimate solution for health care organizations will likely require a systems-based approach that both limits the potential for human error and intercepts errors that do occur before they reach patients.

References

1. Leape LL. Error in medicine. *JAMA.*1994; 272:1851-1857.
2. Krueger GP. Fatigue, Performance, and Medical Error. In: Bogner MS, ed. *Human Error in Medicine*. Hillsdale, N.J.: L. Erlbaum Associates; 1994:311, 326.
3. Kohn LT, Corrigan J, Donaldson MS. *To err is human: building a safer health system*. Washington, DC: National Academy Press; 2000.
4. Lagnado L. Hospitals overwork young doctors in New York. *Wall Street Journal.* May 19, 1998, 1998.
5. Marcus CL, Loughlin GM. Effect of sleep deprivation on driving safety in housestaff. *Sleep.* 1996;19:763-766.
6. Schwartz AJ, Black ER, Goldstein MG, Jozefowicz RF, Emmings FG. Levels and causes of stress among residents. *J Med Educ.* 1987;62:744-753.
7. Small GW. House officer stress syndrome. *Psychosomatics.* 1981;22:860-869.
8. Rosekind MR, Gander PH, Gregory KB, et al. Managing fatigue in operational settings 1: Physiological considerations and counter-measures. *Hosp Top.* 1997;75:23-30.
9. Pilcher JJ, Huffcutt AI. Effects of sleep deprivation on performance: a meta-analysis. *Sleep.* 1996;19:318-326.
10. Koslowsky M, Babkoff H. Meta-analysis of the relationship between total sleep deprivation and performance. *Chronobiol Int.* 1992;9:132-136.

11. Cox T K, GP, ed. *Stress and Sustained Performnace.* 1 ed; 1989. Work and Stress; No. 3.
12. Krueger G, ed. *Sustained work, fatigue, sleep loss and performance: A review of the issues.* 1 ed; 1989. Work and Stress; No. 3.
13. Coffey LC, Skipper JK, Jr., Jung FD. Nurses and shift work: effects on job performance and job-related stress. *J Adv Nurs.* 1988;13:245-254.
14. Mitler MM, Carskadon MA, Czeisler CA, Dement WC, Dinges DF, Graeber RC. Catastrophes, sleep, and public policy: consensus report. *Sleep.* 1988;11:100-109.
15. Rosekind MR, Gregory, K.B., Miller, D.L., Co EL, Lebacqz, J.V. *Aircraft Accident Report: Uncontrolled Collision with Terrain, American International Airways Flight 808, Douglas DC-8, N814CK, U.S. Naval Air Station, Guantanamo Bay, Cuba, August 18,1993*: National Transportation Safety Board; 1994.
16. Wylie CD, Shultz, T., Miller, J.C. *Commercial motor vehicle driver fatigue and alertness study*: Essex Corporation; October 1996.
17. Akerstedt T, Levi L. Circadian rhythms in the secretion of cortisol, adrenaline and noradrenaline. *Eur J Clin Invest.* 1978;8:57-58.
18. Salvendy G. *Handbook of human factors and ergonomics*. 2nd ed. New York: Wiley; 1997.
19. Smith-Coggins R, Rosekind MR, Hurd S, Buccino KR. Relationship of day versus night sleep to physician performance and mood. *Ann Emerg Med.* 1994;24:928-934.
20. Smith-Coggins R, Rosekind MR, Buccino KR, Dinges DF, Moser RP. Rotating shiftwork schedules: can we enhance physician adaptation to night shifts? *Acad Emerg Med.* 1997;4:951-961.
21. Akerstedt T, Torsvall L. Shift work. Shift-dependent well-being and individual differences. *Ergonomics.* 1981;24:265-273.
22. Akerstedt T, Kecklund G, Knutsson A. Manifest sleepiness and the spectral content of the EEG during shift work. *Sleep.* 1991;14:221-225.
23. Akerstedt T. Sleepiness as a consequence of shift work. *Sleep.* 1988;11:17-34.
24. Tucker P, Smith L, Macdonald I, Folkard S. Shift length as a determinant of retrospective on-shift alertness. *Scandinavian Journal of Work, Environment and Health.* 1998;24 Suppl 3:49-54.
25. Green MJ. What (if anything) is wrong with residency overwork? *Ann Intern Med.* 1995;123:512-517.
26. Daugherty SR, Baldwin DC, Jr., Rowley BD. Learning, satisfaction, and mistreatment during medical internship: a national survey of working conditions. *JAMA.* 1998;279:1194-1199.
27. Harvey R, Jarrett PG, Peltekian KM. Patterns of paging medical interns during night calls at two teaching hospitals. *CMAJ.* 1994;151:307-311.
28. Asch DA, Parker RM. The Libby Zion case. One step forward or two steps backward? *N Engl J Med.* 1988;318:771-775.
29. New York State Health Code. *Section 405*; 1989.
30. DeBuono BA, Osten WM. The medical resident workload: the case of New York State. *JAMA.* 1998;280:1882-1883.
31. Education ACfGM. *Percent of programs cited for work hours 1999 and 2000*: Accreditation Council for Graduate Medical Education; 2001 May 9 2001.
32. Li J, Tabor R, Martinez M. Survey of moonlighting practices and work requirements of emergency medicine residents. *Am J Emerg Med.* 2000;18:147-151.
33. McCue JD, Janiszewski M, Stickley WT. Residents' views of the value of moonlighting. *Arch Intern Med.* 1990;150:1511-1513.

34. Majidian AM, Brinker MR, Rice JC, Kerstein MD. Moonlighting in a university surgical training program. *South Med J.* 1993;86:441-446.
35. Hunt KR, Hillman BJ, Witzke DB. Moonlighting during the radiology residency. *Invest Radiol.* 1992;27:978-983.
36. Chalian AA, Kagan SH. Backside first in head and neck surgery?: preventing pressure ulcers in extended length surgeries. *Head Neck.* 2001;23:25-28.
37. Greenberg MS. *Handbook of Neurosurgery.* Vol 4. Lakeland, Florida: Greenberg Graphics, Inc.; 1997.
38. Samkoff JS, Jacques CH. A review of studies concerning effects of sleep deprivation and fatigue on residents' performance. *Acad Med.* 1991;66:687-693.
39. Gold DR, Rogacz S, Bock N, et al. Rotating shift work, sleep, and accidents related to sleepiness in hospital nurses. *Am J Public Health.* 1992; 82:1011-1014.
40. Hawkins MR, Vichick DA, Silsby HD, Kruzich DJ, Butler R. Sleep and nutritional deprivation and performance of house officers. *J Med Educ.* 1985;60:530-535.
41. Hart RP, Buchsbaum DG, Wade JB, Hamer RM, Kwentus JA. Effect of sleep deprivation on first-year residents' response times, memory, and mood. *J Med Educ.* 1987;62:940-942.
42. Rubin R, Orris P, Lau SL, Hryhorczuk DO, Furner S, Letz R. Neurobehavioral effects of the on-call experience in housestaff physicians. *J Occup Med.* 1991;33:13-18.
43. Robbins J, Gottlieb F. Sleep deprivation and cognitive testing in internal medicine house staff. *West J Med.* 1990;152:82-86.
44. Taffinder NJ, McManus IC, Gul Y, Russell RC, Darzi A. Effect of sleep deprivation on surgeons' dexterity on laparoscopy simulator. *Lancet.* 1998;352:1191.
45. Denisco RA, Drummond JN, Gravenstein JS. The effect of fatigue on the performance of a simulated anesthetic monitoring task. *J Clin Monit.* 1987;3:22-24.
46. Reznick RK, Folse JR. Effect of sleep deprivation on the performance of surgical residents. *Am J Surg.* 1987;154:520-525.
47. Deaconson TF, O'Hair DP, Levy MF, Lee MB, Schueneman AL, Codon RE. Sleep deprivation and resident performance. *JAMA.* 1988;260:1721-1727.
48. Weinger MB, Vora, S. Hendon, C.N., Howard, S.K, Smith, B.E., Mazzei, W.J., Rosekind, M.R., Gaba D.M. *Evaluation of the Effects of Fatigue and Sleepiness on Clinical Performance in On-call Anesthesia Residents During Actual Nighttime cases and simulated cases*. Paper presented at: Evaluating Patient Safety and Reducing Errors in Health Care; November 8-10, 1998, 1998; Rancho Mirage, CA.
49. Haynes DF, Schwedler M, Dyslin DC, Rice JC, Kerstein MD. Are postoperative complications related to resident sleep deprivation? *South Med J.* 1995; 88:283-289.
50. Hänecke K, Tiedemann S, Nachreiner F, Grzech-Sukalo H. Accident risk as a function of hour at work and time of day as determined from accident data and exposure models for the German working population. *Scandinavian Journal of Work, Environment and Health.* 1998; 24 Suppl 3:43-48.
51. Axelsson J, Kecklund G, Akerstedt T, Lowden A. Effects of alternating 8- and 12-hour shifts on sleep, sleepiness, physical effort and performance. *Scandinavian Journal of Work, Environment and Health.* 1998; Vol 24 Suppl 3:62-68.
52. Lowden A, Kecklund G, Axelsson J, Akerstedt T. Change from an 8-hour shift to a 12-hour shift, attitudes, sleep, sleepiness and performance. *Scandinavian Journal of Work, Environment and Health.* 1998; 24 Suppl 3:69-75.

53. Overland DW. *Comparison of Effects of Change From 8 to 12 hour shifts on Air Force Aircraft Maintenance Workers*. Alabama: Graduate School of Logistics Acquisition Management, Air Force Institute of Technology; 1997.
54. Reid N, Robinson G, Todd C. The quantity of nursing care on wards working 8- and 12-hour shifts. *Int J Nurs Stud.* 1993;30:403-413.
55. Todd C, Reid N, Robinson G. The quality of nursing care on wards working eight and twelve hour shifts: a repeated measures study using the MONITOR index of quality of care. *Int J Nurs Stud.* 1989;26:359-368.
56. Smith L, Folkard S, Tucker P, Macdonald I. Work shift duration: a review comparing eight hour and 12 hour shift systems. *Occup Environ Med.* 1998;55:217-229.
57. Todd C, Robinson G, Reid N. 12-hour shifts: job satisfaction of nurses. *J Nurs Manag.* 1993;1:215-220.
58. Fields WL, Loveridge C. Critical thinking and fatigue: how do nurses on 8- & 12-hour shifts compare? *Nurs Econ.* 1988;6:189-195.
59. Mills ME, Arnold B, Wood CM. Core-12: a controlled study of the impact of 12-hour scheduling. *Nurs Res.* 1983;32:356-361.
60. Ugrovics A, Wright J. 12-hour shifts: does fatigue undermine ICU nursing judgments? *Nurs Manage.* 1990;21:64A, 64D, 64F-64G.
61. Washburn MS. Fatigue and critical thinking on eight-and twelve-hour shifts. *Nurs Manage.* 1991;22:80A, 80D, 80F-80H.
62. Thomas H, Jr., Schwartz E, Whitehead DC. Eight- versus 12-hour shifts: implications for emergency physicians. *Ann Emerg Med.* 1994;23:1096-1100.
63. Luna TD. Air traffic controller shiftwork: what are the implications for aviation safety? A review. *Aviat Space Environ Med.* 1997;68:69-79.
64. Price WJ, Holley DC. Shiftwork and safety in aviation. *Occup Med.* 1990;5:343-377.
65. Martin TC. Adverse effects of rotating schedules on the circadian rhythms of air medical crews. *Air Med J.* 1995;14:83-86.
66. Laine C, Goldman L, Soukup JR, Hayes JG. The impact of a regulation restricting medical house staff working hours on the quality of patient care. *JAMA.* 1993; 269:374-378.
67. Petersen LA, Brennan TA, O'Neil AC, Cook EF, Lee TH. Does housestaff discontinuity of care increase the risk for preventable adverse events? *Ann Intern Med.* 1994; 121:866-872.
68. Gottlieb DJ, Parenti CM, Peterson CA, Lofgren RP. Effect of a change in house staff work schedule on resource utilization and patient care. *Arch Intern Med.* 1991; 151:2065-2070.
69. Thorpe KE. House staff supervision and working hours. Implications of regulatory change in New York State. *JAMA.* 1990;263:3177-3181.
70. Holzman IR, Barnett SH. The Bell Commission: ethical implications for the training of physicians. *Mt Sinai J Med.* 2000;67:136-139.
71. Czeisler CA, Moore-Ede MC, Coleman RH. Rotating shift work schedules that disrupt sleep are improved by applying circadian principles. *Science.* 1982;217:460-463.
72. Akerstedt T. Shifted sleep hours. *Ann Clin Res.* 1985;17:273-279.
73. Folkard S. Shiftwork and performance. Paper presented at: Symposium on the Variations of Work-Sleep Schedules, 1981.
74. Knauth P. Speed and direction of shift rotation. *J Sleep Res.* 1995; 4:41-46.
75. Comperatore C.A. K, G.P. Circadian rhythm desynchronosis, jet lag, shift lag, and coping strategies. In: A.J. S, ed. *Occupational medicine: Shiftwork. State of the art reviews*. Philadelphia, PA: Hanley & Belfus; 1990:323-341.

76. Tucker P, Smith L, Macdonald I, Folkard S. Effects of direction of rotation in continuous and discontinuous 8 hour shift systems. *Occup Environ Med.* 2000;57:678-684.
77. Barton J, Folkard S, Smith L, Poole CJ. Effects on health of a change from a delaying to an advancing shift system. *Occup Environ Med.* 1994;51:749-755.
78. Knauth P, Rutenfranz J, Schulz H, et al. Experimental shift work studies of permanent night, and rapidly rotating, shift systems. II. Behaviour of various characteristics of sleep. *Int Arch Occup Environ Health.* 1980;46:111-125.
79. Pilcher JJ, Lambert BJ, Huffcutt AI. Differential effects of permanent and rotating shifts on self-report sleep length: a meta-analytic review. *Sleep.* 2000;23:155-163.
80. Williamson AM, Sanderson JW. Changing the speed of shift rotation: a field study. *Ergonomics.* 1986;29:1085-1095.
81. Morin CM, Colecchi C, Stone J, Sood R, Brink D. Behavioral and pharmacological therapies for late-life insomnia: a randomized controlled trial. *JAMA.* 1999;281:991-999.
82. Friedman L, Benson K, Noda A, et al. An actigraphic comparison of sleep restriction and sleep hygiene treatments for insomnia in older adults. *J Geriatr Psychiatry Neurol.* 2000;13:17-27.
83. Vgontzas AN, Kales A. Sleep and its disorders. *Annu Rev Med.* 1999;50:387-400.
84. Holbrook MI, White MH, Hutt MJ. Increasing awareness of sleep hygiene in rotating shift workers: arming law-enforcement officers against impaired performance. *Percept Mot Skills.* 1994;79:520-522.
85. Monk TH, Folkard, S. *Making Shift Work Tolerable*. London: Taylor and Frances; 1992.
86. Budnick LD, Lerman SE, Nicolich MJ. An evaluation of scheduled bright light and darkness on rotating shiftworkers: trial and limitations. *Am J Ind Med.* 1995; 27:771-782.
87. Foret J, Daurat A, Tirilly G. Effect of bright light at night on core temperature, subjective alertness and performance as a function of exposure time. *Scand J Work Environ Health.* 1998; 24:115-120.
88. Czeisler CA, Johnson MP, Duffy JF, Brown EN, Ronda JM, Kronauer RE. Exposure to bright light and darkness to treat physiologic maladaptation to night work. *N Engl J Med.* 1990;322:1253-1259.
89. Eastman CI, Boulos Z, Terman M, Campbell SS, Dijk DJ, Lewy AJ. Light treatment for sleep disorders: consensus report. VI. Shift work. *J Biol Rhythms.* 1995;10:157-164.
90. Chesson AL, Jr., Littner M, Davila D, et al. Practice parameters for the use of light therapy in the treatment of sleep disorders. Standards of Practice Committee, American Academy of Sleep Medicine. *Sleep.* 1999;22:641-660.
91. Putcha L DD, Nimmagudda R, Stewart KT, Kripke DF. Chronobiological measurements in astronauts. *Sleep Research.* 1997;26:746.
92. Baker TL. *Use of a circadian lighting system to improve night shift alertness and performance at the USNRC's Headquarters Operations Center*. Paper presented at: Safety of Operating Nuclear Reactions; September 17-20, 1995, 2001; Seattle, WA.
93. Bullough J, Rea, M.S. Lighting for neonatal intensive care units: some critical information for design. *Lighting Research and Technology.* 1996;28:189-198.
94. Akerstedt T, Torsvall L. Napping in shift work. *Sleep.* 1985;8:105-109.
95. Harma M, Knauth P, Ilmarinen J. Daytime napping and its effects on alertness and short-term memory performance in shiftworkers. *Int Arch Occup Environ Health.* 1989;61:341-345.
96. Gillberg M, Kecklund G, Axelsson J, Akerstedt T. The effects of a short daytime nap after restricted night sleep. *Sleep.* 1996;19:570-575.

97. Nicholson AN, Pascoe PA, Roehrs T, et al. Sustained performance with short evening and morning sleeps. *Aviat Space Environ Med.* 1985;56:105-114.
98. Gillberg M. The effects of two alternative timings of a one-hour nap on early morning performance. *Biol Psychol.* 1984;19:45-54.
99. Dinges DF, Orne MT, Whitehouse WG, Orne EC. Temporal placement of a nap for alertness: contributions of circadian phase and prior wakefulness. *Sleep.* 1987;10:313-329.
100. Taub JM. Effects of scheduled afternoon naps and bedrest on daytime alertness. *Int J Neurosci.* 1982;16:107-127.
101. Bonnet MH, Arand DL. Impact of naps and caffeine on extended nocturnal performance. *Physiol Behav.* 1994;56:103-109.
102. Taub JM, Tanguay PE, Clarkson D. Effects of daytime naps on performance and mood in a college student population. *J Abnorm Psychol.* 1976;85:210-217.
103. Lubin A, Hord DJ, Tracy ML, Johnson LC. Effects of exercise, bedrest and napping on performance decrement during 40 hours. *Psychophysiology.* 1976;13:334-339.
104. Lumley M, Roehrs T, Zorick F, Lamphere J, Roth T. The alerting effects of naps in sleep-deprived subjects. *Psychophysiology.* 1986;23:403-408.
105. Mullaney DJ, Kripke DF, Fleck PA, Johnson LC. Sleep loss and nap effects on sustained continuous performance. *Psychophysiology.* 1983;20:643-651.
106. Matsumoto K. Effects of nighttime naps on body temperature changes, sleep patterns, and self-evaluation of sleep. *J Hum Ergol (Tokyo).* 1981;10:173-184.
107. Naitoh P, Englund CE, Ryman D. Restorative power of naps in designing continuous work schedules. *J Hum Ergol (Tokyo).* 1982;11:259-278.
108. Rosekind MR, Graeber, R. C., Dinges, D. F., Connell, L. J., Rountree, M. S., Spinweber C. L., Gillen, K. A. *Crew Factors in Flight Operations IX: Effects of Planned Cockpit Rest on Crew Performance and Alertness in Long-Haul Operations.* Moffett Field, California: NASA; 1994.
109. Gillberg M, Kecklund G, Akerstedt T. Sleepiness and performance of professional drivers in a truck simulator- -comparisons between day and night driving. *J Sleep Res.* 1996;5:12-15.
110. Rosa RR, Bonnet MH, Bootzin RR, et al. Intervention factors for promoting adjustment to nightwork and shiftwork. *Occup Med.* 1990;5:391-415.
111. Reinberg A, Andlauer P, Vieux N, Permanent Commission and International Association on Occupational Health. Scientific Committee on Shift Work. *Night and shift work : biological and social aspects : proceedings of the Fifth International Symposium on Night and Shift Work : Scientific Committee on Shift Work of the Permanent Commission and International Association on Occupational Health (PCIAOH) Rouen, 12-16 May 1980.* 1st ed. Oxford ; New York: Pergamon Press; 1981.
112. Ferrara M, De Gennaro L. The sleep inertia phenomenon during the sleep-wake transition: theoretical and operational issues. *Aviat Space Environ Med.* 2000;71:843-848.
113. Takahashi M, Arito H, Fukuda H. Nurses' workload associated with 16-h night shifts. II: Effects of a nap taken during the shifts. *Psychiatry Clin Neurosci.* 1999;53:223-225.
114. Ferrara M, De Gennaro L, Bertini M. The effects of slow-wave sleep (SWS) deprivation and time of night on behavioral performance upon awakening. *Physiol Behav.* 1999;68:55-61.
115. Ferrara M, De Gennaro L, Casagrande M, Bertini M. Selective slow-wave sleep deprivation and time-of-night effects on cognitive performance upon awakening. *Psychophysiology.* 2000;37:440-446.

116. Bruck D, Pisani DL. The effects of sleep inertia on decision-making performance. *J Sleep Res.* 1999;8:95-103.
117. Ferrara M, De Gennaro L, Bertini M. Time-course of sleep inertia upon awakening from nighttime sleep with different sleep homeostasis conditions. *Aviat Space Environ Med.* 2000;71:225-229.
118. Jewett ME, Wyatt JK, Ritz-De Cecco A, Khalsa SB, Dijk DJ, Czeisler CA. Time course of sleep inertia dissipation in human performance and alertness. *J Sleep Res.* 1999;8:1-8.
119. Rosekind MR, Smith RM, Miller DL, et al. Alertness management: strategic naps in operational settings. *J Sleep Res.* 1995;4:62-66.
120. James M, Tremea MO, Jones JS, Krohmer JR. Can melatonin improve adaptation to night shift? *Am J Emerg Med.* 1998; 16:367-370.
121. Jorgensen KM, Witting MD. Does exogenous melatonin improve day sleep or night alertness in emergency physicians working night shifts? *Ann Emerg Med.* 1998;31:699-704.
122. Wrenn K, Wright S. Melatonin after night shift work. *Ann Emerg Med.* 1999;33:479.
123. Wright SW, Lawrence LM, Wrenn KD, Haynes ML, Welch LW, Schlack HM. Randomized clinical trial of melatonin after night-shift work: efficacy and neuropsychologic effects. *Ann Emerg Med.* 1998;32:334-340.
124. Walsh JK, Muehlbach MJ, Humm TM, Dickins QS, Sugerman JL, Schweitzer PK. Effect of caffeine on physiological sleep tendency and ability to sustain wakefulness at night. *Psychopharmacology.* 1990;101:271-273.
125. Gaba DM. Physician work hours: *The "sore thumb" of organizational safety in tertiary health care*. Paper presented at: Proceedings of Enhancing Patient Safety and Reducing Errors in Health Care, 1998; Rancho Mirage, CA.