Neurobehavioral, Health, and Safety Consequences Associated With Shift Work in Safety-Sensitive Professions

Laura K. Barger, PhD, Steven W. Lockley, PhD, Shantha M. W. Rajaratnam, PhD, and Christopher P. Landrigan, MD, MPH

Corresponding author
Laura K. Barger, PhD
Division of Sleep Medicine, Brigham and Women's Hospital, 221 Longwood Avenue, BLI 438, Boston, MA 02115, USA.
E-mail: lkbarger@hms.harvard.edu

Current Neurology and Neuroscience Reports 2009, **9**:155–164
Current Medicine Group LLC ISSN 1528-4042

Almost 15% of the full-time workers in the United States are shift workers. We review the physiologic challenges inherent not only in traditional night or rotating shifts but also in extended-duration shifts and other nonstandard hours. The challenging schedules of those in particularly safety-sensitive professions such as police officers, firefighters, and health care providers are highlighted. Recent findings describing the neurobehavioral, health, and safety outcomes associated with shift work also are reviewed. Comprehensive fatigue management programs that include education, screening for common sleep disorders, and appropriate interventions need to be developed to minimize these negative consequences associated with shift work.

Introduction

Although the term *shift worker* typically evokes an image of a manual laborer working overnight in a plant or factory, shift work in fact takes many forms and involves a tremendously diverse workforce in the United States. Broadly, a shift worker is anyone who works extended-duration shifts and other variable and nonstandard hours, including workers who work late into the night or start working very early in the morning. Almost 15% of full-time workers in the United States are shift workers [1] who are employed across a wide variety of industries. About 8 million of these shift workers regularly work during the overnight hours, and about 20 million people are estimated to have unusually early start times [1], including those for whom optimal functioning at all times is critical. These safety-sensitive occupations include police officers, firefighters, other first responders, nurses, physicians, airline pilots, those operating heavy machinery, supervisors in high-risk environments such as nuclear power plants, and military personnel. Working at night or during unusual hours presents specific physiologic challenges to sleep–wake and alertness rhythms and consequently is associated with decrements in workplace performance, health, and safety. (See Folkard and Lombardi [2•] for a review of industrial accident models.)

There are four major physiologic determinants of alertness and performance in healthy subjects: 1) circadian phase (time of day); 2) number of hours awake (acute sleep deprivation); 3) nightly sleep duration (chronic sleep deprivation); 4) and sleep inertia (impaired performance upon waking). Each of these four factors has been independently associated with decrements in neurobehavioral performance and an increased risk of accidents. Shift workers experience all of them to some degree, varying according to occupation (Fig. 1).

Impact of Circadian Phase and Time of Day on Neurobehavioral Performance

In humans, there is a daily 24-hour rhythm of alertness and performance that is driven by an endogenous circadian pacemaker located in the suprachiasmatic nuclei of the hypothalamus. The circadian pacemaker is sensitive to light and drives circadian (~ 24-hour) rhythms of virtually all physiologic and behavioral variables. This pacemaker typically promotes alertness and high performance by day and decrements in alertness and performance at night, when the propensity for sleep is highest. The worst performance decrements are seen several hours before typical wake time (eg, 3:00–6:00 AM) [3] (Fig. 1A). In addition to changes in wake quality, the quality and quantity of sleep varies with circadian phase such that sleep during the day is shorter and less consolidated than sleep during the night [4]. Thus, the circadian clock directly affects a night

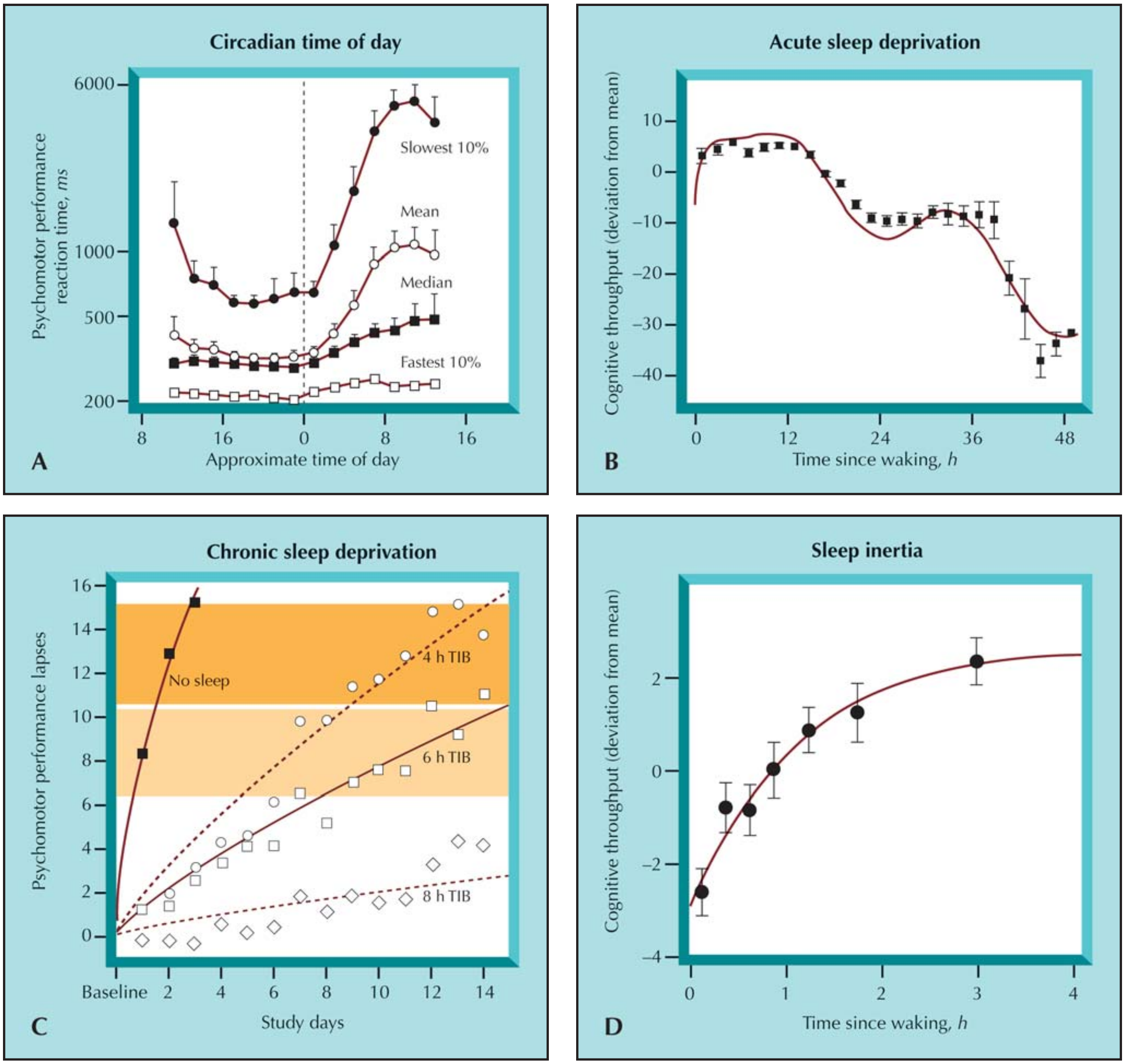

Figure 1. Examples from experimental data sets of the four major physiologic determinants of fatigue. (**A**) The endogenous circadian rhythm in visual psychomotor performance over a 32-hour vigil under constant conditions (n = 10). Performance is poorest toward the end of the biological night but then improves slightly even in subjects remaining continuously awake (although not equivalent to the same clock time 24 hours earlier, because of the prolonged acute sleep deprivation), due to the drive for alertness emanating from the endogenous circadian pacemaker. Although average reaction times may slow to about 1 second, there is more than a 10-fold increase in the slowest 10% of responses, which averages nearly 6 seconds at the circadian nadir before the subject reacts to a visual stimulus. This delay would represent a significant lapse of attention under real-world conditions. (*From* Cajochen et al. [73], with permission.) (**B**) The effects of 48 hours of continuous wakefulness on mean (± SEM) cognitive throughput, as measured by a simple addition test (n = 94). A circadian component can also be observed but, again, cognition declines across all circadian phases with increasing time awake. The line represents a model prediction of cognition under these conditions. (*From* Jewett et al. [74], with permission.) (**C**) A representation of how different amounts of chronic partial sleep deprivation affect psychomotor performance. The figure compares the time course of average daily lapses in attention (based on 2-hourly tests from 7:30 AM to 11:30 PM) over 2 weeks in subjects with an 8-hour (open diamond, n = 9), 6-hour (open square, n = 13), and 4-hour (open circle, n = 13) time-in-bed (TIB) sleep opportunity each day and 88 hours of continuous sleep deprivation (closed square, n = 13). Performance deteriorated in the 6- and 4-hour sleep groups such that after 14 days the participants in the 6-hour sleep group performed at an equivalent level to those kept awake for 24 hours continuously and members of the 4-hour group were performing at the same level as someone kept awake for 3 entire days. (*From* Van Dongen et al. [12], with permission.) (**D**) The time course of sleep inertia in cognitive throughput over the first 4 hours of wakefulness after a normal 8-hour sleep for 3 days. Although there is an exponential improvement in performance over time, it takes at least 2 hours to reach maximal performance and there is a high risk of a fatigue-related error in the first 30 minutes after waking. (*From* Jewett et al. [18], with permission.)

shift worker's ability to remain alert but also indirectly affects him or her by limiting the ability to obtain sleep of sufficient quality and quantity during his or her time off during daytime hours. As a net consequence of these direct and indirect effects, there are more industrial and driving accidents at night than during the day [5] and an elevated rate of single-vehicle truck accidents at night [6].

Acute Sleep Deprivation and Neurobehavioral Performance

Acute sleep deprivation has been systematically documented to cause decrements in human alertness and performance, independent of the circadian system [3]. With increasing time awake, the homeostatic drive for sleep increases, which results in deteriorating performance (Fig. 1B). Operationally, this is illustrated by an increase in the risk of fatigue-related fatal truck crashes with increased hours of driving and being awake [7]. Compared with the first hour, there is more than a 15-fold increase in the risk of a fatigue-related fatal crash after 13 hours of driving. Dawson and Reid [8] equated the impairment of cognitive performance to a blood alcohol concentration of 0.05% after 19 hours of sustained wakefulness and a concentration of about 0.10% after 24 hours [8]. This equivalence in performance degradation also has been demonstrated using other performance criteria [9]. Most interestingly, it has been shown that the risks of driving while sleepy are at least as great as the risks of driving while legally drunk [10].

Chronic Partial Sleep Loss and Performance

The recent history of one's nightly sleep duration also has been demonstrated to affect alertness and performance. Sleep loss on a nightly basis, formally known as chronic partial sleep deprivation, results in a sleep "debt." The consequences of the sleep debt are cumulative and negatively affect health and performance [11]. Van Dongen et al. [12] reported that the frequency of lapses on a vigilance task increased significantly when subjects were restricted to about 5 hours of nightly sleep for 7 nights; the loss of even 2 hours of nightly sleep for 1 week caused decrements in performance comparable to those seen after 24 hours of continuous wakefulness; after 2 weeks, the lapses of attention were comparable to those observed after 48 hours of total sleep deprivation (Fig. 1C) [12]. In a similar study in which Belenky and colleagues [13] restricted subjects to 3, 5, 7, or 9 hours in bed for 1 week, lapses in attention significantly increased in those limited to 3 and 5 hours in bed. Reaction time and vigilance lapses remained at baseline levels in those allowed to spend 9 hours in bed each night [13].

Effects of Sleep Inertia on Neurobehavioral Performance

Alertness and performance are quite impaired immediately following awakening [14], even in subjects who are not sleep deprived and are waking at their normal circadian phase [15]. This grogginess or impairment is called sleep inertia [16] and can substantially impair performance [17]. The effect dissipates over time in an exponential manner but can take 2 to 4 hours to fully dissipate [15,18] (Fig. 1D). Two recent studies used "forced desynchrony" protocols that distributed sleep and wakefulness across all phases of the circadian cycle [19,20]. An endogenous circadian rhythm in sleep inertia was demonstrated both in young [19] and older adults [20], with the poorest performance occurring when wake time occurred during the biological night. In an operational study of Israeli Air Force flight accidents, pilots were more likely to make errors shortly after awakening than later in the day [21].

Shift Work and Health

In addition to shift work's immediate effects on alertness and performance, the circadian desynchrony and sleep deprivation associated with shift work cause significant short- and long-term health problems. Sleep deprivation and working during an adverse circadian phase have been linked with increased risks of obesity [22], gastric and duodenal ulcers [23], cardiovascular disease [23], and cancer [24]. Workers who routinely work extended hours and night shifts are at particularly high risk for suffering health consequences. In fact, the International Agency for Research on Cancer, a part of the World Health Organization, concluded that shift work is probably carcinogenic to humans [25]. Davis and Mirick recently reviewed cancer risk [26•].

Sleep Disorders

Shift workers with clinical sleep disorders are particularly vulnerable to sleepiness given the combination of poor sleep attributable to their disorder coupled with demanding work schedules and sleeping at an adverse circadian phase. Clearly, working frequent overnight shifts or a rotating shift schedule increases the risk of shift-work disorder (SWD) [27], but other sleep disorders may exacerbate sleepiness further. Several demographic variables have been demonstrated to increase the risk of sleep disorders. Increasing age is associated with an increased risk of sleep disorders [28]. There is an extremely high prevalence of obstructive sleep apnea (OSA) in men 30 to 60 years old, with overweight and obesity increasing the risk significantly [28]. In total, chronic sleep disorders affect 60% to 80% of all shift workers [29].

Sleep disorders lead to increased mortality from accidents and cardiovascular disease, decreased quality of life, and decreased workplace productivity. Sleep-related breathing disorders expose individuals to increased daytime sleepiness and a higher risk of accidents. Obstructive sleep apnea syndrome (OSAS), which has a prevalence of 1% to 4% in the general population [28], 4% to 8% in 40- to 59-year-old men [28], and up to 40% in long-distance truck drivers [28], is associated with a sevenfold increased risk of traffic accidents [30]. Successful treatment of OSAS with continuous positive airway pressure therapy has resulted in a significant decrease in driving accident rates [31,32]. One study found that patients with sleep disorders may be responsible for up to 71% of all sleep-related automobile accidents [33]. A decade ago, the annual cost of motor vehicle crashes due to sleepiness was estimated to be $29 billion to $38 billion [29]. Because sleep disorders are often underrecognized but are highly treatable, shift workers should to be screened, evaluated, and treated, if necessary, for common sleep disorders to avoid the excess accident risk.

Sleep Deprivation and Performance in Safety-Sensitive, High-Risk Occupations

It is notable that many of the people who work shifts are individuals upon whom we rely to protect, defend, and heal us. Adverse consequences associated with shift workers in particularly safety-sensitive occupations, such as police officers, firefighters, and health care providers, can have profound effects on the general public.

Police officers

There are about 700,000 full-time police officers in the United States. Many of them work extended shifts and long work weeks, especially in recent years in response to escalating threats to homeland security. There is no standard work schedule for police departments across the United States. A wide array of work schedules are used, including fixed shifts, rotating shifts, and varying shift lengths—most commonly 8-, 10-, and 12-hour shifts. The unpredictable and operational nature of police work results in frequent requirements for overtime, which is often scheduled in a haphazard manner. To earn extra money, many officers supplement their contracted 40-hour work week with additional work, which can include court appearances, detail work, voluntary and mandatory overtime, and second jobs.

Police officers' schedules, especially those involving night or rotating shifts, can lead to misalignment of circadian phase, acute sleep deprivation, chronic partial sleep deprivation, and consequent cumulative sleep debt. Their combined effect creates an imposing biological force that can overpower an officer's ability to remain alert and to maintain a high level of performance, particularly for tasks requiring sustained vigilance such as driving. Moreover, police officers are often expected to make demanding, complicated decisions, often in split seconds, with potentially grave results for individuals, families, and communities [34].

Accident hazards are particularly important for police officers, because more officers are killed annually by accidents than by felonies [35]. In one study, one-third of officers reported being involved in preventable police vehicle crashes on the night shift, and 19% reported being involved in preventable crashes during the early afternoon when going to court after a night shift [36]. The AAA Foundation for Traffic Study found in 1996 that 90% of troopers reported driving on duty while drowsy and 25% reported falling asleep at the wheel [36]. On July 8, 2001, CBS Healthwatch reported four incidents of police officers falling asleep at the wheel in their patrol cars, including one that resulted in a fatality to a civilian. Two of the crashes occurred while the officers were working the night shift, one on the commute home following a night shift, and one while working a double shift. Although hard data on police fatigue have been limited, increasing evidence suggests that fatigue plays an important role in police officer accidents, injuries, and citizen complaints [34].

Recently, Neylan and colleagues reported that police officers had significantly worse sleep quality and less average sleep duration than control subjects and work stress was strongly associated with poor global sleep quality [37]. Additionally, Italian state police shift workers reported sleep disturbances twice as often as non–shift workers [38].

The Harvard Work Hours, Health, and Safety Group recently found a high prevalence of risk for major sleep disorders in a sample of North American police officers [39]. A total of 4471 officers completed a self-report survey that screened for risk of common sleep disorders. Validated screening questionnaires were used for OSA, insomnia, restless legs syndrome, and narcolepsy with cataplexy. SWD screening questions were based on the International Classification of Sleep Disorders-II diagnostic criteria but required participants to show both insomnia and excessive sleepiness that were temporally associated with a recurring work schedule that overlapped the usual sleep time. Nearly two-fifths (38.4%) of the officers were at high risk of having at least one of the sleep disorders: OSA, 35.1%; insomnia, 6.8%; restless legs syndrome, 0.7%; severe SWD (severe), 2.0%; and narcolepsy, 0.5% [39]. In another study of police officer health, all-cause mortality, particularly from malignant tumors, cirrhosis of the liver, and suicide, was significantly higher in Buffalo (New York) police officers than in age, race, and sex-matched controls [40,41].

Firefighters

In fire departments throughout the United States, extended-duration work shifts and long work weeks are common. Shift durations and schedules vary greatly and depend on local needs and preferences. However, 24-hour shifts are an established tradition in firefighting, and 48-hour shifts have become increasingly popular to reduce the number of commutes per week. In some jurisdictions, up to 96 hours of total weekly work are allowed. Similar to police officers, many firefighters supplement their standard contract of employment with additional paid work.

The detrimental effects of each of the four physiologic determinants of alertness are exacerbated by the extended shifts worked by firefighters. Consequently, their performance is likely to be significantly degraded when working extended shifts. First, firefighters regularly work during the biological night when the endogenous drive for alertness is lowest. Second, because 24- and 48-hour shifts are common, long continuous episodes of wakefulness that induce fatigue inevitably result. Although federal regulations strictly limit the number of consecutive hours that truck drivers can drive and that pilots can fly, firefighters' shift durations are not strictly regulated. Third, firefighters are regularly exposed to chronic partial sleep deprivation because they may repeatedly fail to gain adequate recovery sleep after extended shifts. Finally, firefighters who do manage to sleep when on an overnight shift are often asked to perform emergent actions immediately upon awakening, when sleep inertia is maximal.

The West Metro Fire Protection District in the suburbs of Denver recently conducted a 9-month trial of 48-hour shifts. A review of newly implemented 48-hour shifts reported that firefighters had significantly more injuries in the second day than the first day of the shift (http://westmetrofire.org/docs/2006/ops/west%20metro4896final.doc). Furthermore, the two leading causes of death in firefighters—heart disease and motor vehicle accidents [42]—are closely associated with sleep disorders and fatigue. Sleep apnea, for example, the most common sleep disorder in middle-aged men, increases blood pressure and heart rate due to repeated abrupt awakenings, oxygen desaturation, and increased sympathetic activity during sleep, and it increases the risk of heart attack and stroke. Moreover, the work stress inherent in the work of firefighters may exacerbate sleep disruption and consequently cause sleepiness. Stress, sleep disorders, and shift work may interact with the processes controlling appetite and metabolism, increasing the risk of weight gain, a risk factor for sleep apnea, and leading to long-term increases in the risk of cardiovascular disease and diabetes.

A few studies on the work hours, health, and safety of firefighters have been published (reviewed by Elliott and Kuehl [43•]). Murphy and colleagues [44] conducted an anonymous mail survey of about 700 firefighters and reported that "sleep disturbance" was ranked as one of the top five job stressors [44]. However, the risk of motor vehicle crashes associated with the work hours of firefighters has not been studied systematically on a nationwide scale. Data reported by the National Fire Protection Agency (http://www.nfpa.org) indicate a disproportionately higher rate of injury in the early morning (ie, when propensity for sleep is at its highest), consistent with laboratory studies and studies conducted in other occupations with around-the-clock hours.

Health care providers

Physicians and surgeons not only work particularly long hours during their residency but often throughout their careers as well. We conducted a prospective nationwide survey of 2737 residents in their first postgraduate year (PGY-1) [45]. In the 17,003 monthly surveys, PGY-1 residents reported being in the hospital 70.7 ± 26.0 hours per week and sleeping for only 3.2 ± 4.2 hours of that time. The number of extended-duration work shifts (≥ 24 hours) was 3.9 ± 3.4 per month, and the mean duration of each extended-duration work shift was 32.0 ± 0.7 hours.

The association between work hours and percutaneous injuries, motor vehicle crashes, and medical errors was examined using case-crossover within-subject analyses. Of the 500 reported percutaneous exposures, 298 were due to lacerations from a sharp instrument (such as a scalpel), and 202 were due to a needle stick (hollow bore or suture). By far, the most commonly self-reported contributing factor was fatigue or a lapse in attention. The rate of exposures was twice as high at night than in the day (OR, 2.04; 95% CI, 1.98–2.11), and the rate of events was 60% greater during post-call days (following an extended-duration work shift) versus non–post-call days (OR, 1.61; 95% CI, 1.46–1.78) [46]. The increased risk of self-injury is likely due to decrements in vigilance and motor coordination consistent with windows of circadian vulnerability and acute and chronic sleep loss.

A total of 320 motor vehicle crashes were reported in the survey, 40% of which occurred during the commute from work. The number of crashes and near-miss incidents that occurred following an extended-duration work shift was compared with those following a nonextended shift for each subject. The Mantel-Haenszel OR was 2.3 (95% CI, 1.6–3.3) for a crash on the commute following an extended shift and 5.9 (95% CI, 5.4–6.3) for a near-miss incident. Based on prospective reports of scheduled extended-duration work shifts, Poisson regression analysis revealed an 8.8% (95% CI, 3.2%–14.4%) increased monthly risk of any motor vehicle crash and a 16% (95% CI, 7.6%,–24.4%) increased risk of a motor vehicle crash on the commute from work for each extended-duration shift worked per month. Further, the risk of nodding off or falling asleep while driving or while stopped in traffic significantly increased with the number of extended-duration shifts worked per month [45].

In the same survey respondents, the odds of making self-reported medical errors due to fatigue, and associated adverse events and fatalities, increased as the number of extended-duration shifts worked per month increased [47]. Medical errors made for reasons other than fatigue were not strongly associated with the number of shifts worked per month (Table 1).

Many additional studies of health care workers have corroborated these results. Arnedt et al. [48] reported that pediatric residents working a traditional schedule with shifts of at least 24 hours every four or five nights impaired residents' neurobehavioral and driving performance to the same degree as a blood alcohol level of 0.04% or 0.05% even though the residents obtained an average of 3 hours of sleep while working overnight shifts in the hospital [48]. In a meta-analysis that brought together the results of 60 studies of sleep deprivation in resident physicians and others, Philibert [49] found that residents' mean performance on clinical tasks after 24 hours of sleep deprivation dropped almost 2 SDs to the seventh percentile of their mean rested performance level.

Table 1. Results of a survey of self-reported medical errors attributable to fatigue*

	0 extended-duration work shifts			1–4 extended-duration work shifts				≥ 5 extended-duration work shifts			
	PM	PM with positive responses	Rate of positive responses/PM	PM	PM with positive responses	Rate of positive response/PM	OR (95% CI)	PM	PM with positive responses	Rate of positive responses/PM	OR (95% CI)
Do you believe sleep deprivation or fatigue caused you to make a significant medical error?	3323	125	0.038	3329	327	0.098	3.50 (3.30–3.71)	7355	1153	0.157	7.49 (7.19–7.79)
Error resulted in an adverse patient outcome	3323	7	0.002	3329	38	0.011	8.71 (3.39–22.4)	7355	118	0.016	6.99 (4.33–11.3)
Error resulted in a fatality	3205	3	0.001	3040	8	0.003	3.20 (0.1–106)	6325	23	0.004	4.11 (1.35–12.5)
Do you believe you made any significant medical errors other than those due to sleep deprivation or fatigue?	3326	213	0.064	3329	264	0.079	1.05 (1.01–1.09)	7345	670	0.091	1.43 (1.39–1.46)
Error resulted in an adverse patient outcome	3326	33	0.01	3329	45	0.014	1.07 (0.89–1.27)	7345	99	0.013	1.05 (0.90–1.22)
Error resulted in a fatality	3145	8	0.003	3109	13	0.004	0.80 (0.41–1.56)	6773	21	0.003	1.26 (0.60–2.65)

*ORs are reported in months with extended-duration work shifts as compared with months without extended-duration work shifts.
PM—person-months.
(*Adapted from* Barger et al. [47].)

As with physician residents, nurses' medical errors and occupational injuries are significantly associated with work hours and overtime hours [50]. Rogers and colleagues [50] found that about one-third of hospital staff nurses reported making at least one medical error and one-third reported at least one near-error; error rates increased significantly with shift lengths exceeding 12 hours. Scott et al. [51] similarly found that reported error rates almost doubled among critical care nurses working more than 12 consecutive hours [51]. Trinkoff and colleagues [52] found needlestick injuries to increase by 55% with more than 13 consecutive work hours.

Intervention Strategies

Fatigue intervention strategies

Even though the effects of shift work on sleep, alertness, performance, and health have been well documented, there have been far fewer systematic assessments of interventions to reduce the adverse effects of sleep deprivation. In the earliest published shift work intervention study in 1982, Czeisler et al. [53] were able to improve work schedule satisfaction, subjective health estimates, personnel turnover, and worker productivity in a group of mining and chemical workers by implementing a work schedule that adhered to circadian principles.

Elimination of extended work hours for medical interns

Initial studies in medical interns have suggested that elimination of extended shifts can improve safety. Reducing intern work shifts from 24 to 30 continuous hours to no more than 16 consecutive scheduled hours has been shown to decrease rates of medical errors [54,55]. In a randomized crossover trial, 20 PGY-1 residents were studied during 3-week rotations while working a traditional on-call schedule and an intervention schedule that limited work hours. The intervention schedule reduced weekly work hours and totally eliminated extended work shifts (≥ 24 hours). Residents slept more on average (7.4 ± 0.9 h/d) while on the intervention schedule than when they worked on the traditional schedule (6.6 ± 0.8 h/d) and exhibited less than half the rate of attentional failures while on duty overnight [54]. As measured by a comprehensive error surveillance methodology that included direct continuous observation, PGY-1 residents made 35.9% more serious medical errors when working the traditional schedule than when they worked the intervention schedule [55]. They made 27.8% more intercepted serious errors and 56.6% more nonintercepted serious errors while on the traditional schedule than on the intervention schedule. Similar scientifically rigorous studies of medical errors need to be conducted to understand the optimal work schedule for all health care professionals—not just residents—across all clinical settings.

Other intervention strategies

Several intervention strategies besides improved schedule design have been proposed to reduce the detrimental effects of shift work. These interventions are primarily concerned with increasing the rate of circadian adaptation to shift schedules, promoting wakefulness during work and sleep during rest times, and alertness monitoring.

Interventions to improve circadian adaptation to shift schedules include the use of appropriately timed bright light [56]. The color of the light is also important; most recently it has been reported that light in the blue part of the spectrum (446–484 nm) is the most potent region of the wavelength for circadian responses [57]. Melatonin can be used to facilitate a shift in the circadian system to align with night shift work [58]. The timing of the light exposure and melatonin ingestion is critical and dependent on the timing of one's endogenous circadian clock. Therefore, these countermeasures are most effective under the advisement of a sleep specialist.

Countermeasures to promote wakefulness include pharmacologic agents, such as caffeine [59,60], and modafinil, the only US Food and Drug Administration–approved treatment for excessive sleepiness in SWD [61]. Changes to sleep schedules, diet, and the work environment also may be beneficial [2•,62]. Scheduled breaks may provide brief improvements in alertness. For instance, pilots given a brief break during flight showed greater objective alertness for 15 minutes after the break [63]. Bright lights have been shown to increase alertness acutely [64].

Sedative hypnotics [65] or melatonin [66] can be used to promote sleep during off times between shifts, especially when sleep must occur outside of the biological night. Napping should be encouraged during extended-duration work shifts [67] provided that enough time is available following the nap to allow for the dissipation of sleep inertia. Moreover, napping prior to night shifts, especially the first in a series of night shifts, is effective in reducing attentional impairment and cognitive slowing during the nighttime working hours [68].

It also may be beneficial to identify and screen out individuals who have greater difficulty adapting to shift work [69] or those who have sleep disorders [70] so that appropriate treatment and countermeasures can be used. Finally, the use of physiologic screening devices to detect fatigue before or during a shift [71,72] may identify workers who are not properly rested.

Conclusions

Shift work, extended-duration shifts, and nonstandard schedules are associated with fatigue and poor performance. Fatigue management programs, work hour reduction, and appropriate countermeasures that take into account the four physiologic determinants of alertness have the potential to improve safety significantly. The further development and dissemination of these programs is most important in safety-sensitive occupational groups such as police officers, firefighters, and health care professionals and has the potential to significantly improve public health.

Acknowledgments

The authors thank the members of the Harvard Work Hours, Health, and Safety Group who contributed to some of the results reviewed herein: Daniel Aeschbach, PhD, Najib T. Ayas, MD, MPH, David E. Bates, MD, Sean Benedix, Elizabeth Burdick, MS, Brian E. Cade, MS, John W. Cronin, MD, Erin E. Evans, RPSGT, Amy Hallal, Joel T. Katz, MD, Rainu Kaushal, MD, MPH, Clark J. Lee, AB, Craig M. Lilly, MD, Marissa Moritz, MS, Conor O'Brien, Salim Qadri, Bernard Rosner, PhD, Jeffrey M. Rothschild, MD, MPH, Frank E. Speizer, MD, and Peter H. Stone, MD.

The work of the Harvard Work Hours, Health, and Safety Group discussed in this article has been supported by grants from the Agency for Healthcare Research and Quality (U18 HS015906; RO1 HS12032), the National Institute for Occupational Safety and Health within the US Centers for Disease Control and Prevention (R01 OH07567; R01 OH008496), Brigham and Women's Hospital, and the National Institute of Justice (2004-FS-BX-001).

Disclosures

Dr. Barger was the recipient of a National Heart, Lung, and Blood Institute (NHLBI) fellowship in the sleep, circadian, and respiratory neurobiology training program at Brigham and Women's Hospital (NHLBI: T32 HL079010).

Dr. Lockley has been paid by a law firm for serving as an expert witness in arbitration hearings related to shift work. He also has been paid for consulting on a government-funded research project at Warwick Medical School in the United Kingdom.

Dr. Rajaratnam has received research grants from Vanda Pharmaceuticals, Takeda Pharmaceuticals, the ResMed Foundation, Philips Lighting, and Respironics; educational grants from Vanda Pharmaceuticals and Takeda Pharmaceuticals; and equipment support from Sleep Diagnostics, Compumedics, and Tyco Healthcare.

Dr. Landrigan is the recipient of an Agency for Healthcare Research and Quality career development award (K08 HS13333).

References and Recommended Reading

Papers of particular interest, published recently, have been highlighted as:

- • Of importance
- •• Of major importance

1. Bureau of Labor Statistics: **Workers on Flexible and Shift Schedules in May 2004.** Available at http://www.bls.gov/news.release/pdf/flex.pdf. Accessed January 22, 2009.
2.• Folkard S, Lombardi DA: **Modeling the impact of the components of long work hours on injuries and "accidents."** *Am J Ind Med* 2006, **49:**953–963.
The risk of accidents and injuries associated with work schedules is pooled from published epidemiologic studies using an additive model, and a "risk index" is calculated. The risk depends on the length of the shift, type of shift (eg, night shift), and the frequency of rest breaks. The estimated risks for various standard work schedules are presented in this article.
3. Dijk DJ, Duffy JF, Czeisler CA: **Circadian and sleep/wake dependent aspects of subjective alertness and cognitive performance.** *J Sleep Res* 1992, **1:**112–117.
4. Dijk DJ, Czeisler CA: **Contribution of the circadian pacemaker and the sleep homeostat to sleep propensity, sleep structure, electroencephalographic slow waves, and sleep spindle activity in humans.** *J Neurosci* 1995, **15:**3526–3538.
5. Folkard S, Tucker P: **Shift work, safety and productivity.** *Occup Med (Lond)* 2003, **53:**95–101.
6. National Highway Traffic Safety Administration: *Traffic Safety Facts 1999: A Compilation of Motor Vehicle Crash Data From the Fatality Analysis Reporting System and the General Estimates System.* Washington, DC: National Center for Statistics and Analysis; US Department of Transportation; 2000.
7. Department of Transportation: **Federal Motor Carrier Safety Administration.** *Fed Reg* 2000, **65**(85)**:**25541–25611.
8. Dawson D, Reid K: **Fatigue, alcohol and performance impairment.** *Nature* 1997, **388:**235.
9. Lamond N, Dawson D: **Quantifying the performance impairment associated with fatigue.** *J Sleep Res* 1999, **8:**255–262.
10. Hack MA, Choi SJ, Vijayapalan P, et al.: **Comparison of the effects of sleep deprivation, alcohol and obstructive sleep apnoea (OSA) on simulated steering performance.** *Respir Med* 2001, **95:**594–601.
11. Balkin T, Rupp T, Picchioni D, Wesensten N: **Sleep loss and sleepiness: current issues.** *Chest* 2008, **134:**653–660.
12. Van Dongen HP, Maislin G, Mullington JM, Dinges DF: **The cumulative cost of additional wakefulness: dose-response effects on neurobehavioral functions and sleep physiology from chronic sleep restriction and total sleep deprivation.** *Sleep* 2003, **26:**117–126.
13. Belenky G, Wesensten NJ, Thorne DR, et al.: **Patterns of performance degradation and restoration during sleep restriction and subsequent recovery: a sleep dose-response study.** *J Sleep Res* 2003, **12:**1–12.
14. Dinges DF: **Are you awake? Cognitive performance and reverie during the hypnopompic state.** In *Sleep and Cognition.* Edited by Bootzin R, Kihlstrom J, Schacter D. Washington DC: American Psychological Association; 1990:159–175.
15. Achermann P, Werth E, Dijk DJ, Borbély AA: **Time course of sleep inertia after nighttime and daytime sleep episodes.** *Arch Ital Biol* 1995, **134:**109–119.
16. Dinges DF: **Sleep inertia.** In *Encyclopedia of Sleep and Dreaming.* Edited by Carskadon MA. New York: Macmillan Publishing; 1993:553–554.
17. Wertz AT, Ronda JM, Czeisler CA, Wright KP Jr.: **Effects of sleep inertia on cognition.** *JAMA* 2006, **295:**163–164.
18. Jewett ME, Wyatt JK, Ritz-De Cecco A, et al.: **Time course of sleep inertia dissipation in human performance and alertness.** *J Sleep Res* 1999, **8:**1–8.
19. Scheer FA, Shea TJ, Hilton MF, Shea SA: **An endogenous circadian rhythm in sleep inertia results in greatest cognitive impairment upon awakening during the biological night.** *J Biol Rhythms* 2008, **23:**353–361.
20. Silva EJ, Duffy JF: **Sleep inertia varies with circadian phase and sleep stage in older adults.** *Behav Neurosci* 2008, **122:**928–935.
21. Ribak J, Ashkenazi IE, Klepfish A, et al.: **Diurnal rhythmicity and air force flight accidents due to pilot error.** *Aviat Space Environ Med* 1983, **54:**1096–1099.
22. Di Lorenzo L, De Pergola G, Zocchetti C, et al.: **Effect of shift work on body mass index: results of a study performed in 319 glucose-tolerant men working in a Southern Italian industry.** *Int J Obes Relat Metab Disord* 2003, **27:**1353–1358.
23. Knutsson A: **Health disorders of shift workers.** *Occup Med (Lond)* 2003, **53:**103–108.
24. Davis S, Mirick DK, Stevens RG: **Night shift work, light at night, and risk of breast cancer.** *J Natl Cancer Inst* 2001, **93:**1557–1562.
25. Straif K, Baan R, Grosse Y, et al.: **Carcinogenicity of shift-work, painting and fire-fighting.** *Lancet Oncol* 2007, **8:**1065–1066.

26.• Davis S, Mirick DK: **Circadian disruption, shift work and the risk of cancer: a summary of the evidence and studies in Seattle.** *Cancer Causes Control* 2006, **17**:539–545.
The disruption of normal circadian rhythmicity may increase the risk of developing cancer. This article reviews several studies that have been conducted in Seattle that investigate the effects of factors (ie, night shift work) that can disrupt circadian rhythm and alter normal nocturnal production of melatonin and reproductive hormones of relevance to breast cancer etiology.
27. Guilleminault C, Czeisler C, Coleman R, Miles L: **Circadian rhythm disturbances and sleep disorders in shift workers.** *Electroencephalogr Clin Neurophysiol Suppl* 1982, **36**:709–714.
28. Bixler EO, Vgontzas AN, Ten Have T, et al.: **Effects of age on sleep apnea in men: I. Prevalence and severity.** *Am J Respir Crit Care Med* 1998, **157**:144–148.
29. Leger D: **The cost of sleep-related accidents: a report for the National Commission on Sleep Disorders Research.** *Sleep* 1994, **17**:84–93.
30. Findley LJ, Unverzagt ME, Suratt PM: **Automobile accidents involving patients with obstructive sleep apnea.** *Am Rev Respir Dis* 1988, **138**:337–340.
31. Sassani A, Findley LJ, Kryger M, et al.: **Reducing motor-vehicle collisions, costs, and fatalities by treating obstructive sleep apnea syndrome.** *Sleep* 2004, **27**:453–458.
32. Krieger J, Meslier N, Lebrun T, et al.: **Accidents in obstructive sleep apnea patients treated with nasal continuous positive airway pressure: a prospective study. The Working Group ANTADIR, Paris and CRESGE, Lille, France. Association Nationale de Traitement a Domicile des Insuffisants Respiratoires.** *Chest* 1997, **112**:1561–1566.
33. Aldrich MS: **Automobile accidents in patients with sleep disorders.** *Sleep* 1989, **12**:487–494.
34. Vila B: **Impact of long work hours on police officers and the communities they serve.** *Am J Ind Med* 2006, **49**:972–980.
35. The National Uniform Crime Reporting (UCR) Program (Federal Bureau of Investigation): **Law Enforcement Officers Killed and Assaulted; 2004.** Available at http://www.fbi.gov/ucr/killed/2004/openpage.htm. Accessed January 29, 2009.
36. Vila B, Kenney DJ: **Tired cops: the prevalance and potential consequences of police fatigue.** *NIJ J* 2002, **248**:16–21.
37. Neylan T, Metzler M, Best S, et al.: **Critical incident exposure and sleep quality in police officers.** *Psychosom Med* 2002, **64**:352.
38. Garbarino S, Nobili L, Beelke M, et al.: **Sleep disorders and daytime sleepiness in state police shiftworkers.** *Arch Environ Health* 2002, **57**:167–173.
39. Rajaratnam SMW, Barger LK, Lockley SW, et al.: **Screening for sleep disorders in North American police officers [abstract].** *Sleep* 2007, **30(Suppl)**:A209.
40. Violanti JM, Vena J, Marshall JR, Petralia S: **A comparative evaluation of police officer suicide rate validity.** *Suicide Life Threat Behav* 1996, **26**:79–85.
41. Violanti JM, Vena J, Petralia S: **Mortality of a police cohort: 1950-1990.** *Am J Ind Med* 1998, **33**:366–373.
42. Centers for Disease Control and Prevention: **Fatalities among volunteer and career firefighters--United States, 1994-2004.** *JAMA* 2006, **295**:2594–2596.
43.• Elliott D, Kuehl K: *Effects of Sleep Deprivation on Fire Fighters and EMS Responders*. Fairfax, VA: International Association of Fire Chiefs (IAFC) and the United States Fire Administration (USFA); 2007.
This is a comprehensive review of firefighters' work hours, sleep, and associated risks.
44. Murphy S, Beaton R, Cain K, Pike K: **Gender differences in fire figher job stressors and symptoms of stress.** *Women Health* 1994, **22**:55–69.
45. Barger LK, Cade BE, Ayas NT, et al.: **Extended work shifts and the risk of motor vehicle crashes among interns.** *N Engl J Med* 2005, **352**:125–134.
46. Ayas NT, Barger LK, Cade BE, et al.: **Extended work duration and the risk of self-reported percutaneous injuries in interns.** *JAMA* 2006, **296**:1055–1062.
47. Barger LK, Ayas NT, Cade BE, et al.: **Impact of extended-duration shifts on medical errors, adverse events, and attentional failures.** *PLoS Med* 2006, **3**:0001–0009.
48. Arnedt JT, Owens J, Crouch M, et al.: **Neurobehavioral performance of residents after heavy night call vs after alcohol ingestion.** *JAMA* 2005, **294**:1025–1033.
49. Philibert I: **Sleep loss and performance in residents and nonphysicians: a meta-analytic examination.** *Sleep* 2005, **28**:1392–1402.
50. Rogers AE, Hwang WT, Scott LD, et al.: **The working hours of hospital staff nurses and patient safety.** *Health Aff (Millwood)* 2004, **23**:202–212.
51. Scott LD, Rogers AE, Hwang WT, Zhang Y: **Effects of critical care nurses' work hours on vigilance and patients' safety.** *Am J Crit Care* 2006, **15**:30–37.
52. Trinkoff AM, Le R, Geiger-Brown J, Lipscomb J: **Work schedule, needle use, and needlestick injuries among registered nurses.** *Infect Control Hosp Epidemiol* 2007, **28**:156–164.
53. Czeisler CA, Moore-Ede MC, Coleman RM: **Rotating shift work schedules that disrupt sleep are improved by applying circadian principles.** *Science* 1982, **217**:460–463.
54. Lockley SW, Cronin JW, Evans EE, et al.: **Effect of reducing interns' weekly work hours on sleep and attentional failures.** *N Engl J Med* 2004, **351**:1829–1837.
55. Landrigan CP, Rothschild JM, Cronin JW, et al.: **Effect of reducing interns' work hours on serious medical errors in intensive care units.** *N Engl J Med* 2004, **351**:1838–1848.
56. Eastman CI, Boulos Z, Terman M, et al.: **Light treatment for sleep disorders: consensus report. VI. Shift work.** *J Biol Rhythms* 1995, **10**:157–164.
57. Hanifin JP, Brainard GC: **Photoreception for circadian, neuroendocrine and neurobehavioral regulation.** *J Physiol Anthropol* 2007, **26**:87–94.
58. Sharkey KM, Eastman CI: **Melatonin phase shifts human circadian rhythms in a placebo-controlled simulated night-work study.** *Am J Physiol Regul Integr Comp Physiol* 2002, **282**:R454–R463.
59. Walsh JK, Muehlbach MJ, Humm TM, et al.: **Effect of caffeine on physiological sleep tendency and ability to sustain wakefulness at night.** *Psychopharmacology (Berl)* 1990, **101**:271–273.
60. Wyatt JK, Cajochen C, Ritz-De Cecco A, et al.: **Low-dose, repeated caffeine administration for circadian-phase-dependent performance degradation during extended wakefulness.** *Sleep* 2004, **27**:374–381.
61. Czeisler CA, Walsh JK, Roth T, et al.: **Modafinil for excessive sleepiness associated with shift work sleep disorder.** *N Engl J Med* 2005, **353**:476–486.
62. Rosa RR, Bonnet MH, Bootzin RR, et al.: **Intervention factors for promoting adjustment to nightwork and shiftwork.** *Occup Med* 1990, **5**:391–415.
63. Neri DF, Mallis MM, Oyung RL, Dinges DF: **Do activity breaks reduce sleepiness in pilots during a night flight.** *Sleep* 1999, **22**:s150.
64. Lockley SW, Evans EE, Scheer FA, et al.: **Short-wavelength sensitivity for the direct effects of light on alertness, vigilance, and the waking electroencephalogram in humans.** *Sleep* 2006, **29**:161–168.
65. Porcu S, Bellatreccia A, Ferrara M, Casagrande M: **Performance, ability to stay awake, and tendency to fall asleep during the night after a diurnal sleep with temazepam or placebo.** *Sleep* 1997, **20**:535–541.
66. Arendt J, Rajaratnam SM: **Melatonin and its agonists: an update.** *Br J Psychiatry* 2008, **193**:267–269.
67. Rosekind MR, Graeber RC, Dinges DF, et al.: **Crew Factors in Flight Operations IX: Effects of Planned Cockpit Rest on Crew Performance and Alertness in Long-Haul Operations [technical memo 108839, 1-64].** Washington, DC: National Aeronautics and Space Administration; 1994.
68. Santhi N, Horowitz TS, Duffy JF, Czeisler CA: **Acute sleep deprivation and circadian misalignment associated with transition onto the first night of work impairs visual selective attention.** *PLos ONE* 2007, **2**:e123.

69. Van Dongen HPA, Baynard MD, Maislin G, Dinges DF: **Systematic interindividual differences in neurobehavioral impairment from sleep loss: evidence of trait-like differential vulnerability.** *Sleep* 2004, **27:**423–433.
70. American Psychiatric Association: *Diagnostic and Statistical Manual of Mental Disorders,* edn 4. Washington, DC: American Psychiatric Association; 2000.
71. Sullivan JJ: **Fighting fatigue.** *Public Roads*. Available at http://www.tfhrc.gov/pubrds/03sep/04.htm. Accessed January 29, 2009.
72. **FIT 2000; Fitness-for-Duty/Impairment Screeners.** Available at http://www.pmifit.com/. Accessed Feburary 5, 2009.
73. Cajochen C, Khalsa SBS, Wyatt JK, et al.: **EEG and ocular correlates of circadian melatonin phase and human performance decrements during sleep loss.** *Am J Physiol* 1999, **277:**R640–R649.
74. Jewett ME, Dijk DJ, Kronauer RE, Czeisler CA: **Sigmoidal decline of homeostatic component in subjective alertness and cognitive throughput.** *Sleep* 1999, **22(Suppl):**S94–S95.