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Summary of the Performance Effects of Sustained Operations

Valerie Gawron

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Abstract

Sustained operations missions are performed in diverse environments. These environments include military command and control, process control, medical practice, and security surveillance. Research on the related fatigue effects of sustained operations is reviewed for each of these diverse environments. For military surge operations, both ground and airborne command and control operators show similar decrements in visual performance as a function of sleep loss. Other decrements include increased number of errors in vigilance tasks and reaction time tasks. In process control experiments, longer shifts resulted in more variance in reaction time to grammatical reasoning tasks. Night shift was associated with slower reaction times. For medicine, many studies compare performance on laboratory tasks across duty days as well as between participants who are rested and those who are not. Decrements occurred in reaction times. In security, both loss of sleep and work at night degrades operator performance.

Keywords: sustained operations, fatigue, security surveillance, military command and control, process control, medical practice

Fatigue can arise from two sources: sleep loss and time on duty. The causes of sleep loss include injury associated with physical fatigue, psychological stress, mental illness, disease, sleep disorders, desynchronosis with circadian and other biological rhythms, and sustained operations. Each of these has different effects on performance since each of these affects how quickly a person can recover the sleep debt, the quality of that sleep, and the duration of exposure to that cause of sleep loss. For injury and disease, performance decrements may be due to sleep loss but more likely to the injury or the disease itself. An example of comorbid conditions, depression, and sleep quality is presented by Hayashino et al. (2010). The focus of this paper is on the effect of sleep loss not known to be associated with injury, illness, disease, or desynchronosis. These environments include military command and control, process control, medical practice, and security surveillance. In addition, studies of operator safety during the drive home from work are also reviewed.

Military Command and Control

Military command and control research has been conducted using both ground and airborne operators.

Ground-based Command and Control—Neri, Dinges, and Rosekind (1997) summarized the literature relevant to military surge operations with similar decrements in visual performance as a function of sleep loss. However, DeJohn, Reames, and Hochhaus (1992) compared performance on cognitive, visual, and auditory tasks before and after an extended overwater training mission. There were no significant differences in the performance of the cognitive or visual tasks. There was an improvement in understanding of noise-degraded speech. The authors concluded that the improvement was due to practice. Tyagi, Shen, Shao, and Li (2009) compared the performance of eight male students on an auditory working-memory vigilance task as well as psychomotor vigilance test (PVT) over the course of a 25-hour sleep deprivation study. Data were collected hourly. There was a significant effect of sleep deprivation in comparing across time.

Baranski et al. (2007) measured the performance of 64 adults composed of four-person teams. Eight teams consisted of military persons, the other eight of civilians. Participants made individual or team decisions while playing the Team and Individual Threat Assessment Task (TITAN), a computer simulation of a naval shipboard surveillance and threat assessment task. During day 1, participants were trained, fed (no caffeine after noon), and allowed to sleep. Civilians spent significantly more time in bed than the military participants but also spent significantly more time in bed being awake. Assessment errors

decreased and target processing time decreased from day 2 0800 through day 2 1900. Both steadily increased from that point until the end of the experiment (day 3 1000). Further military teams had significantly longer target processing times than the civilians. There was no significant effect of subordinate feedback on either error or time. However, teams had significantly better performance than an individual's solo performance as the amount of sleep deprivation increased. After 30 hours there was a 2 percent difference in errors and a 14-second difference in target processing time.

Lieberman et al. (2006) evaluated the performance of 13 male soldiers over a four-day sustained operations mission. Tasks included set up and pack a command post, land navigation, battle drills, road march, obstacle course, litter carry, unload truck, 50-minute walk at 3.5 mph 7 percent grade in 35 degree centigrade temperature, physical training, and light training. In addition, cognitive and physical performance tests were given. Visual vigilance significantly decreased in days 3 and 4 of the sustained operations mission but only in the number of hits not in the number of false alarms or in the reaction time. However, there were significant decreases in the number of correct responses on a four-choice reaction time task on day 3 of the sustained operations mission as well as an increase in reaction time.

McLellan, Kamimori, Voss, Tate, and Smith (2007) examined the performance of 20 male New Zealand Special Operations personnel. These personnel were given caffeine or a placebo over a five-day period. During this time they completed an obstacle course and performed a vigilance task, which required them to record where, when, and what activity occurred in a building under observation. The vigilance task lasted 120 minutes and was scored with one point for every correct answer. The group using the caffeine gum had significantly higher vigilance scores on days 3 through 5 than the placebo group. The caffeine group also did significantly better during three overnight testing periods. Night vigilance score was significantly less for both groups on day 4 as compared to day 3.

In a larger study, Castellani, Nindl, Lieberman, and Montain (2006) compared the performance of 13 male soldiers over two 84-hour periods: control and sustained operations. The sustained operations included 49 hours of military tasks. Cognitive and physical performance was measured in the morning of days 1, 3, and 4 of each 84-hour period. The cognitive tests were visual vigilance, four-choice reaction time, matching to sample, and repeat of a 12 key press pattern. The number of correct detections in the visual vigilance task decreased over the experiment in both conditions. For the four-choice reaction time test the number of correct responses decreased over time and the number of errors increased. The total number of errors was highest on day 4 of the sustained operations condition. For the matching to sample, the number of timeout errors increased across the experiment.

Airborne Command and Control—The United States Air Force and Navy both have airborne command and controllers. For the Air Force, it is Airborne Warning and Control System (AWACS) operators. There are up to 14 mission crew in the cabin of an E-3 aircraft. For the Navy, the E-2 carries three mission personnel: combat information center officer, air control officer, and radar operator. Fatigue of these aircrews was a concern among both services. The Air Force designed a research specifically to study sustained operations in the AWACS (Shiflett, Strome, Eddy, & Dalrymple, 1990). Chaiken et al. (2004) evaluated the performance of 10 three-person crews drawn from United States Air Force officers awaiting Air Battle Management training. Each participant completed nine hours of training on the Automated Neuropsychological Assessment Metric (ANAM) cognitive task battery and 30 hours of training on an AWACS simulation and decision support system. They performed command and control tasks from 1830 to 1100 the following morning. The tasks included control of surveillance aerial vehicles, airstrike coordinated between bombers and airborne jammers, and controlling air-to-air fighters. ANAM scores indicated an initial increase in performance followed by a decrease to the early morning hours and a recovery mid-morning. Mission-dependent variables were no gas (i.e., poor fuel management), threat killed, and friendlies lost. There was a small but significant increase in the hostile penetrations with fatigue and a concordant decrease in the number of threats killed. In addition, there was a significant increase in "return to base" order with fatigue, especially with the air-to-ground mission. Finally, fewer tactical orders were given during the later hours of the day.

Using a similar simulation, Whitmore, Chaiken, Fischer, Harrison, and Harville (2008) measured the performance of 30 United States officers over a 30-hour period performing airborne command and control tasks as well as ANAM tasks. There was only one significant effect on individual performance—the number of friendly aircraft attacked did not return to the baseline level during the recovery day. However, the number of air targets engaged during the recovery period was significantly higher than during the baseline trial. For the teams, there were significantly more air targets engaged during recovery than during baseline. There were also significant decrements in performance over time in the ANAM continuous processing and math tasks. For math, there was a recovery above baseline at the end of the experiment.

Process Control

Most process control studies require participants to perform laboratory tasks before, during, or after a shift. For example, Mitchell and Williamson (2000) compared the performance of 15 employees working 8-hour shifts in an electric power plant versus that of 12 employees working 12-hour shifts. Tasks were a five-minute simple reaction

time task, a three-minute grammatical reasoning task, a ten-minute vigilance task, and a five-minute critical tracking task. Employees had significantly faster reaction time at the end than at the beginning of the shift on the simple reaction time task. Employees on the 12-hour shift also had more variance in the reaction time for correct responses to the grammatical reasoning task. For these employees there were significantly more errors in the vigilance task at the end of the shift as well.

In a larger study, Ansiau, Wild, Niezborala, Rouch, and Marquié (2008) compared cognitive performances of 2,337 workers during a yearly medical exam. The cognitive tasks were immediate free recall from a list of 16 words, delayed free recall, digit symbol substitution, and selective attention. Ages were 32, 42, 52, and 62. Both males (1,152) and females (1,185) were included in the analysis. Most reported typical work schedule (1,911), less than eight hours working (1,511), low workload (1,911), and mental tasks (956) rather than physical (679) or social (702). About half woke at least once during the previous night (1,182). Some had difficulty getting back to sleep (424). The group was split on sleep dissatisfaction (yes 1,169, no 1,168). A decrease in sleep length was significantly associated with being 52 (rather than 32), having worked more than ten hours the previous day (rather than less than eight hours), with atypical schedule and having a high workload. The number of awakenings was greater for 52- or 62-year-olds, working between eight and ten hours on the previous day, and reporting higher workload. Higher age was negatively associated with performance of all cognitive tests. Working prior to 6 a.m. or after 10 p.m. on the previous day was associated with poorer performance on three of the tasks (immediate and delayed recall, selective attention). Bedtime was not significantly associated with performance on any of the four cognitive tasks. Persons working mental tasks on the previous day had significantly better performance on the cognitive tasks than those who reported working on physical tasks on the previous day. Performing social tasks on the previous day was associated with better performance on immediate and delayed recall and digit symbol substitution. Unexpectedly, higher sleep lengths were associated with poorer performance on the selective attention task.

In a field study of 20 male smelter workers over a 14-day period, Baulk, Fletcher, Kandelaars, Dawson, and Roach (2009) measured (using a diary as well as activity monitors) sleep, subjective fatigue, and performance on the PVT completed at the beginning, middle, and end of each shift. Less sleep was obtained on the second night of shift work than on the first night. Subjective fatigue was higher after a shift than before it. The PVT response was slower for the night shift and degraded from the first to the second night of shift work.

Using a different research paradigm, Barnes and Wagner (2009) analyzed the injury rates for miners from 1983 to 2006 based on data reported to the Mine Safety and Health Administration. There was a significant increase with an

hour lost due to converting to Daylight Savings Time but no significant change with an hour gained due to the return to Standard Time. In a second study, the authors used the American Time Use Survey data for 2004 through 2006. These data are collected through telephone interviews made by employees of the Bureau of Labor Statistics. On average, people slept 40 minutes less after converting to Daylight Savings Time than on days without the shift. Further, the loss of sleep was greater than the gain of sleep with the return to Standard Time. The authors suggest that the increase in injury rate may be associated with the sleep loss.

Medicine

Many studies compare performance on laboratory tasks across duty days as well as between participants who are rested and those who are not. A few studies examined the effect of fatigue on actual medical tasks. Studies have focused on interns but some have also included nurses.

Same Participants across Duty Days (some studies are across a single day)—In an early study using grammatical reasoning, Poulton, Hunt, Carpenter, and Edwards (1978) reported a significant reduction in efficiency (i.e., number completed per three-minute trial) on this test with a sleep deficit of three hours or more. The participants were 30 junior hospital doctors. Sleep debt was calculated from duty and sleep charts.

Orton and Gruzelier (1989) measured the performance of 20 house officers in a British hospital twice—once mid-afternoon near the end of a day shift and once near the end of a day shift that had followed a night shift. The order of testing was equally split between the officers. At least one week elapsed between tests. Tests included choice reaction time, reaction time to the presentation of an “x” in a string of letters, and haptic sorting of letters and numbers while blindfolded. The vigilance reaction times (responses to “x”) were significantly slower and had greater variability after night duty. Haptic sorting was significantly slower after the night duty but there was no significant difference in the number of errors. Choice reaction times were significantly slower for participants after less than five hours of sleep in the last of three blocks of trials.

Andreyka and Tell (1996) compared the task performance of 24 obstetrical residents after being on call for 36 hours (sleep-deprived state) versus before being on call (rested state). There were significant increases in errors of omission and errors of commission in the sleep-deprived state. There were also significant differences in both response time and response time variability, but the authors did not provide information on the direction of the difference.

Leonard, Fanning, Attwood, and Buckley (1998) compared the performance of 16 interns at the end of either a normal (8- to 10-hour) shift or a 32-hour shift. Testing was conducted between 1600 and 1800 for each group. There

was significant degradation in performance of the trail-making test (draw a line between circles with the number 1 to 13 or the letters a to l) and Stroop Color Word test for those who worked the 32-hour shift but no difference in the performance of delayed story recall, Critical Flicker Fusion, or three-minute grammatical reasoning test.

Bartel, Offermeier, Smith, and Becker (2004) measured the reaction time and accuracy of 33 resident anesthesiologists preceding night duty (average 7.04 hours sleep) and 24 hours after night duty (1.66 hours sleep during night duty). Four reaction time tests increasing in complexity (simple, choice, sequential one back, sequential two back) were performed over a 35-minute period. Reaction times were significantly longer after night duty for simple (12%), choice (6%), and one back (7%) tests. Accuracy was significantly decreased after night duty for both the one back (2%) and two back (4%) tests.

Mak and Spurgeon (2004) reported no significant difference between performance at the beginning and at the end of a call day for 21 residents. The task was completion of a complex numeric pattern.

Lingenfelter et al. (1994) compared the performance of 40 young doctors after a night off (at least 6 hours sleep) and after a night on call (in the hospital for 24 hours). Tasks were connecting numbers, recall of a list of items, choice reaction time, Stroop test, and electrocardiogram simulation. There were significant decrements in the performance of all five tasks.

Some studies measured performance across multiple days. Rollinson et al. (2003) studied the performance of 12 interns working 12-hour consecutive night shifts in an emergency department. Data were collected at the beginning of a day shift and the end of night shifts on day 1 and day 3 of four consecutive night shifts. The tests were delayed recognition, vigilance, and the Santa Ana Form Board test. There was a significant decrease (18.5%) in the number correct before first error on the delayed recognition test. Neither of the other two tests had any significant differences.

Klose, Wallace-Barnhill, and Craythorne (1985) measured the performance of 14 residents over five days. Tasks were digit symbol, card sort, pegboard, and Stroop. There was a significant effect for day with a general increase in score over time. Dula, Dula, Hamrick, and Wood (2001) reported significantly higher scores on the Kaufman Adolescent and Adult Intelligence Test for eight emergency medicine residents working day shifts compared to eight working five consecutive night shifts.

Deaconson et al. (1988) evaluated the performance of 26 surgical residents over a 19-day period. These researchers defined sleep deprivation as less than 4 hours of sleep in the preceding 24 hours. This was determined from a sleep log maintained by the residents. Tasks were paced auditory serial addition, connecting randomly marked points, grammatical reasoning, mentally assembling a geometric figure, and the Purdue Pegboard. There were no significant

differences between sleep-deprived and non-sleep-deprived residents.

Different Participants: Rested Versus Not Rested—Light et al. (1989) compared the performance two groups of surgical residents—21 rested and 21 sleep deprived. There were eight tests. The only significant difference was on the pegboard test with decrements for both the dominant and non-dominant hand when sleep deprived. In a similar study Hart, Buchsbaum, Wade, Hammer, and Kwentus (1987) compared the performance of 16 sleep-deprived and 14 normal first-year residents. The tasks were recall from stories, Sternberg short-term memory task, and a paced auditory serial addition task. The sleep-deprived residents recalled less information and tended to have longer response latencies on the Sternberg task ($p < 0.10$).

Richardson et al. (1996) reported no effect of sleep loss. Their participants were 26 physicians who either had four hours of protected time for sleep during a 36-hour call day or did not. The task was simultaneous tracking with visual reaction time.

Medical Tasks—In an early study of sleep loss, Friedman, Kornfeld, and Bigger (1973) (also Friedman, Bigger, & Kornfeld, 1971) evaluated the performance of 13 male and 1 female intern. The task was detecting arrhythmias in an electrocardiogram over a 20-minute period. Sleep-deprived participants had an average of 1.8 hours sleep during the previous 32 hours while rested participants had an average of 7 hours sleep. The sleep-deprived participants were significantly less able to detect the arrhythmias. Interviews conducted after the task identified difficulties in thinking, memory loss, depression, irritability, sensitivity to criticism, depersonalization, and black humor. Christensen, Dietz, Murry, and Moore (1977) compared the nodule detection rate in radiographs for seven rested and seven fatigued residents (i.e., worked at least 15 hours). They reported no significant difference between the two groups.

In another early study, Beatty, Ahern, and Katz (1976) compared the vigilance of six anesthesiologists in a simulated surgical task under rested (following a night of normal sleep) or sleep loss (after a night on duty with no more than 2 hours of sleep in the last 24 hours) conditions. In addition, a letter-search task, a grammatical reasoning task, and a rotated letters task were completed. Performance of the surgical task was poorer for four of the six anesthesiologists. There was no decrement in the letter-search task. However, there was a 23 percent increase in the time to complete the grammatical reasoning task. The results for the rotated letters task were not presented.

Deary and Tait (1987) compared the performance of 12 residents after a night spent off duty, a night spent on call, and a night spent admitting emergency cases. The tests were digit span, counting backwards from 200 in steps of 13, recall of 23 facts from a read passage immediately after reading the passage, recall of 23 facts from a read passage delayed after

reading the passage, sort patient reports into normal and abnormal, and make electrocardiogram assessments. There was only one significant effect—an impairment of immediate recall associated with waiting while on call.

Denisco, Drummond, and Gravenstein (1987) compared the performance of 21 resident anesthesiologists after a night with rest and after 24 hours of in-hospital service. The residents were asked to detect deviations in heart rate and blood pressure outside defined limits. Heart rate and blood pressure were presented in a 30-minute video tape. Residents were scored 0 to 5 with 5 being detection of the deviation within 10 seconds. One point was subtracted for every 10 seconds in which the deviation was not detected. Responses given before the deviation were scored 0. Residents scored significantly lower when they were fatigued than when they were rested.

Engel, Seime, Powell, and D'Alessandri (1987) reported that there was no significant decrement in the clinical performance of seven interns after being on call or not. Performance was the score of an attending physician, an actor playing a patient, or an intern's write up.

Reznick and Folse (1987) measured performance on a factual recall of basic surgical science knowledge task, a concentration ability task requiring identification of abnormal results in laboratory reports, a manual dexterity task requiring closing a simulated wound, and the Purdue Pegboard test. The participants were 21 surgery residents who performed the tests sleep deprived and rested. There were no significant differences on any of the first three tests. However, participants performed significantly better on the Purdue Pegboard task in the non-sleep-deprived condition using the dominant hand. There was no significant sleep state effect using the non-dominant hand. In another recall of medical knowledge study, Stone, Doyle, Bosch, Bothe, and Steele (2000) reported no significant effect on American Board of Surgery In-Training Examination (ABSITE) scores for surgical residents on call the night before the exam and those who were not. The data were from 424 residents in 15 general surgery programs.

Eastridge et al. (2003) compared the performance of a simulated laparoscopic surgery of 35 surgical residents pre-call, on-call, and post-call. There were significantly more errors and a significant increase in time to complete for the post-call. However, Jensen et al. (2004) evaluated the effects of sleep deficit on acquisition of laparoscopic skills. Sleep deficit was determined by the self-reported amount of sleep the night before the test. The participants were 40 surgical residents. Data were time to complete and number of errors for pegboard, cup drop, rope pass, pattern cutting, endoscopic clip application, and endoscopic loop application. There was no effect of sleep on any measure of any test.

In a field study, Jacques, Lynch, and Samkoff (1990) compared the scores of 353 family practice residents based on total number of hours slept the night before the examination, number of hours worked each week, and the

average on-call frequency. These authors reported a significant decrease in scores for decreased sleep the night before and for each year of training with first-year residents showing the greatest decrement.

Haynes, Schwedler, Dyslin, Rice, and Kerstein (1995) compared the incidents of postsurgical complications between residents who operated the day after a 24-hour on-call period and those who had not been on call. For the 6,371 cases reviewed, there were 351 incidents. There were no significant differences in the two groups. Ellman et al. (2004) reported no significant effect of sleep deprivation when comparing mortality rates and operative, pulmonary, renal, neurological, or infectious complications of sleep-deprived and non-sleep-deprived surgeons. Sleep deprivation was defined as either performing a case that started between 10 p.m. and 5 a.m. or ended between 11 p.m. and 7:30 a.m. The data were 6,751 cases collected over a 9-year period.

Landrigan et al. (2004) compared the number of serious medical errors made by interns working a traditional schedule (24-hour or more work shifts every other night) against a schedule without extended hours but with restricted hours per week. The interns were under continuous direct observation over 2,203 patient days. Interns on the traditional schedule made significantly more serious medical errors than those on the restricted schedule (see Figure 1). Note that the seriousness of error was rated by two physicians with no direct knowledge of the interns.

Gottlieb, Parenti, Peterson, and Lofgren (1991) compared the performance of 32 internal medicine residents under two schedules. The first was a four-day rotation consisting of long call and short call days followed by one non-admitting day. Residents remained in the hospital on long call days. The second was a seven-day rotation with one long call, three short call, and three non-admitting days. There were 520 patients seen in the first schedule and 583 seen in the

Figure 1. Number of serious medical errors (Landrigan et al., 2004).

second schedule. A sample of the charts from each group was reviewed and medication errors counted. There were 16.9 errors per 100 patients in the first schedule and 12.0 errors in the second.

Smith-Coggins, Rosekind, Buccino, Dinges, and Moser (1997) evaluated the effects of a literature-based program to promote good sleep hygiene on six attending physicians. Performance was evaluated on three tests repeated four times across the day—after primary sleep period and beginning, middle, and end of shift. The tests were the PVT, electrocardiogram interpretation, and intubation of a mannequin. The researchers compared day and night shift. There were significant differences associated with the education on sleep hygiene, specifically, using more strategies for sleeping during the day including masking daytime noise with a fan, napping before night shifts, changing activity when bored, and reducing ambient temperature when drowsy. For the PVT, median reaction time increased significantly across the night shift. There were no significant differences in electrocardiogram interpretation but physicians took longer to intubate during the night shift than the day shift but were faster in the later portions of their shift.

Smith-Coggins et al. (2006) compared the performance of 49 residents and nurses with and without a nap during a night shift. All participants had worked at least three consecutive 12-hour night shifts in the emergency department. The data were collected on night two (no nap) and three (40-minute nap between 3 and 4 a.m. or no nap depending on group). Both groups performed on the second and third nights at pre, mid, and post shifts. The tasks were the PVT, a probed recall memory task (30 seconds to memorize six words), and a computer-based intravenous insertion simulation. They also drove a car simulator post shift for about 40 minutes. The group who napped had fewer lapses during the 7:30 a.m. PVT and reported more quickly on their slowest response than the group who did not nap. For the recall, there was one significant difference—the group that napped had fewer correct responses at 4 a.m. than those who did not a nap. For the catheter insertion, the no nap group performed more quickly than the nap group during the preshift interval. There were no significant differences in driving performance between the nap and no nap groups. However, both groups spent about 8 percent of the drive leaving the road or colliding with an oncoming car.

Nurses—Dorrian et al. (2008) analyzed the self-reported work hours, estimated sleep length and quality, fatigue, sleepiness, stress, errors (frequency, type, and severity), and drowsiness while driving home of 41 Australian full-time nurses in a metropolitan hospital. A total of 1,148 days of information was collected. Thirty-eight errors and 38 near errors were reported with the majority of the errors occurring during the morning and day shift, while near errors were distributed through the working hours. There

were also 65 reports of observing someone else's error with the majority of these occurring at night. Nurses had significantly more sleep prior to evening shifts than to morning or night shifts. There was significantly fewer hours of sleep in the preceding 24 hours when errors occurred. Across the 34 nurses who drove to work, there were 70 occurrences of extreme drowsiness and seven near accidents with almost half of these occurring between 0700 and 0900, the end of the night shift. Forty percent of the remaining occurrences of extreme drowsiness and near accidents occurred between 1400 and 1900 peaking at the end of the morning shift (1500).

Scott, Rogers, Hwang, and Zhang (2006) analyzed 14-day logbooks from 502 critical care nurses in the United States. The nurses logged work, sleep, mood, caffeine intake, problems remaining awake, and errors or near errors made. Eighty-six percent of the reported shifts included overtime with four percent mandatory overtime. Twenty-nine percent were between 85 and 12.5 hours, and 62 percent equal or greater than 12.5 hours. Sixty-five percent of the nurses reported problems staying awake at least once during the two-week period. Forty percent of drowsiness and 23 percent of sleep during work occurred between 6 a.m. and midnight although the most reports of drowsiness and sleep episodes occurred between 2 a.m. and 4 a.m. with 12 to 2 a.m. and 4 to 6 a.m. close seconds. Twenty-seven percent of the nurses reported making at least one error and 38 percent near errors. The risk of making an error was greater when nurses worked 12.5 or more consecutive hours (odds ratio 1.94). A similar result occurred for nurses working more than 40 hours per week (odds ratio 1.93).

Summary of the Medical Practice Literature—Samkoff and Jacques (1991) reviewed studies of the effects of sleep deprivation on residents' performance that had been conducted between 1970 and 1990. They concluded from these studies that vigilance was degraded while manual dexterity, reaction time, and short-term recall were not. In a review of 29 studies reported in the literature from 1994 through 2003, Muecke (2005) concluded that the adverse relationship of fatigue and performance affected older nurses (over 40) more than younger nurses. Further, shift work may degrade patient safety as well quality of care especially in critical care settings. In a similar review but of 37 articles, Joffe (2006) concluded that fatigue reduction is critical in reducing medical error. Further, a culture change must occur in which sleep management is practiced especially among older physicians. Joffe's specialty was pediatric emergency services. For suggestions on identifying and treating fatigue, see Rosenthal, Majeroni, Pretorius, and Malik (2008).

Security Surveillance

In security, both loss of sleep and work at night degrade operator performance. Basner et al. (2008) recorded the

accuracy of detecting threats in a simulated luggage-screening task over a five-day period. There were 24 subjects who were tasked at night and also after a night without sleep. At night, there was a significant decrease in accuracy of detection and a significant increase in false alarm rate compared with performance during the day. Performance after a night without sleep showed significant further decreases in accuracy and hit rate.

Studies Related to Safety during Drive Home

Connor et al. (2002) examined the drivers and passengers of vehicles driven in the Auckland area of New Zealand between April 1998 and July 1999 who were admitted to hospital or died as the result of a car crash. Excluded were drivers of heavy vehicles, taxis, and emergency vehicles as well as drivers on lowest functional classification roads. A control group was made up of drivers on roads within the area and not on lowest functional classification roads. All participants rated their sleepiness using the Stanford sleepiness scale as well as their alertness (on a rating scale of one to seven) immediately before the crash or survey. Drivers with scores of four or above on the Stanford scale had an 11-fold risk of injury crash versus those with scores below four. Furthermore, drivers who reported five or fewer hours of sleep in the past 24 hours had increased risk, with drivers who had three hours of sleep or less having the highest risk. The greatest risk was driving between 2 a.m. and 5 a.m.

Another traffic study was reported by Åkerstedt, Peters, Anund, and Kecklund (2005). Five male and five female shift workers completed two two-hour drives in a high-fidelity moving-base automobile simulator—one drive after a normal night's sleep and the other after a night shift. Four of the participants did not complete the two-hour drive after a night shift due to excessive sleepiness. For the remaining participants there were significantly more accidents after the night shift versus after normal sleep. Since four participants terminated early, the time to first accident or termination was used. Again, the results were significant, with the time shorter in the night shift group (83 ± 11.5 minutes) than in the normal sleep group (115.5 ± 3.0 minutes). There was also a significant increase in the sleepiness rating after the night shift.

In a simulator study, Balkin et al. (2004) measured the math performance of 66 commercial motor vehicle drivers (aged 24 to 62) after nine, seven, five, or three hours in bed for four consecutive days. There was a significant increase in the time to complete a serial addition/subtraction task. Further, performance in a driving simulator showed significantly larger standard deviations in lane tracking and larger relative lane position in the sleep-restricted conditions than in the baseline (normal) sleep condition.

Finally, Barger et al. (2005) evaluated the relationship of extended work shifts and the risk of motor vehicle

accidents among interns. The data were collected from a Web-based survey of 2,737 interns who reported work hours, motor vehicle crashes, and near misses as well as involuntary sleeping. These authors reported that “every extended work shift that was scheduled in a month increased the monthly risk of a motor vehicle crash by 9.1 percent (95 percent confidence interval, 3.4 to 14.7 percent) and increased the monthly risk of a crash during the commute from work by 16.2 percent (95 percent confidence interval, 7.8 to 24.7 percent)” (p. 125). Further working five or more extended shifts within one month significantly increased the risk of falling asleep while driving or stopped in traffic.

Summary of the Performance Effects of Sustained Operations

Sustained operations occur in diverse environments from military command and control to process control to medicine to security to driving home after a shift. A summary of the results of the research reviewed in this paper is presented in Table 1. Operations resulting in fatigue degrade vigilance (6 out of 52 studies) and reaction time (9) task performance across all environments. However, there are some studies showing no effect on vigilance (3) or reaction time (1) and even one that showed performance enhancement on a reaction time task. Related to both these tasks is detection, which typically shows degraded performance (4) although there is one study reporting no effect.

Memory tasks typically have degraded performance (8) but not always (3). Performance on the Stroop Color Word Task degrades (3). Sorting is another task that shows degraded performance (3 out of 52 studies). However, one study reported no effect. Manual dexterity tasks such as the Purdue Pegboard degrade (3) but again not always (1). Other studies have indicated both decrements (1) and no effect on manual tasks (3). Inconsistent results also occurred with math tasks: three studies indicate degradation and three no effect. Simulated combat performance shows both improvements (2) as well as degradations depending on the time on or type of task (4) or no effect (1). Grammatical reasoning shows no effect (2) but trail making shows both degradations (1) and no effect (1).

For specific domains, nursing is consistently degraded with sustained operation (4 studies). In addition, for medicine surgery shows both degradations (2) and no effect (2). Critical care, medication, diagnosis, and intubation are all degraded with sustained operations (3) but medical assessment performance shows no effect (2). All driving tasks were negatively affected (4 studies).

In summary, all tasks can be degraded during sustained operations but tasks requiring high levels of attention (vigilance, detection) or cognitive processing (memory, sorting, Stroop Color Word, nursing, critical care,

Table 1
Summary of the performance effects of sustained operations.

Environment	Degrade	No Effect	Improve	Reference
Military command and control	Visual			Neri et al. (1997)
	Vigilance, reaction time (RT)	Cognitive, visual, auditory	Understanding of noise degraded speech	DeJohn et al. (1992)
	Assessment, target processing (day 2 1900 through day 3 1000)		Assessment, target processing (day 2 0800 through 1900)	Tyagi et al. (2009)
	Vigilance, RT			Baranski et al. (2007)
Process control	Vigilance			Lieberman et al. (2006)
	Vigilance, RT			McLellan et al. (2007)
	Prevent hostile penetrations, kill threats			Castellani et al. (2006)
	Continuous processing, math			Chaiken et al. (2004)
	Vigilance		RT	Whitmore et al. (2008)
	Memory		Selective attention	Mitchell and Williamson (2000)
	RT			Ansiau et al. (2008)
	Safety			Baulk et al. (2009)
Medical practice	Efficiency			Barnes and Wagner (2009)
	Vigilance, RT, sorting			Poulton et al. (1978)
	Sorting			Orton and Gruzelier (1989)
	Trail making, Stroop Color Word			Andreyka and Tell (1996)
	RT	Recall, Critical Flicker Fusion, grammatical reasoning		Leonard et al. (1998)
	Math, recall, RT, Stroop	Math		Bartel et al. (2004)
	Delayed recognition			Mak and Spurgeon (2004)
	Math, sort, pegboard, Stroop	Vigilance, Santa Ana Form Board		Lingenfelter et al. (1994)
Kaufman Adolescent and Adult Intelligence				Rollinson et al. (2003)
				Klose et al. (1985)
				Dula et al. (2001)
		Math, trail making, grammatical reasoning, geometry, Purdue Pegboard		Deaconson et al. (1988)
Pegboard	Recall			Light et al. (1989)
				Hart et al. (1987)
		Tracking, RT		Richardson et al. (1996)
				Friedman et al. (1973)
Detection		Detection		Christensen et al. (1977)
	Simulated surgery	Letter search		Beatty et al. (1976)
	Recall	Math, sorting, assessment		Deary and Tait (1987)
	Detection			Denisco et al. (1987)
Purdue Pegboard		Assessment		Engel et al. (1987)
		Recall, detection, manual dexterity		Reznick and Folse (1987)
		Recall		Stone et al. (2000)
	Simulated surgery	Manual		Eastridge et al. (2003)
Recall				Jacques et al. (1990)
		Surgery		Haynes et al. (1995)
		Surgery		Ellman et al. (2004)
	Critical care, medication, diagnosis			Landrigan et al. (2004)
Medication				Gottlieb et al. (1991)

RT, intubation	Assessment	Smith-Coggins et al. (1997)
Nursing		Dorrian et al. (2008)
Nursing		Scott et al. (2006)
Vigilance, manual dexterity, RT, recall		Sankoff and Jacques (1991)
Nursing		Muecke (2005)
Critical care		Joffe (2006)
Detection		Basner et al. (2008)
Driving		Connor et al. (2002)
Driving		Åkerstedt et al. (2005)
Simulated driving, math		Balkin et al. (2004)
Driving		Barger et al. (2005)
Security surveillance		
Drive home		

medication) or speed (reaction time) seem to be especially vulnerable.

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