Exh. CAC-1T
Witness: Charles A. Czeisler

BEFORE THE WASHINGTON
UTILITIES AND TRANSPORTATION COMMISSION

WASHINGTON UTILITIES AND TRANSPORTATION COMMISSION, **Complainant,** **v.** **PUGET SOUND PILOTS,** **Respondent.**	**Docket TP-**

TESTIMONY OF

CHARLES A. CZEISLER

ON BEHALF OF PUGET SOUND PILOTS

JUNE 29, 2022

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I. IDENTIFICATION OF WITNESS

Q: Please state your name, occupation and business address.

A: My name is Dr. Charles A. Czeisler. I am currently the Frank Baldino, Jr., Ph.D. Professor of Sleep Medicine, Professor of Medicine and Director of the Division of Sleep Medicine at the Harvard Medical School, and I am Chief of the Division of Sleep and Circadian Disorders in the Departments of Medicine and Neurology and Director of the Sleep Matters Initiative, both at Brigham and Women's Hospital in Boston, Massachusetts. My business address is 221 Longwood Ave., BLI 438, Boston, MA 02115-5817.

Q: Please describe your educational background.

A: I received my bachelor's degree from Harvard College in biochemistry and molecular biology magna cum laude in 1974 and was inducted into Phi Beta Kappa at Harvard College in 1999. I received the degree of Doctor in Philosophy (Ph.D.) in Neuro- and Biobehavioral Sciences in 1978 from Stanford University and the degree of Medical Doctor (M.D.) from Stanford University in 1981.

Q: Please describe your experience in the physiology of the human circadian timing system and its relationship to the sleep-wake cycle.

A: I have more than four decades of experience in the field of basic and applied research on the physiology of the human circadian timing system and its relationship to the sleep-wake cycle. Together with my collaborators, I have done significant study and research into the areas of sleep and fatigue. This research has resulted in 286 original reports in peer-reviewed journals and 118 review articles/proceedings of meetings, as well as five books/monographs/theses and numerous abstracts of research.

I am a Diplomate of the American Board of Sleep Medicine, a Fellow of the American Academy of Sleep Medicine, a Fellow of the American Physiological Society and an elected Fellow of the Royal College of Physicians (London). I have also served as President of the Sleep Research Society; Chairman of the Board of Trustees of the National Sleep Foundation; Chairman of the National Institutes of Health Sleep Disorders Research Advisory Board of the National Center on Sleep Disorders Research in the National Heart, Lung and Blood Institute; Chair, Steering Committee, Academic Alliance for Sleep Research; and Chair, Steering Committee, Sleep Research Network. For ten years, I served as the Team Leader of the Human Performance Factors, Sleep and Chronobiology Team of NASA's National Space Biomedical Research Institute in Houston, Texas.

I have also been elected as a Fellow of the American Society for Clinical Investigation, a Member of the Association of American Physicians, a Member of the International Academy of Astronautics and a Member of the National Academy of Medicine (formerly called the Institute of Medicine of the National Academies). I served on the faculty of the World Economic Forum in Davos, Switzerland in 2014, the Aspen Ideas Festival Spotlight Health in Aspen, Colorado in 2016 and 2017, and Aspen Brain Health in 2018.

In addition, I serve or have served as a committee member on a number of national and international advisory panels in the public and private sectors related to sleep and circadian rhythmicity, including: the New Developments in Neuroscience Advisory Panel responsible for the report on "Biological Rhythms: Implications for the Worker" by the Office of Technology Assessment, U.S. Congress; the Work Hours, Sleepiness and Accidents Consensus Conference, National Institute for Psychosocial Factors and Health, Department of Clinical Neuroscience, Karolinska Institute, Stockholm, Sweden; the Advisory Committee on Night Operations and Human Chronobiology, Life and Environmental Sciences Division, Air Force Office of Scientific Research; the Panel on Workload Transition, Committee on Behavioral and Social Sciences and Education, National Research Council; the Research Briefing Panel on Basic Sleep Research, Division of Health Science Policy, Institute of Medicine, National Academy of Sciences; Plenary Address, American Trucking Association Foundation Conference on Managing Fatigue in Transportation; the NASA Advisory Panel on the Pre-flight Circadian Shifting of Shuttle Flight Crews, Space and Life Sciences Directorate, National Aeronautics and Space Administration; the Biological Rhythms Task Force, Mental Health Research Network I, John D. and Catherine T. MacArthur Foundation; the External Advisory Committee, National Science Foundation Center for Biological Timing at the University of Virginia; External Advisory Committee, University of Wisconsin Sleep Center; External Advisory Committee, Neuroscience Institute, Morehouse School of Medicine; the Boards of Trustees/Directors of the National Sleep Foundation, the Association for Patient-Oriented Research, the Institute for Experimental Psychiatry Research Foundation, the Sleep Research Society and the Sleep Research Society Foundation; Circadian Rhythm Sleep Disorders Advisory Board, Takeda Pharmaceutical Company, Inc.; Sleep-Wake Scientific Advisory Board, Cephalon, Inc.; Scientific Advisory Board, Hypnion, Inc.; Executive Committee, Chair, Research Committee, Chair, Presidential Task Force on Sleep and Public Policy, and President, Sleep Research Society; President, Sleep Research Society Foundation; Chair, Scientific Advisory Panel, Mars Exploration Rover Surface Operations Program, NASA Jet Propulsion Laboratory, California Institute of Technology; Scientific Advisory Board, Air Transport Association of America; the

Neuroscience Psychiatry Advisory Board, Pfizer, Inc; Chair, Scientific Advisory Board, Vanda Pharmaceuticals, Inc.; Scientific Advisory Board, Zeo, Inc. (formerly Axon Labs, Inc.); Expert Consultant, Committee on Sleep Medicine and Research, Institute of Medicine, National Academy of Sciences; Member, External Advisory Panel, International Space Station and Shuttle Utilization Reinvention Team, NASA; Member, Medical Expert Panel on Sleep Apnea and Commercial Truck Driving, Federal Motor Carrier Safety Administration (FMCSA), US Department of Transportation (DOT); Expert Consultant, Committee on Optimizing Graduate Medical Trainee (Resident) Hours and Work Schedules to Improve Patient Safety, Institute of Medicine, National Academy of Sciences; External Advisory Committee, Wisconsin Sleep Center, University of Wisconsin; Panelist, Fatigued Driving Committee, National Highway Traffic Safety Administration's (NHTSA) Office of Behavioral Safety Research; Member, Expert Panel on Obstetrics, Staffing and Communication Task Group, Betsy Lehman Center for Patient Safety, Boston, MA; Member, Steering Committees, Academic Alliance for Sleep Research; Member and Chair, Sleep Disorders Research Advisory Board, National Heart, Lung, and Blood Institute; Member, Advisory Board on Insomnia, Novartis Consumer Health; Member and Chair, Steering Committee, Sleep Research Network, Clinical and Translational Science Award (CTSA) institutions; and Member, Drowsy Driving Commission for the Commonwealth of Massachusetts.

In December 2011, I provided a briefing to the FMCSA's Motor Carrier Safety Advisory Committee (MCSAC) and the FMCSA's Medical Review Board on "Addressing Obstructive Sleep Apnea in Commercial Motor Vehicle Drivers." In 2014–2015, I served as a Task Force Member of a Panel on Truck Safety, Hours of Service, and Fatigue for the National Research Council of the National Academy of Sciences (NAS) [3]; in 2018-2019, I have served as a member of an Expert Panel for the National Highway Transportation Safety Administration and currently chair the National Sleep Foundation Sleep Timing and Variability Consensus Panel.

At the Brigham and Women's Hospital, Partners HealthCare and the Harvard Medical School, my research and educational programs, and those of the Divisions that I direct, have been supported by a number of federal agencies, public charities and foundations, and industry. These include: Agency for Healthcare Research and Quality (AHRQ); Air Force Office of Scientific Research (AFOSR); Alza Corporation; Apria Healthcare; Brigham and Women's Hospital; Brigham Health; Bristol Myers-Squibb Company; Beth Israel Deaconess Medical Center, Boston; Centers for Disease Control (CDC); Cephalon, Inc.; City of Philadelphia/Fraternal Order of Police (Lodge 5); Dayzz Live Well Ltd.; Defense Advanced Research Projects Agency (DARPA); Department of Defense (DoD); Falck Foundation; Federal Air Marshal Service (FAMS), Transportation Security Administration (TSA), Department of Homeland Security (DHS); Federal Aviation Administration (FAA); Federal Emergency Management Agency (FEMA), Department of Homeland Security (DHS); Harvard Medical School; Harvard University; Helena Rubinstein Foundation; Jazz Pharmaceuticals, Inc.; Josiah Macy Foundation; Koninklijke Philips Electronics, N.V.; March of Dimes Birth Defect Foundation; Mary Ann & Stanley Snider via Combined Jewish Philanthropies; Merck Research Laboratories; National Aeronautics and Space Administration (NASA); Harvard Catalyst; Lighting Science Group; National Center for Advancing Translational Sciences (NCATS); National Center for Research Resources (NCRR); National Center for Complementary and Alternative Medicine (NCCAM); National Football League (NFL) Charities; National Geographic Society; National Heart, Lung and Blood Institute (NHLBI); National Institute of Child Health and Human Development (NICHD); National Institute of Environmental Health

Sciences (NIEHS); National Institute of General Medical Sciences (NIGMS); National Institute of Justice (NIJ), Department of Justice (DOJ); National Institute of Mental Health (NIMH); National Institute of Neurological and Communicative Disorders and Stroke (NINCDS); National Institute on Aging (NIA); National Institute of Occupational Health and Safety (NIOSH); National Space Biomedical Research Institute (NSBRI); Office of Naval Research (ONR); Optum; Partners HealthCare; Peter Bent Brigham Hospital Biomedical Research Support Grant (BRSG); Peter Brown and Margaret Hamburg; Pfizer, Inc.; Regeneron Pharmaceuticals, Inc.; ResMed Foundation; Respironics, Inc.; Rx Foundation; Sanofi Aventis, Inc.; Sanofi S.A.; San Francisco Bar Pilots; Schering Plough Pharmaceutical Corporation; Schneider National, Inc.; Sepracor, Inc.; Simmons Bedding Company; Sleep HealthCenters, Inc.; Sysco; Takeda Pharmaceuticals North America, Inc.; Tempur-Pedic, Inc.; Teva Pharmaceutical Industries, Ltd.; United States Olympic Committee; Vanda Pharmaceuticals, Inc.; W.K. Kellogg Foundation; Wake Up Narcolepsy; and Whoop, Inc.

In addition to my employment by the Brigham and Women's Hospital, which is a Founding Member of Mass General Brigham, I founded the Center for Design of Industrial Schedules, which I directed for over a decade, and which consulted with businesses on the application of sleep and circadian principles in the design of work schedules, pioneering the field of fatigue risk management consulting.

I serve or have served as a consultant for: A2Z Development Center, Accelerator Corp.; Actelion, Ltd.; Accreditation Council of Graduate Medical Education; Air Transport Association of America; Alfresa Pharmaceutical Company; Amazon.com, Inc., American Academy of Allergy and Infectious Disease; American Academy of Sleep Medicine; Association of University Anesthesiologists; Aventis, Inc.; Avera Pharmaceuticals, Inc.; Axis Healthcare, Inc.;

Bose Corporation; Boston Bruins; Boston Celtics; Boston Edison, Inc.; Boston Red Sox; Bristol-Myers Squibb; Center for Design of Industrial Schedules; Cephalon, Inc.; Chevron Chemicals, Inc.; Citgo, Inc.; Cleveland Browns; Columbia River Bar Pilots; CME Outfitters; Cornell Medical College; M. Davis and Company; Department of Homeland Security, U.S. Fire Administration; Eli Lilly and Co.; Exxon Chemical Co.; FedEx Kinko's; Federal Motor Carriers Safety Administration, U.S. Department of Transportation; Fraternal Order of Police, Lodge 5; Fusion Medical Education, LLC; Garda Inspectorate, Republic of Ireland; General Electric; Gerson Lehman Group, Great Salt Lake Minerals and Chemical Co.; Harvard College; Harvard Medical International; Health Science Communications, Inc.; Hypnion, Inc. (acquired by Eli Lilly and Co. in April 2007); Innovative Medical Technologies, Inc.; Institute of Digital Media and Child Development; Institute of Medicine; Institute of Sleep Health Promotion; Jack Mattson Group; Japan National Railroad; Jet Propulsion Laboratory, California Institute of Technology; Jazz Pharmaceuticals, Inc.; Koninklijke Philips Electronics, N.V.; Light Sciences, Inc.; Lifetrac Systems, Inc.; Massachusetts Institute of Technology; Medical Consulting; Medical Science Partners; Merck and Co.; Merck Sharpe and Dohme, Inc.; Michelin Tire Co.; Minnesota Timberwolves; 3M; Montefiore Hospital and Medical Center; Morgan Stanley; MPM Asset Management; the National Academies; National Broadcasting Company (NBC); National Research Council, the National Academies; National Space Biomedical Research Institute; New South Wales Clinical Excellence Commission; Neurocrine, Inc.; North Pacific Paper Co.; Northeast Utilities, Inc.; Novartis Consumer Health, S.A.; Novartis, Inc.; Office of Technology Assessment, U.S. Congress; Oxford Biosignals; Pfizer, Inc.; Philips Respironics, Inc.; the Portland Trailblazers; Primary Research, LLC; Purdue Pharma; Quest Diagnostics, Inc.; Rohm and Haas; Respironics, Inc.; Rockpointe, Inc.; Saatchi and Saatchi, Inc.; Samsung Electronics

Co., Ltd.; San Francisco Bar Pilots; Sanofi Aventis, Inc.; Sanofi Synthelabo, Inc.; Sepracor, Inc.; ShiftWork Systems, Inc.; Sleep Multimedia, Inc.; Society for Neurological Surgeons; Somnus Therapeutics, Inc.; Swiss Air; Tanabe Seiyaku Co., Ltd.; Takeda North America Pharmaceuticals, Inc.; Teva, Inc.; Tokyo Electric Power Co., Inc.; Unilever, Inc.; United Airlines, Inc.; U.S. Air Force; U.S. Central Intelligence Agency; U.S. National Aeronautics and Space Administration (NASA); U.S. National Institutes of Health; U.S. Navy; U.S. Nuclear Regulatory Commission; U.S. Olympic Committee; U.S. Secret Service; University of Virginia National Science and Technology Center, National Science Foundation; Wisconsin Sleep Center, University of Wisconsin; Valero, Inc.; Vanda Pharmaceuticals, Inc.; Vital Issues in Medicine; Warburg-Pincus; Washington Board of Pilotage Commissioners; With Deep, Inc.; and Zeo, Inc. (formerly Axon Labs, Inc.). Since 1985, I have also served as an expert witness/consultant on a number of civil matters, criminal matters, and arbitration cases, including those involving the following commercial and government entities: Advanced Power Technologies; Alvarado Hospital, LLC; Amtrak; Aransas-Corpus Christi Pilots; Bombardier, Inc.; Burlington Northern Railroad; Casper Sleep, Inc.; Catapult Energy Services Group, LLC; Celadon Group Inc.; CEVA Logistics; Charlotte, North Carolina Police Department; CITGO Petroleum Corporation; City of Albany, New York; C&J Energy Services; Clyde Machines, Inc.; Columbia River Bar Pilots; Complete General Construction Company; Covenant Testing Technologies, LLC; Crete Carrier Corporation; Covenant Testing Technologies, LLC; Dallas Police Association; Dallas Police Department; Delta Airlines/Comair; EAN Holdings LLC, d/b/a Enterprise Rent-A-Car; Fédération des Médecins Résidents du Québec (FMRQ); FedEx; Greyhound Lines, Inc./Motor Coach Industries/Firstgroup America; Fraternal Order of Police, Lodge 5; H.G. Energy LLC; Maricopa County, Arizona Sheriff's Office; Miami Truck Leasing, Inc.; Municipal Light and

Power, City of Anchorage, Alaska; Murrieta Valley Unified School District; Pomerado Hospital, Palomar Health District; Philadelphia Electric; Philadelphia Police Department; Puckett EMS; Purdue Pharma; South Carolina Central Railroad Company, LLC.; State of New Hampshire; Steel Warehouse, Inc.; St. Louis University; Tideport Distributing, Inc.; Town of Natick, Massachusetts; Union Pacific Railroad; United Parcel Service; Vanda Pharmaceuticals, Inc.; Valero Energy Corporation; and the United States of America.

Q: What awards and recognition have you received for your work?

I received the William C. Dement Academic Achievement Award from the American Academy of Sleep Medicine; the Lifetime Achievement Award from the National Sleep Foundation; the Lord Adrian Gold Medal from the Royal Society of Medicine (London); the Distinguished Scientist Award from the Sleep Research Society; the Senator Mark O. Hatfield Public Policy Award from the American Academy of Sleep Medicine; the Mary A. Carskadon Outstanding Educator Award from the American Academy of Sleep Medicine; the National Institute for Occupational Safety and Health (NIOSH) Director's Award for Scientific Leadership in Occupational Safety and Health; "Aschoff's Rule" International Award in Circadian Biology; the NASA Johnson Space Center Director's Innovation Award from National Aeronautics and Space Administration; a 2013 Major League Baseball World Championship Ring from the Boston Red Sox; the 2018 Green Cross for Safety Innovation Award from the National Safety Council; the Harriet Hardy Award from the New England College of Occupational and Environmental Medicine; the Healthy Sleep Community Award (for research done by the Harvard Work Hours, Health and Safety Group on the occupational safety impact of the work hours of resident physicians) from the National Sleep Foundation; the E.H. Ahrens, Jr.

Award from the Association for Patient Oriented Research; the Gordon Wilson Lectureship Award from the American Clinical and Climatological Association; the Robert R. J. Hilker Award by the Central States Occupational Medical Association; the Honorary Membership and Keynote Lectureship Award from the American Academy of Dental Sleep Medicine; the Golden Mind-Body Medicine Lectureship from the University of Buffalo; the Distinguished Speakership from the Walter Reed Army Institute for Research; the Michael S. Aldrich Commemorative Lectureship from the University of Michigan; the 2018 Jürgen Walther Ludwig Aschoff, Ph.D.—Colin Stephenson Pittendrigh, Ph.D. Keynote Lectureship at the bi-annual meeting of the Society for Research on Biological Rhythms; the 2018 Distinguished Lectureship from the Office of Naval Research; the 2019 Bernese Sleep Award from the University of Bern in Bern, Switzerland; the 2019 Peter C. Farrell Prize in Sleep Medicine from the Division of Sleep Medicine at the Harvard Medical School; the 2019 J.E. Wallace Sterling Lifetime Achievement Award in Medicine from the Stanford Medical Alumni Association; and the 2022 Thomas Roth, Ph.D. Keynote Lectureship of Excellence on Sleep Education from the Associated Professional Sleep Societies.

A copy of my curriculum vitae is Exhibit CAC-02.

II. PURPOSE OF TESTIMONY.

Q: What is the purpose of your testimony?

A: My testimony addresses the following topics:

1. A summary of my experience advising U.S. maritime pilot groups and other transportation sector workers on the importance of sound fatigue risk management practices;

2. A review of the factors influencing alertness, cognitive performance, risk of error/accident and health of night shift workers;

3. Influence of circadian phase (biological time of day);

4. The sleep homeostat;

5. The impact of chronic sleep curtailment;

6. Drowsy driving and sleep-related motor vehicle crashes;

7. Interruptions of sleep and sleep inertia;

8. Night shift work induces misalignment between the phase of circadian pacemaker and the work sleep schedule;

9. Night shift work leads to sleep deprivation;

10. Worker survey data on the effects of shift work;

11. Sleep disorders and crash risk;

12. A summary of the evaluation performed by my colleagues and I at the Brigham and Women's Hospital Division of Sleep and Circadian Disorders evaluating Puget Sound Pilot's scheduling efficiency and making recommendations for improvement.

A. Summary of Experience Advising U.S. Maritime Pilot Groups and Other Transportation Sector Workers on Fatigue Risk Management Practices

Q: Please describe your involvement in the Columbia River Bar Pilots' 2004 rate proceeding.

A: In June 2004 I was contacted by Attorney Michael E. Haglund in preparation for the Columbia River Bar Pilots' 2004 Rate Proceedings, requesting my assistance as an expert in sleep medicine to evaluate the existing schedule of the Columbia River Bar Pilots and to recommend a new schedule and appropriate staffing levels to manage fatigue in the Pilots' safety-sensitive jobs. On November 15, 2004, I provided a report to Haglund, Kelley, Horngren, Jones & Wilder, LLP on the matter. On January 18, 2005, I conducted a site visit in Astoria, during which time I met with the Columbia River Bar Pilots and provided them with an educational session about sleep, circadian rhythms, performance and safety. That night, I crossed the Columbia River Bar with Captain Roger Nelson via the Chinook pilot boat, climbed aboard the Alam Mesra with Captain Nelson at midnight using a pilot rope ladder, and observed Captain Nelson pilot the Alam Mesra across the Columbia River Bar to Astoria, Oregon. On February 28, 2005, I testified before Judge Allan Arlow at a rate proceeding hearing of the Board of Maritime Pilots of the State of Oregon. In February 2010, I was contacted again by Attorney Haglund in connection with the then-current pending rate proceeding and asked to review the current status of the Columbia River Bar Pilots. I again reviewed the work schedules of the Columbia River Bar Pilots and interviewed Captain Gary Lewin and various other pilots. On March 29, 2010, I provided Declaration Testimony before the Board of Maritime Pilots of the State of Oregon in the matter of the petition of the Columbia River Bar Pilots for a change in pilotage rates.

Q: Please describe your involvement with the shipping industry in Corpus Christi, Texas and the Aransas-Corpus Christi Pilots Association.

A: In June 2013, I was contacted by Attorney Keith Letourneau, Attorney at Law, of Houston, Texas, on behalf of Valero Energy Corporation, CITGO Petroleum Corporation and other shippers whose ships are guided to and from the harbor in Corpus Christi, Texas by members of the Aransas-Corpus Christi Pilots Association. I spoke with Attorney Letourneau, who asked me to review materials related to the work-rest schedules of the pilots and to render an expert opinion regarding best practices related to fatigue risk management in such a round-the-clock transportation operation. Every year, vessels and barges from around the world transport about 80 million tons of cargo on about 6,000 vessels and barges through Corpus Christi Port, which is the fifth largest port in the United States as measured by tonnage. Each of these arriving and departing vessels and barges is piloted through the Corpus Christi Port harbor by the harbor pilots of the Aransas-Corpus Christi Pilots Association, which has indicated that safety and protection of the environment are its highest priorities. I requested and received from Ms. Lorène Rothschild, of Compton & Wendler, P.C., detailed information regarding the work schedules of four Aransas-Corpus Christi pilots throughout the 2012 calendar year. I also reviewed a copy of the July 29, 2013, Order of The Board of Pilot Commissioners for the Port of Corpus Christi Authority Regarding Pilotage Rules, Regulations and Rates and correspondence regarding Aransas-Corpus Christi Pilots Fatigue Guidelines. Based on my analysis of these materials, on October 6, 2013, I developed and provided a set of recommendations for the Aransas-Corpus Christi Pilots designed to reduce the risk of fatigue-related errors and accidents.

Q: Please discuss your relationship with the San Francisco Bar Pilots and the study that you formed for them in 2013.

On or about August 16, 2013, I was contacted by Captain Joe Long of the San Francisco Bar Pilots, who explained that the Board of Pilot Commissioners governing the San Franciso Bar Pilots had been charged by the California legislature to contract with an independent entity to conduct a study of the effects of work and rest periods on psychological ability and safety for pilots. The legislature specified that the study "shall evaluate sleep- and human-related factors for pilots, and shall include information and recommendations on how to prevent pilot fatigue and ensure the safe operation of vessels." Cal. Harb. & Nav. Code § 1196.5(a). In preparation for that initiative, the San Francisco Bar Pilots requested that I initiate a study, which I did with Dr.

Laura Barger, to assess the impact of the hours worked by the San Francisco Bar Pilots and make recommendations on how best to mitigate the impact of fatigue on the health of their pilots and safety of their operations. In order to gather information about the history and operations of the San Francisco Bar Pilots, we reviewed a Manalytics study that had been conducted in 1986 and then interviewed almost half of the San Francisco Bar Pilots to explore their preferences and perspectives. We also reviewed the current work rules governing San Francisco Bar Pilots' schedules. To analyze the San Francisco Bar Pilots' schedules for factors that affect physiological measures of alertness and performance, scheduling data from a full year was reviewed. On May 7, 2014, I accompanied Captain Joe Long on an operational night shift during which we departed Pier 9 at night by maritime pilot boat and were transferred to the offshore station boat, 11 miles out at sea. Thereafter, Captain Long and I used a pilot rope ladder to climb aboard the container vessel Oakland Express during the night, which Captain Long then piloted across the San Francisco Bay and docked shortly after dawn at the Port of Oakland. That experience confirmed what I had learned from working with the Columbia River Bar Pilots about the intense and demanding nature of the work that maritime pilots perform, and the challenging conditions under which they must carry out their safety-sensitive operations. The importance of instituting a comprehensive fatigue management program for the San Francisco Bar Pilots was reaffirmed. This evaluation of the work hours of the San Francisco Bar Pilots enabled Dr. Laura Barger and I to develop and provide recommendations for a Fatigue Risk Management Program there. We also conducted an education session for the San Francisco Bar Pilots. On October 24, 2014, Dr. Laura Barger and I provided a report to the San Francisco Bar Pilots on the results of our evaluation and recommendations to improve the health and safety of the San Francisco Bar Pilots. On April 7, 2016, I made an invited presentation on Pilotage, Sleep and Circadian

Rhythms to the 2016 West Coast Pilots' Conference held at the Barbey Maritime Center/Columbia Maritime Museum in Astoria, Oregon, at which both the Columbia River Bar Pilots and the San Francisco Bar Pilots were represented, along with many other pilot groups. At that time, I also made a separate presentation on fatigue risk management training to the Columbia River Bar Pilots.

Q: Please describe the work that you performed for the Washington State Board of Pilotage Commissioners in 2017.

A: On June 8, 2017, Sheri J. Tonn, Chair of the Washington State Board of Pilotage Commissioners contacted me, indicating that the Board wanted to gather information about current best practices in sleep science and wanted an overview of best practices with other pilotage programs around the US and abroad, an assessment of how the Puget Sound Pilots fatigue management program is functioning, an evaluation of the importance of measuring and accounting for "time on task" vs "bridge time" and recommendations for any improvements that could be made to the existing program. The Board had invited the then-president of Puget Sound Pilots to give a presentation at the July 13, 2017, meeting of the Board. Board Chair Tonn indicated that the Board was seeking the assistance of a sleep professional because information about fatigue management would be an important factor in determining the number of licensed pilots. Chair Tonn indicated that the Washington State Legislature was reviewing the Pilotage Commission for best practices, and the Board planned to have a final report for the legislature for the 2018 legislative session that began in January 2018. Therefore, I met in Seattle with Chairperson Tonn and Interim Executive Director of the Board Jaimie Bever regarding the issue of fatigue and safety on September 21, 2017. Following the meeting, I was contracted by the

Washington State Board of Pilotage Commissioners to make a Fatigue Management presentation to the Board at the regular public meeting on December 14, 2017 in which I (a) outlined the science of and current best practices for fatigue management; (b) explained how I view the Board's then-current rest rules (RCW 88.16.103 and WAC 363-116-081); (c) explained how I view the pilot's rest rules (including assignment time vs. bridge time); (d) compared BPC/PSP rest rules; and I recommended any improvements. In my December 14, 2017, presentation to the Washington State Board of Pilotage Commissioners, I critiqued the Agency's then-current Rest Rules, which excluded travel time in hours of service, potentially allowing unsafe, extended duration work shifts. I also critiqued the then-current Agency rules, which did not limit duration of work shifts and therefore allowed unsafe, extended duration work shifts. As written at that time, a 6.9-hour pilotage assignment could be followed by an assignment of 22 or more hours, resulting in a 29-hour work shift, including travel time. The then-current Agency rules promulgated by the Washington State Board of Pilotage Commissioners provided inadequate time for rest between work shifts, potentially creating an unsafe condition. I indicated that seven hours of off-duty time is inadequate for maritime pilots to fulfill their daily sleep need, inducing sleep deficiency that could cause fatigue. The then-current Agency rules promulgated by the Washington State Board of Pilotage Commissioners failed to ensure that pilots were provided with 34 consecutive hours of uninterrupted rest, including two nights between midnight and 6 am, within every running 7-day interval. Fortunately, the Puget Sound Pilots had promulgated rules that addressed some of the deficiencies in the Agency rules. However, as I pointed out at the time, voluntary inclusion of travel time in work hours restrictions by the Puget Sound Pilots, for example, was not sufficient to substitute for regulatory action by the Washington State Board of Pilotage Commissioners. After reviewing the existing regulations promulgated by the

Washington State Board of Pilotage Commissioners, I recommended a series of 10 improvements to the existing program, as requested by the Board. The complete slides from my presentation to the Washington State Board of Pilotage Commissioners, which include a summary of each of those ten recommendations, are included as Exhibit CAC-03.

Q: Have You Worked Directly with the Puget Sound Pilots Before?

A: Yes. On March 12, 2021, Captain Ivan Carlson, President of the Puget Sound Pilots, contacted Dr. Laura Barger requesting consultation regarding the recommendation by the Utility and Transportation Commission for Puget Sound Pilots to improve their efficiency without sacrificing safety or prudent fatigue mitigation efforts. Subsequent discussions led the Puget Sound Pilots to commission the Sleep Matters Initiative in the Division of Sleep and Circadian Disorders to conduct a quality improvement program through the Brigham and Women's Physicians Organization in which Dr. Barger and I evaluated the Puget Sound Pilots' scheduling efficiency and made recommendations for improvement, with a final report delivered on June 1, 2022.

B. A Review of the Factors Influencing Alertness, Cognitive Performance, Risk of Error/Accident and Health of Night Shift Workers

Q: The Puget Sound Pilots regularly work night shifts yet perform a high-risk service that requires constant alertness and mental fortitude. In light of that, what factors influence night shift workers' ability to sustain effective waking neurocognitive performance?

A: Multiple factors influence the ability to sustain effective waking neurocognitive performance in healthy individuals not taking medications. These include biological time of day (i.e., circadian phase); the length of prior wakefulness; nightly sleep duration; and the recency of the last sleep episode (sleep inertia). While the effects of these circadian and homeostatic sleep regulatory processes can be modified by environmental conditions, physical activity and pharmacological agents (i.e., caffeine and/or nicotine during night wakefulness or hypnotics during day sleep), they cannot consistently overcome the impact of adverse circadian phase and/or sleep deprivation on performance. The effect of these four factors (misalignment of circadian phase and work/sleep schedule, cumulative sleep deprivation, lengthy prior wakefulness and/or recent awakening) can create an imposing biological force that can overpower a worker's ability to remain awake and attentive while at work and during the commute to and from work [2, 4-18]. This can lead to impaired neurocognitive performance, including memory consolidation, and deterioration of waking performance marked by increased rates of attentional failures [8, 18]. These consequences are particularly evident while attempting to sustain attention for a continuous duration of time (e.g., for 10–20 minutes or more) or when performing a routine, highly overlearned task, such as driving, for 10–20 minutes or more.

Q: What are some possible effects that these factors have on worker performance?

A: Sleep-related performance decrements can lead to impaired job performance and higher rates of errors, accidents and injuries. In fact, sleep deficiency and sleep disorders cost U.S. businesses an estimated $411 billion per year in absenteeism, workplace accidents, lost productivity and healthcare costs [1, 19] [20]. Drowsiness, which is a fluctuating state of reduced awareness and impaired performance, is estimated to be a possible contributing factor in nearly 30% of railway collisions [21, 22]. The National Transportation Safety Board, which is charged with conducting root-cause investigations on major transportation accidents in the United States, has identified fatigue as a probable cause, a contributing factor or a finding in 17% of its railroad crash investigations, 23% of its major aviation investigations and nearly 40% of its highway crash investigations [23]. Moreover, sleep deficiency and circadian disruption have a major impact on safety in the general population. Every year, motor vehicle crashes worldwide cause 20–50 million injuries and cost more than a half-trillion dollars. *Road Traffic Injuries,* World Health Organization (June 20, 2022), https://www.who.int/news-room/fact-sheets/detail/road-traffic-injuries. At least twenty percent of crashes, serious injuries and deaths occurring in road crashes are due to driver sleepiness [1, 24, 25]. In fact, when 9 hours of time in bed per night is used as the referent, data from a recent prospective cohort study reveals that up to forty percent of motor vehicle crashes in the general population are attributable to sleep deficiency and sleep disorders [25].

Q: What effect do sleep disorders have on sleep deficiency and other health risks?

A: The prevalence of sleep disorders, which are a major cause of sleep deficiency, has increased substantially in recent years. In addition to impairment of neurocognitive performance, chronic sleep deficiency and recurrent circadian disruption have adverse health effects. The Institute of Medicine concluded that "50 to 70 million Americans chronically suffer from disorders of sleep and wakefulness, hindering daily functioning and adversely affecting health and longevity" [1]. The Institute of Medicine further concluded that "the cumulative long-term effects of sleep loss and sleep disorders have been associated with a wide range of deleterious health consequences, including an increased risk of hypertension, diabetes, obesity, depression, heart attack and stroke" [1, 26], while the World Health Organization International Agency for

Research on Cancer has classified night shift work as being "probably carcinogenic to humans" [27].

C. Influence of Circadian Phase (Biological Time of Day)

Q: What are circadian rhythms?

A: Circadian rhythms, i.e., biological rhythms oscillating with an approximate period of twenty-four hours (from the Latin words: *circa* [about] and *dies* [day]), are present at all levels of biological complexity from unicellular organisms to humans. Circadian rhythms are endogenous (i.e., internally generated), self-sustaining oscillations that persist in the absence of periodic external time cues. In humans, many physiological processes, including the body temperature cycle, endocrine patterns, renal and cardiac function, subjective alertness, sleep-wake behavior, performance and the risk of sleep-related attentional failures and involuntary micro-sleep episodes vary according to the time of day [2, 28-46].

Q: Generally, how does the circadian rhythm relate to variations in alertness and performance?

A: The circadian contribution to variations in alertness and performance is generated by a light-sensitive circadian pacemaker that also drives the circadian rhythms of core body temperature, plasma cortisol and plasma melatonin [44, 47-61]. The endogenous circadian clock is a major determinant of the timing and internal architecture of sleep in humans [37, 42, 44, 60-65]. Experimental studies have demonstrated that spontaneous sleep duration, sleepiness, REM sleep propensity, and both the ability and the tendency to sleep vary markedly with circadian phase or biological time of day and interact with a homeostatic process to regulate sleep propensity and daytime alertness and neurocognitive performance [33, 37, 42, 44, 62, 66-72].

Q: What is the circadian pacemaker, and how does it affect alertness and cognitive performance?

Nearly fifty years ago the central neuroanatomic structures responsible for both the generation of endogenous circadian rhythms and their synchronization with the 24-hour day were identified [73, 74]. Deep within the brain, two bilaterally paired clusters of hypothalamic neurons comprising the suprachiasmatic nuclei (SCN) act as the central neural pacemaker for the generation and/or synchronization of circadian rhythms [44, 75-85]. This endogenous circadian pacemaker is a major determinant of daily variations in subjective alertness and cognitive performance [2, 15, 30, 42, 44, 47, 70, 86, 87]. These and other studies have shown that, as illustrated in Figure 1 below, there is a prominent circadian variation in objective and subjective measures of alertness, performance (psychomotor, vigilance, memory) and attention or ability to concentrate, with a primary peak in the daily rhythm of sleepiness in the latter half of the usual sleep time, just before our usual wake time. Similarly, the peak drive for waking, emanating from the hypothalamic circadian pacemaker, occurs a couple of hours before our habitual bedtime [2, 33, 88]. This paradoxical relationship between the output of the circadian pacemaker and the timing of the sleep-wake cycle is thought to facilitate consolidation of sleep and wakefulness in humans [33, 42, 68].

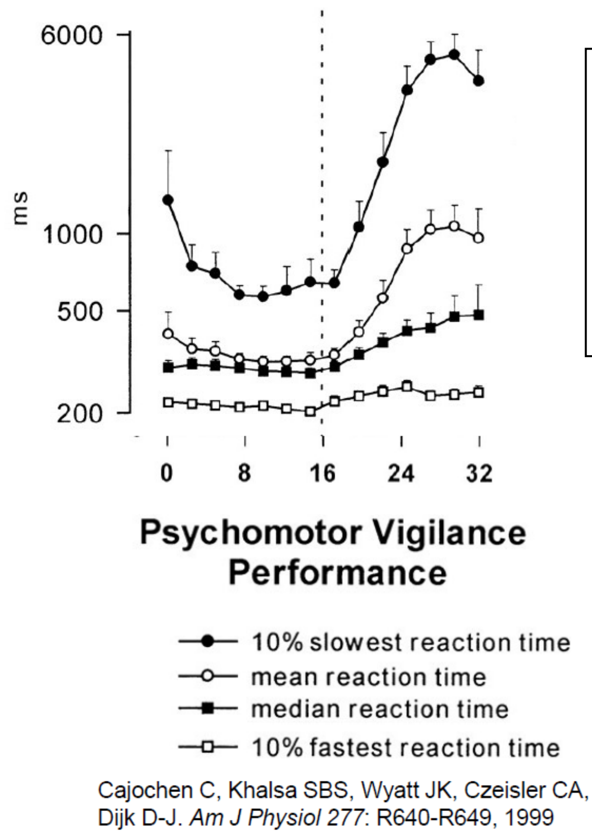


Figure 1: Time course of psychomotor vigilance performance [mean, median, 10% slowest and fastest reaction times in milliseconds (logarithmic scale)] is shown averaged across 10 subjects ± Standard error of the mean. All data were binned in 2-h intervals and expressed with respect to elapsed time since scheduled waketime. Vertical dashed reference line indicates transition of subjects' habitual wake- and bedtime [figure from [2]].

Q: How does the circadian pacemaker affect wakefulness under ordinary circumstances compared to circumstances of sleep deprivation?

A: Under ordinary circumstances, the homeostatic drive for sleep increases throughout the usual 16-hour waking day. In the mid-afternoon, there is a secondary daily peak in sleepiness [89, 90], as noted in Figure 2 below, after which time sleepiness gradually begins to decline as the circadian pacemaker sends out a stronger and stronger drive for waking during the latter half of the habitual waking day. Then, near the peak of the circadian drive for waking, about 1–2 hours before the habitual bedtime, the hormone melatonin is released [91-97]. Activation of melatonin receptors on the surface of the human SCN suppresses the firing of SCN neurons [98, 99]. Suppression of the firing of SCN neurons, which does not interfere with the ability of SCN to oscillate with a near-24-hour period [100], is thought to quiet the wake-promoting signal emanating from the SCN. Melatonin thereby suppresses the wake-promoting signal emanating from the SCN, allowing us to fall asleep at our habitual hour without stopping the circadian oscillation. Similarly, the SCN sends out a strong drive promoting sleep in the latter half of the night, which helps to consolidate sleep once the pressure for deep slow-wave sleep is satiated in the first half of the night [33, 42]. The latter half of the night is richest in REM sleep, which has a very prominent circadian rhythm in its propensity [42, 67, 68, 101].

In the absence of sleep, in the latter half of the night near the habitual wake time, elevated homeostatic drive for sleep interacts with the circadian peak of sleep propensity to create a critical zone of vulnerability [2, 42]. This is a time of increased risk for both motor vehicle crashes [89, 102-106] and train crashes [107] (Figure 2). The magnitude of these circadian variations in sleep propensity is greatly amplified when the homeostatic drive for sleep is elevated [13, 108, 109].

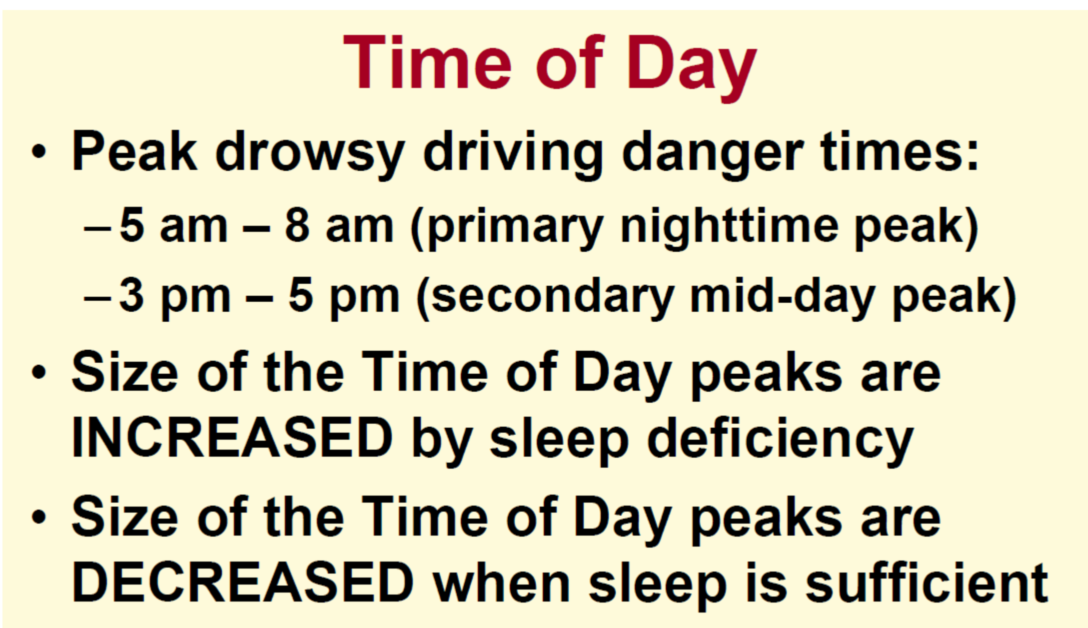


Figure 2. Impact of time of day on risk of fatigue-related crashes [22].

Q: What is the period of a typical circadian rhythm, and what environmental factors influence the circadian pacemaker?

A: In the absence of periodic time cues, the period of the human circadian pacemaker is slightly longer than 24 hours [94, 110-112]. In order for the biological clock to coordinate its function with the timing of events in the external world that operates on a 24-hour schedule, daily information from the environment must therefore reach the circadian pacemaker. The circadian pacemaker is essentially reset by a small amount each day by this external stimulus in order to maintain synchrony with the 24-hour day [44, 49, 60, 110].

Light is the principal environmental synchronizer of the mammalian SCN [44]. The SCN is connected to the retina via a monosynaptic pathway called the retinohypothalamic tract (RHT), the presumed conduit by which information from the external light dark cycle reaches the circadian clock. Research conducted in my laboratory at the Brigham and Women's Hospital/Harvard Medical School has demonstrated that properly timed exposure to bright light and darkness can rapidly shift the phase of the endogenous circadian pacemaker in humans [31, 44, 47-59, 113, 114]. Both the magnitude and direction of the phase shifts induced by light are dependent on the timing, duration, intensity and wavelength of the light exposure [44, 48-50, 55-58, 114-122], together with the prior light exposure history [44, 61, 123]. Exposure to blue-enriched light from a light-emitting eReader can suppress melatonin, shift circadian phase and affect sleep architecture [124, 125]. On average, light exposure occurring during the first half of the biological night resets the circadian clock to a later hour; light received in the last quarter of the biological night resets the circadian clock to an earlier hour [44, 49, 61, 114]. Thus, the circadian pacemaker of an individual living on a conventional schedule of day work and night sleep is synchronized by the naturally occurring light dark cycle to oscillate at the same period as the Earth's solar day, i.e., 24 hours.

D. <u>The Sleep Homeostat</u>

Q: What is the range of senses, traits, and behaviors that sleep deprivation can affect, and how does that compare to alcohol's effects?

A: Without sleep, alertness and neurocognitive performance exhibit a steady deterioration attributable to sleep loss, onto which a rhythmic circadian variation is superimposed [2, 12, 30, 33, 38, 42, 44, 60, 62, 68, 70, 71, 86, 87, 108, 126-132]. During sustained wakefulness, 24 hours of sleep deprivation has been shown to greatly impair neurobehavioral reaction time performance [2, 133, 134], to an extent that is comparable to a level of 0.10 percent blood alcohol concentration [135-140]. The sedative effects of alcohol can persist for more than six hours after alcohol ingestion, even after blood alcohol concentration is no longer elevated [141]. As noted in Figure 3 below, acute sleep deprivation impairs judgment [142-144]; decision making [145]; cognitive performance [15, 146-148]; memory [149]; reaction time [2, 14, 128, 150]; visual-perceptual ability [9, 41, 150-154]; sensorimotor gating [155]; distractibility [150, 156] and ability to focus attention [149, 150], and increases the instability of waking neurobehavioral functions [146, 147, 150] and the probability of eyelid closure and the risk of loss of situational awareness, even when the eyes remain open [150].

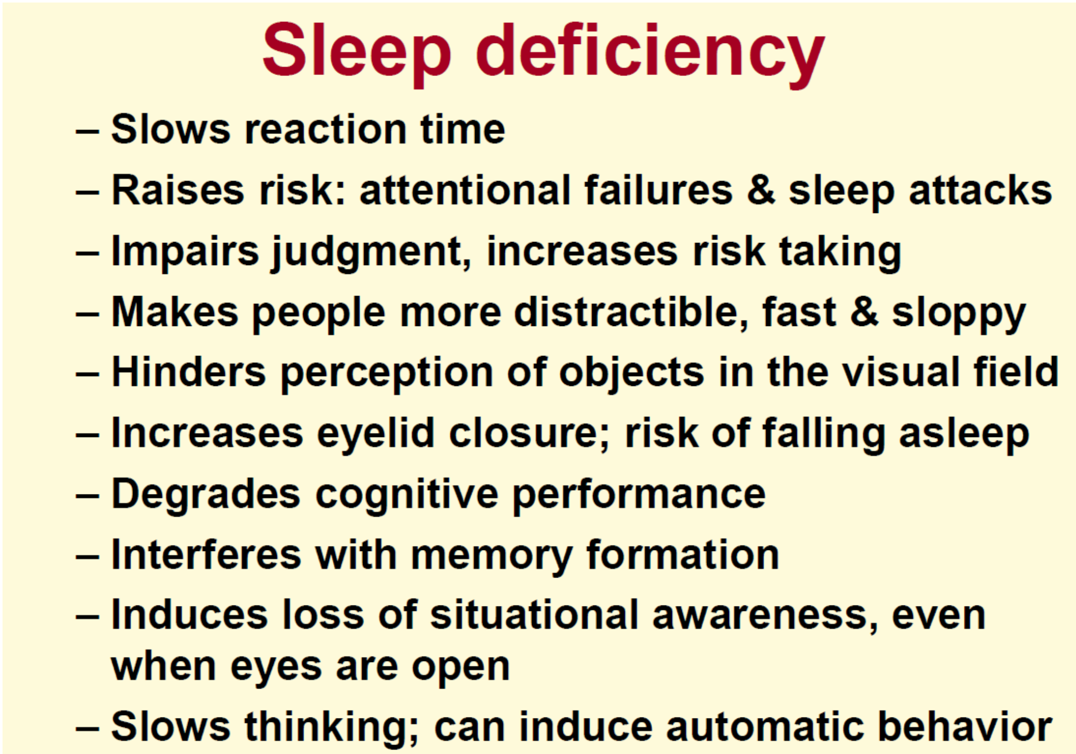


Figure 3. Sleep deficiency, which can be the result of many factors, impairs neurobehavioral performance [22].

Q: How does sleep deprivation affect the likelihood of making mistakes and taking risks?

A: Paradoxically, instead of slowing response times to preserve accuracy, research from my laboratory and from others has demonstrated that sleep-deprived participants increase speed at the expense of making more mistakes (i.e., becoming “fast and sloppy”), taking greater risks [41, 157, 158], and making hasty decisions based on inadequate information [41]. This results in increased rates of errors on selective attention tasks that require a search for targets in the visual field [41]. Commonly used stimulants, such as caffeine, modafinil and amphetamines, all fail to reverse the impairment of decision making and increased risk-taking behavior induced by sleep deficiency, whereas both are restored once recovery sleep is taken [158].

Q: How does sleep deprivation affect the probability of missing signals in the visual field?

A: As shown in Figure 4 below, it has been known for decades that sleep deprivation greatly increases the probability of missing signals in the visual field [151], as we have also more recently shown in the case of attentional failures [8].

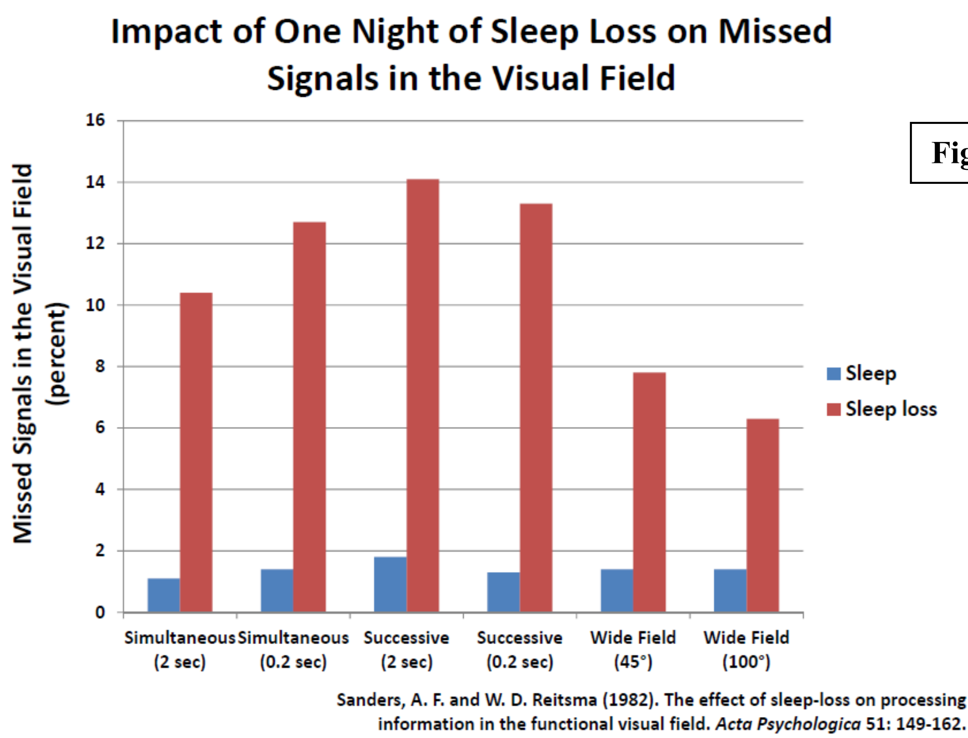


Figure 4

E. <u>The Impact of Chronic Sleep Curtailment</u>.

Q: How do multiple nights of sleep deprivation affect cognitive performance?

A: Multiple nights of insufficient sleep have been shown to have detrimental effects on alertness, vigilance, psychomotor skills, postural stability, judgment and mood [13, 15, 16, 159-166]. The ability to sustain attention, maintain cognitive performance and prevent attentional failures deteriorates when sleep is chronically restricted to 7 or fewer hours per night for a week or longer [1, 16, 163]. This effect is even seen in the absence of extended wakefulness [167]. Subjective measures of stress, tiredness, sleepiness, irritability, hostility, distractibility and the frequency of complaints increase, while sociability and optimism decrease in the face of chronic sleep loss, which significantly increases psychometric measures of total mood disturbance and impairs judgment [143, 145, 156, 168, 169]. Objective measures of performance, including reaction time and memory, worsen with each successive day that insufficient sleep is obtained [16, 163] (see Figure 6 below).

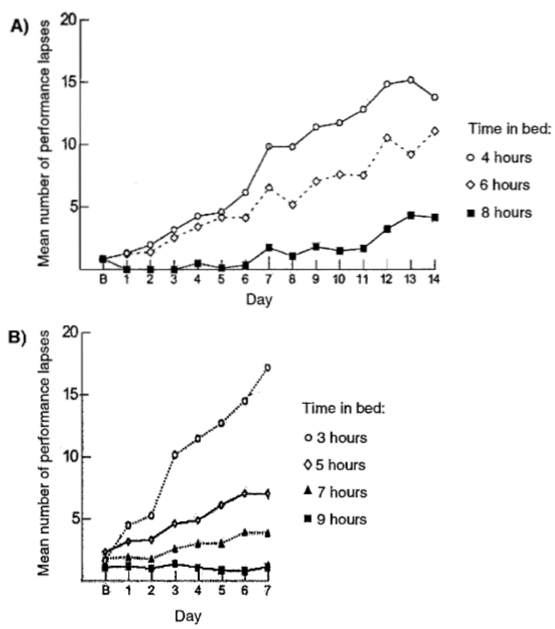


Figure 6. Repeated nights of sleep loss result in cumulative cognitive impairment. Higher number of performance lapses indicate poorer performance and more unstable alertness. Note: B, baseline day.

Figure and legend reprinted from *Sleep Deprivation and Sleep Disorders: An Unmet Public Health Problem*, a report of the Institute of Medicine Committee on Sleep Medicine and Research Sleep Disorders (2006) [1].

Q: How does increasing chronic sleep deprivation affect the frequency of symptoms, and how long do those take to correct?

A: The effects of sleep deprivation are not overcome with a single night of sleep but can carry over several days. Increasing chronic sleep deprivation leads to an increased probability of experiencing lapses of attention and falling asleep involuntarily in inappropriate or dangerous situations. In a condition of chronic sleep deprivation, even if work were scheduled during an appropriate circadian phase, the probability of falling asleep while working is markedly increased.

Q: Can chronic sleep curtailment progressively deteriorate performance with additional weeks of insufficient sleep?

A: Yes. Recent evidence suggests that even after a single night of 8 to 12 hours of recovery sleep, individuals with a history of recent exposure to chronic sleep loss may be more vulnerable to the effects of re-exposure to sleep restriction, exhibiting nearly double the deterioration in performance on a vigilance task upon acute sleep restriction to 4 hours of time in bed as compared with their response to the same challenge when their recovery sleep was not preceded by exposure to chronic sleep debt [170]. Thus, work schedules that induce chronic sleep curtailment may generate a deterioration of performance that becomes progressively greater with additional weeks of insufficient sleep. Despite intermittent opportunities for recovery sleep, individuals exposed to such schedules become increasingly vulnerable to the adverse effects of sleep loss on performance. We recently demonstrated in my laboratory that when individuals are chronically exposed to a schedule that affords inadequate time for sleep (i.e., 5.6 hours available for sleep each day), then the adverse effects of misalignment of circadian phase and acute sleep loss are an order of magnitude greater, even after participants were provided a 10-hour sleep opportunity [13]. We found that even a 10-hour sleep opportunity in bed in a dark and quiet room is insufficient to reverse the increased vulnerability to sleep loss associated with a week of chronic sleep restriction to 5.6 hours of time-in-bed per 24 hours [13]. Moreover, we have found that chronic sleep curtailment, even without extended wakefulness that exceeds 16 hours, similarly degrades human vigilance performance [167].

Q: How exactly does increased and chronic sleep deprivation affect performance and the probability of performance failure?

A: Increasing sleep deprivation leads to cognitive slowing, an increased probability of experiencing lapses of attention, episodes of automatic behavior [171, 172] and/or falling asleep while attempting to remain awake at work or on the commute to or from work. In a condition of chronic sleep deprivation, even if work were scheduled during an appropriate circadian phase, the probability of a sleep-related attentional failure or neurobehavioral performance failure while awake is markedly increased [15, 16, 163]. In fact, six hours of time in bed per night for a week or two brings the average young adult to the same level of neurobehavioral impairment as 24 hours of wakefulness, whereas 4 hours of time in bed per night induces that same level of impairment in four to six days and, within a week or two, induces a level of impairment comparable with 48 hours of wakefulness (i.e., two consecutive days and nights without sleep).

Q: Can you give examples of some other problems associated with sleep deprivation?

A: Young adults are particularly vulnerable to the adverse impact of acute and chronic sleep deficiency on neurobehavioral performance and fatigue-related motor vehicle crash risk [106, 173, 174]. Metabolic studies have demonstrated that such sleep curtailment also has adverse effects on the metabolic and immune systems, leading to alterations in glucose metabolism and increasing the probability of weight gain [175-180]. As with alcohol intoxication, chronically sleep-deprived individuals tend to underestimate the extent to which their performance is impaired, failing to judge accurately the impact of sleep deficiency on their functioning and alertness, despite increasing impairment evident in objective recordings of the rate of lapses of attention (see Figure 7 below from [16]).

Figure 7.

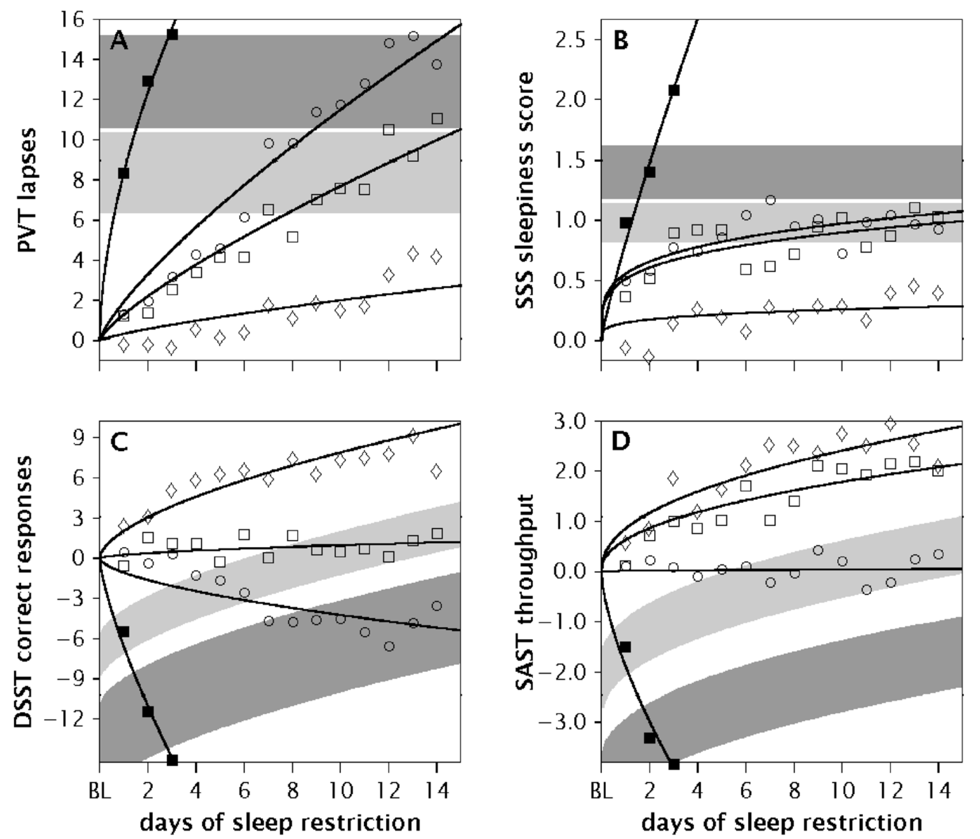


Figure 1—Neurobehavioral responses to varying doses of daily sleep. Four different neurobehavioral assays served to measure cognitive performance capability and subjective sleepiness. Each panel displays group averages for subjects in the 8 h (◊), 6 h (□), and 4 h (○) chronic sleep period conditions across 14 days, and in the 0 h (■) sleep condition across 3 days. Subjects were tested every 2 h each day; data points represent the daily average (07:30–23:30) expressed relative to baseline (BL). Panel A shows psychomotor vigilance task (PVT) performance lapses; panel B shows Stanford Sleepiness Scale (SSS) self-ratings; panel C shows digit symbol substitution task (DSST) correct responses; and panel D shows serial addition/subtraction task (SAST) correct responses per min. Upward corresponds to worse performance on the PVT and greater sleepiness on the SSS, and to better performance on the DSST and the SAST. The curves through the data points represent statistical non-linear model-based best-fitting profiles of the response to sleep deprivation (equation (1)) for subjects in each of the four experimental conditions. The mean ± s.e. ranges of neurobehavioral functions for 1 and 2 days of 0 h sleep (total sleep deprivation) are shown as light and dark gray bands, respectively, allowing comparison of the 3-day total sleep deprivation condition and the 14-day chronic sleep restriction conditions. For the DSST and SAST, these gray bands are curved parallel to the practice effect displayed by the subjects in the 8 h sleep period condition, to compensate for different amounts of practice on these tasks.

F. Sleep-wake Transitions, Sleep Attacks and Automatic Behavior

Q: Are individuals able to force themselves to stay awake when struggling with elevated sleep pressure?

A: Importantly, individuals struggling to stay awake in the face of elevated sleep pressure—whether due to chronic sleep restriction or circadian misalignment—are not always able to do so. Sleep deprivation greatly increases the risk that an individual will succumb to the increased sleep pressure, and that the brain's "sleep switch" located in the ventrolateral preoptic (VLPO) area of the hypothalamus [64] will initiate an involuntary transition from wakefulness to sleep. Due to the influence of the circadian timing system, such an involuntary transition from wakefulness to sleep is most probable in the latter half of the night near the habitual wake time, which coincides with the morning commute, and in the mid-afternoon.

Q: Can you give one common example of where the consequences of sleep deprivation are especially evident?

A: These classic consequences of chronic partial sleep deprivation are particularly evident while doing a routine task like driving. In a condition of chronic sleep deprivation, even when work (or wakefulness) is scheduled during an appropriate circadian phase, the probability of a sleep-related neurobehavioral performance failure while working and/or driving is markedly increased. Of course, once an individual has lost the struggle to stay awake and makes the transition from wakefulness to sleep—however briefly—driving performance is much worse than that of a drunk driver, as the individual is unresponsive to the environment throughout the duration of the micro-sleep episode or the sleep attack. Moreover, when work (or wakefulness) is scheduled during an inappropriate circadian phase, the probability of a sleep-related neurobehavioral performance failure while commuting home from work after the overnight shift is also markedly increased.

In addition, sometimes drowsy individuals linger in an intermediate state between sleep and wakefulness. The operator of a motor vehicle in this sleep-related condition, which probably represents a transitional state in which part of the brain is locally asleep while part of the brain remains awake, may maintain full pressure on the accelerator pedal and proceed for a considerable distance, even negotiating gradual turns and exhibiting goal-directed behavior, but fail to heed stop signals or respond appropriately to traffic conditions in a timely manner. This intermediate state, which has been termed automatic behavior syndrome, is characterized by retention of the ability to maintain pressure on the accelerator, to turn the steering wheel and to carry out rudimentary tasks and to provide semi-automatic responses to stimuli without appropriate cortical integration, often resulting in a complete loss of situational awareness and judgment [171, 181, 182]. In the case of a motor vehicle driver, this could involve driving toward the flashing hazard lights of disabled vehicles in a highway breakdown lane rather than steering clear of those vehicles.

Q: Can you give another example where automatic behavior syndrome has been documented?

A: Another example of automatic behavior syndrome has been repeatedly documented in trains equipped with alerter devices that are designed to stop the train if an engineer were to fall asleep or otherwise be incapacitated. Unfortunately, as Oman and Liu reported in 2007,

"…automatic resetting behavior among engineers … ultimately defeats the purpose [of the alerter]." [Oman CM, Liu AM. Locomotive In-Cab Alerter Technology Assessment. In Development of Alternative Locomotive In-Cab Alerter Technology: Final Technical Report DOT Volpe PR#79-3389, DTS-79, Volpe National Transportation Systems Center, Cambridge, MA, 30 November, 2006]. One stakeholder in the rail industry provided an apt description of the impact of fatigue on the effectiveness of the alerter devices: "Engineers can become inattentive and keep hitting the alerter even when nodding off. 'Alerter naps' has become a commonly used term." Oman and Liu report that: "Accident investigations show that fatigued engineers are able continue their automatic resetting behavior even while in a very low level of physiological arousal, including brief episodes of micro-sleep, thus defeating the original purpose of the alerter." And that "The NTSB has noted that current alerter designs foster the development of automatic pre-emptive resetting behavior by drowsy engineers…."

G. <u>Drowsy Driving and Sleep-related Motor Vehicle Crashes</u>

Q: How frequently do Americans drive drowsy and fall asleep behind the wheel?

A: National survey data reveal that 56 million Americans drive while drowsy each month, and an estimated 8 million Americans fall asleep at the wheel each month—with half of those who do so drifting into another lane or onto the rumble strip and 10 percent running off the road [183]. Remarkably, many drivers continue to operate their vehicles in a nether world between wakefulness and sleep that is associated with automatic behavior, which can occur when part of the brain is awake and part is asleep. A striking example of sleep-related automatic behavior associated with operation of a motor vehicle for an extended duration of time was documented in a video recording, when the husband of a motorist who was nearly driven off the highway by a drowsy driver called 911 to report the drowsy driver and then videotaped the drowsy driver as she drove for 30 minutes on U.S. Interstate 25 in Denver. In that 30-minute video, the driver can be seen with her head leaning back against the headrest, as shown in Figure 8.

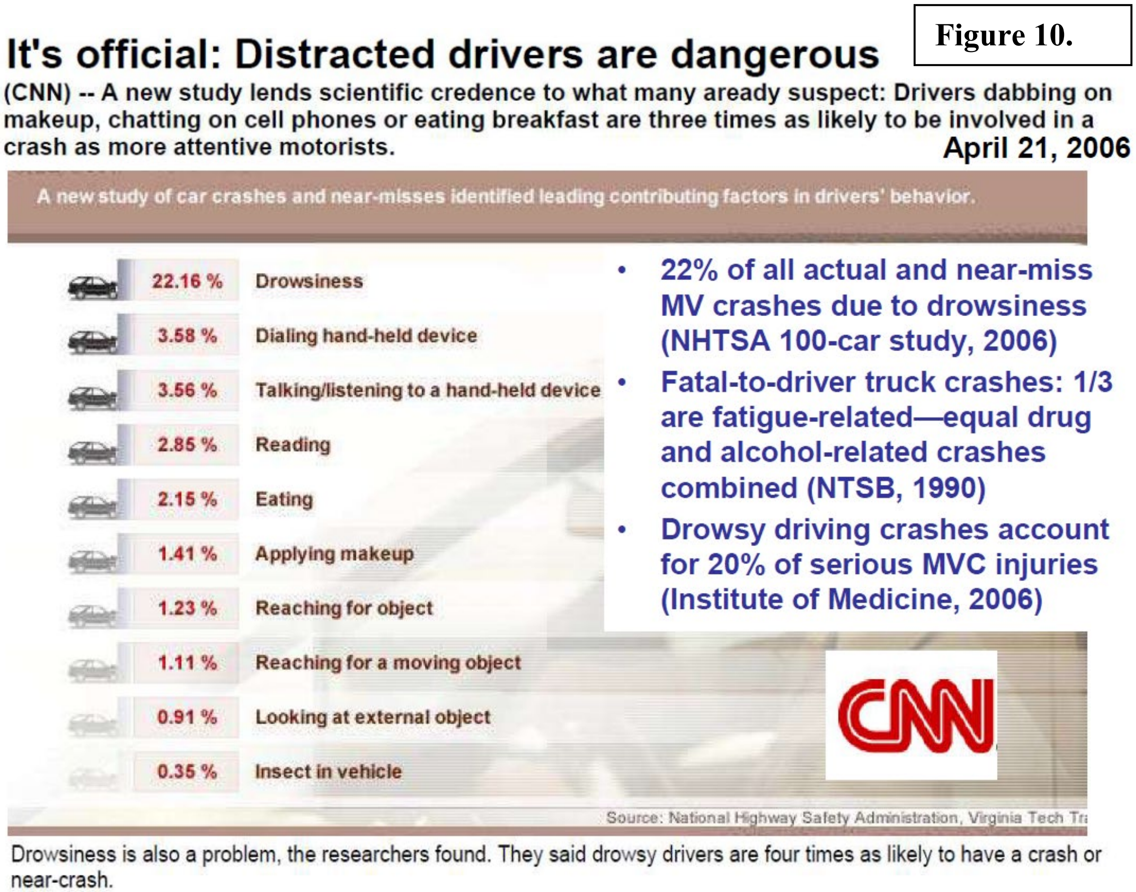
Figure 8. An admittedly drowsy driver, Ms. Karyn Steinert, is shown leaning against the headrest while driving on I-25 in Denver at speeds of up to 70 mph. She reportedly caught herself nodding off at the wheel frequently during this drive and told the Colorado State Trooper who ticketed her for investigation of reckless driving that she only had 2 hours of sleep the night beforehand. The incident was documented on the morning of October 15, 2007 by Christian Pruett and his wife, who was driving on Interstate 25 in Denver, when they both noticed a white sport utility vehicle next to them drifting from lane to lane, and nearly sideswiping their car. Mr. Pruett grabbed their video camera and photographed the sleeping woman with her head back as her vehicle moved along I-25.

Figure 9. Screen capture from a video of a white sport utility vehicle (right) driven by an admitted drowsy driver, Ms. Karyn Steinert. In this image, the white SUV driven by Ms. Steinert is shown drifting across the white line on the left side of the middle lane in which she is driving, forcing the dark-colored pickup truck in the left passing lane over the fog line and the rumble strip and onto the shoulder of the interstate highway. Ms. Steinert admitted that she had caught herself nodding off at the wheel frequently during this 30-minute videotaped drive, in which she similarly caused a tanker truck to go onto the shoulder. The incident was documented on the morning of October 15, 2007 by Christian Pruett and his wife, who was driving on Interstate 25 in Denver, when they both noticed a white sport utility vehicle next to them drifting from lane to lane, and nearly sideswiping their car. After calling the police, Mr. Pruett videotaped and photographed the sleeping woman with her head back as her vehicle moved along I-25.

Q: What percentage of automobile accidents are caused by sleep deficiency and sleep disorders?

A: Sleep deprivation degrades reaction time, impairs judgment, memory and vigilance, reduces attention span, increases distractibility, and raises the risk of attentional failures, automatic behavior, falling asleep at the wheel and motor vehicle crashes, with sleep deficiency and sleep disorders accounting for a population-attributable risk of at least 20 percent of all motor vehicle crashes [25]. This estimate is consistent with the conclusion of the Institute of Medicine and the AAA Foundation for Traffic Safety that sleep deficiency and sleep disorders account for 20 percent of serious crash injuries and deaths, and with the National Center for Statistics and Analysis that "Drowsy/Asleep/Inattentive" drivers account for 20 percent of fatal two-vehicle truck crashes [1, 22, 24, 156, 184, 185]. Moonesinghe, et al., *An Analysis of Fatal Large Truck Crashes*, Mathematical Analysis Division, National Center for Statistics and Analysis, National Highway Traffic Safety Administration, U.S. Dept. of Transp., Report No. DOT HS 809 (Mar. 2003).

Figure 10.



The conclusion that drowsy driving is a causal factor in 20 percent of all serious injuries resulting from motor vehicle crashes in the U.S. [1, 184] is consistent with earlier reports [186] and with estimates in the U.K. [105]. As illustrated in Figure 11 below, sleep-related crashes therefore result in nearly 55,000 debilitating injuries and 6,400 to 6,800 deaths annually [1, 24]

(Figure 12). These estimates are also consistent with data from a recent study conducted by researchers at Virginia Tech that was funded by the U.S. Department of Transportation, in which 100 automobiles were equipped with multiple video monitors, and the driving of all of the individuals driving those cars were monitored over a year-long duration [187]. Sleep deprivation renders drivers unfit to drive [185]. Video camera recording of the driver's face was continuously recorded and scored for distractions, such as cell phone use, eating, personal grooming, conversations with passengers, operating a GPS, etc., and drowsiness. The automobiles were instrumented to capture actual and near-miss crash incidents. Drowsiness was by far the most common contributing factor to these incidents, accounting for 22 percent of them [187, 188], equal to the contribution frequency of all other distracters combined (see Figure 10 above). Legislation is needed at the state level to address the epidemic of drowsy driving [184].

Figure 11.

Q: Can you give some driver-reported statistics that relate to drowsy driving in the United States specifically?

A: Nationally, it is estimated by drivers that drowsy driving contributed to 1.35 million crashes within the prior 5 years. An estimated 7.5 million drivers admit to having fallen asleep at the wheel within the past month, and another estimated 7.5 million drivers admit to having fallen asleep at the wheel during the prior 2–6 months (i.e., an average estimate of 300,000 drivers fall asleep at the wheel per day in the U.S.) [183]. The following text quotation is adapted from the published results of a national survey study conducted in 2002 by NHTSA: "The average drowsy driving experience is associated with the following characteristics: the driver averaged 6.0 hours of sleep the previous night (and 24% had slept fewer than five hours); the driver had been driving for an average of 2.9 hours (but 22% had been driving for more than four hours); the incident occurred while driving on an interstate type highway with posted speeds of 55 mph or higher (59%); and nearly half (48%) of the drivers reported that they nodded off between 9 p.m. and 6 a.m. [183]. The overwhelming majority (92%) of drivers who nodded off while driving within the past six months reported that they were startled awake. However, 33% drifted into another lane or onto the shoulder, and 19% admit that they crossed the centerline. In 10% of cases, the driver reportedly ran off the road. An estimated 292,000 drivers are involved in some type of crash within the past six months as a result of nodding off at the wheel." [183]. In 2009, the Commonwealth of Massachusetts issued the report of the Massachusetts Commission on Drowsy Driving, on which I served as a member, to address this important public safety issue in Massachusetts [184] I also served as Chair of a National Sleep Foundation Task Force to develop a multidisciplinary expert consensus statement on the impact of sleep deficiency on driver fitness [185].

Q: Why are the consequences of sleep deficiency so evident in a routine task like driving?

A: These widely recognized consequences of sleep deficiency are particularly evident while doing a routine task like driving because operating a motor vehicle is a demanding, vigilant task that is uniquely vulnerable to a momentary lapse of attention or slowed reaction time. Moreover, driving is a routine, highly over-learned task with minimal novelty that occurs while drivers are in a sedentary position. Night driving takes place in dim light or near darkness, providing a minimal photic alerting signal to the brain.

Drowsiness is Special Problem for Motor Vehicle Operators

Figure 12.

- Operating motor vehicles is a routine, highly-over-learned task with minimal novelty
- Drivers are usually in a sedentary position
- At night, motor vehicle drivers are usually in dim light or near darkness
- Task is uniquely vulnerable to momentary lapse of attention or slowed reaction time

- Drunk Driving ~10,800 deaths annually
- Drowsy Driving ~ 6,800 deaths annually
- Distracted Driving ~ 5,500 deaths annually

Figure 12. Operating a motor vehicle is a demanding vigilance task that is uniquely vulnerable to sleep deficiency and circadian misalignment and is associated with nearly twenty fatalities in the United States each day [22].

Q: How does chronic sleep deprivation effect driving compared driving under the influence of alcohol?

A: In a condition of chronic sleep deprivation, even when work (or wakefulness) is scheduled during an appropriate circadian phase, the probability of a sleep-related neurobehavioral performance failure while working or driving is markedly increased. Once an individual has lost the struggle to stay awake and makes the transition from wakefulness to sleep—however briefly—driving performance is much worse than that of a drunk driver, as the individual is unresponsive to the environment throughout the duration of a sleep-related attentional failure, such as a sleep-related lapse of attention, a micro-sleep episode or a sleep attack. In 2004, Lamond and colleagues published a study in which they quantified the deterioration in neurobehavioral performance that occurs at the end of the night shift in comparison with that induced by alcohol intoxication [189]. In this laboratory-based study simulating night shift work, individuals were scheduled to work in the laboratory on a series of consecutive 8-hour shifts and scheduled to sleep up to 11 hours per day in a sound-attenuated, dark room during the daytime. Neurobehavioral performance in those participants in the night shift work condition was compared with an alcohol intoxication condition in which those same participants were required to consume alcoholic beverage "consisting of 40% vodka and a non-caffeinated soft drink mixer, at hourly intervals." Notwithstanding the greater opportunity for sleep between shifts afforded by an 8-hour as compared to a > 12-hour shift, after the third consecutive 8-hour overnight shift, "impairment equivalent to that caused by a BAC [blood alcohol concentration] of 0.10% was observed for lapse frequency [i.e., attentional failures] at the 8th hour [i.e., at 7 am]" [189]. As with alcohol intoxication, chronically sleep deprived individuals tend to underestimate the extent to which their performance is impaired, despite increasing impairment evident in objective recordings of the rate of lapses of attention or attentional failures [16]. Moreover, most drivers who cause sleep related motor vehicle crashes are often reportedly unaware that they fell asleep or had a sleep related attentional failure that caused the crash [190]. Sleep deficiency, circadian disruption, sleep-promoting drugs or foods, and medical illness can all increase the risk of impairment by fatigue (Figure 13). Soporific environmental conditions can exacerbate this risk.

Figure 13.

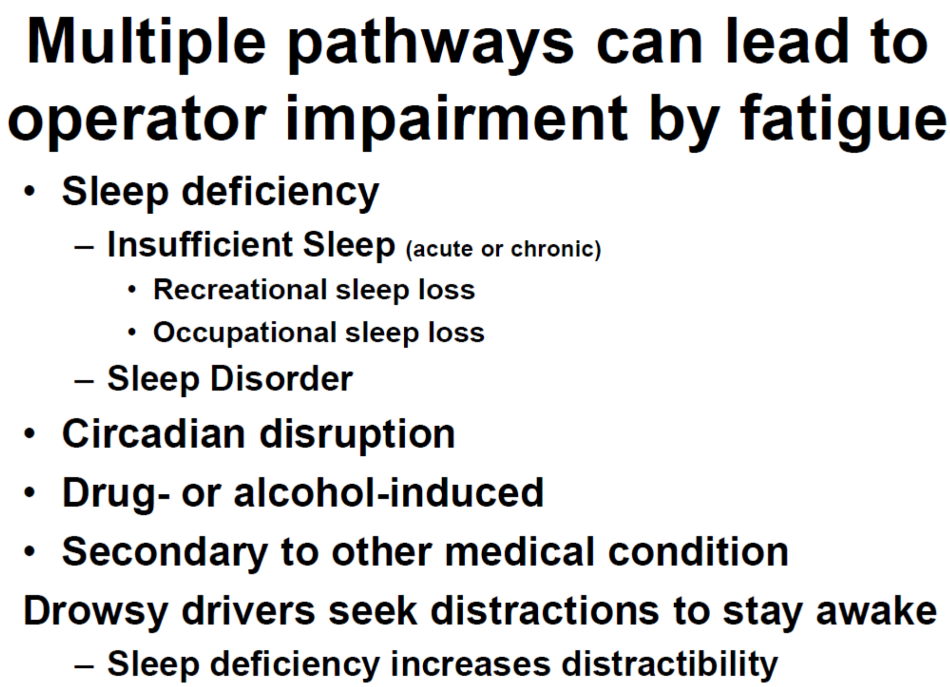


Figure 13. Many different factors can result in the fatigue-related impairment [22].

H. <u>Interruptions of sleep and sleep inertia</u>

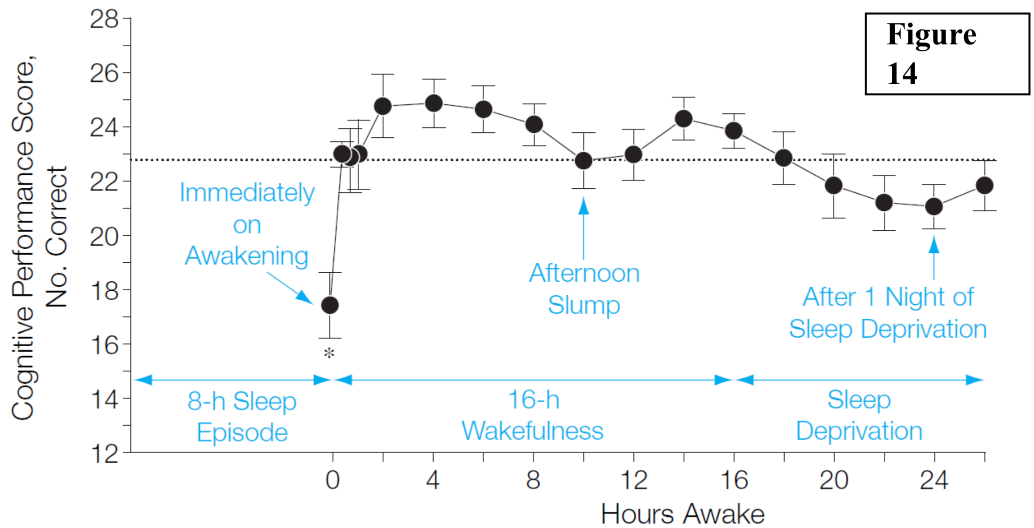
Q: How do sleep interruptions affect alertness and what are some compounding factors?

A: Repeated interruptions of sleep, such as is experienced by employees when they are on call, degrade the restorative quality of sleep, compared to an equal amount of consolidated sleep. Such repeated interruptions of sleep are thought to contribute to the excessive daytime sleepiness associated with sleep disordered breathing, which induces many brief arousals during the night. Interestingly, just being on call itself disturbs sleep, even when the individual is not called [191, 192].

Q: What is sleep inertia and how does it relate to cognitive performance?

A: Cognitive performance is markedly degraded during the transition from sleep to wakefulness [11, 193-204]. The extent to which this phenomenon, which is called sleep inertia, interferes with neurobehavioral performance is related to the depth of the prior sleep episode [200]. Thus, agents that interfere with sleep, such as caffeine, can mute the effect of sleep inertia [205]. The adverse impact of sleep inertia on neurobehavioral performance can exceed the impact of total sleep deprivation, as shown in Figure 14 from our publication in the Journal of the American Medical Association (JAMA)[11]. Individuals who are subjected to acute total sleep deprivation or chronic sleep restriction often experience very deep sleep, which together with an adverse circadian phase will increase the effects of sleep inertia [10, 11, 200, 206, 207]. Upon awakening from sleep, individuals will often be confused and may even lack situational awareness.

Figure. Cognitive Performance on Awakening From Sleep Compared With Subsequent Sleep Deprivation



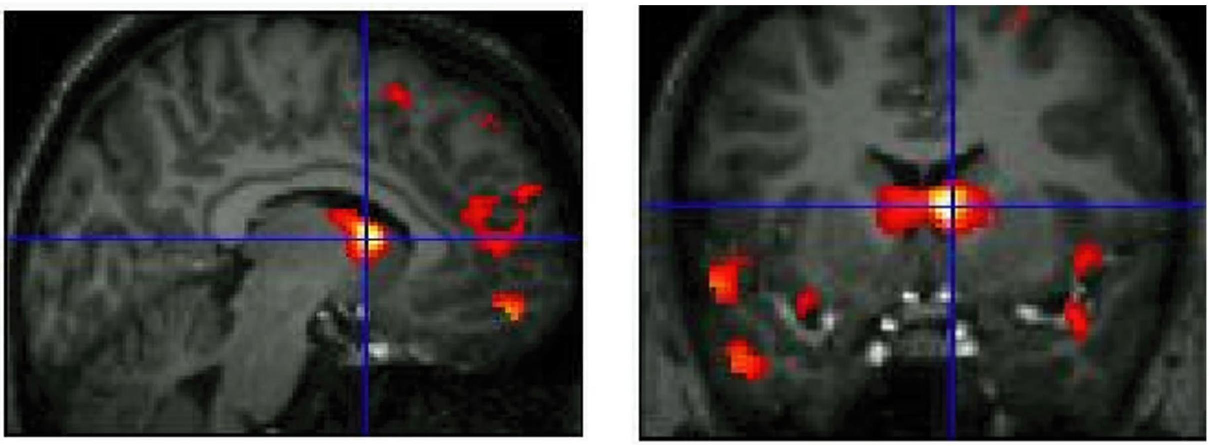
The group mean (horizontal dotted line) across the sleep inertia period and 26-hour awake period has been added to the deviation from the mean scores for the number of correct responses in 2 minutes to permit overall assessment of the magnitude of performance impairment. Error bars indicate SEM; asterisk, differs from all subsequent time points at $P \leq .01$.

Q: You performed research that documents the effects that sleep inertia can have on cognitive performance. Would you please briefly describe that study?

A: Yes. As shown in Figure 15 below from research performed in my laboratory by Dr. SE McCormack in collaboration with Drs. K Kwong and BR Rosen at MIT, sleep inertia following a 45-minute sleep episode in an MRI brain scanner at 4 am is associated with local loss of functional Magnetic Resonance (brain) Imaging activation in response to an attention task. (SE McCormack, D Aeschbach, K Kwong, BR Rosen, CA Czeisler, Presented at the 17th Congress of the European Sleep Research Society, P087, October 9, 2004, Prague, Czech Republic).

Figure 15.

SLEEP INERTIA: Thalamus and frontal cortex are particularly slow to recover in the first 15-30 minutes after awakening



Focal loss of fMRI activation to an attention task following a 45 minute sleep episode at 4 am.
From: SE McCormack, D Aeschbach, K Kwong, BR Rosen, CA Czeisler, Presented at the 17TH Congress of the European Sleep Research Society, P087, October 9, 2004, Prague, Czech Republic

I. Night Shift Work Induces Misalignment Between the Phase of Circadian Pacemaker and the Work Sleep Schedule.

Q: Can night shift workers ever adapt their circadian rhythms to achieve a truly inverted sleep/wake schedule?

A: No. For the night shift worker, scheduled work hours occur during those normally reserved for sleep. As a result, the worker attempts to remain awake during habitual sleeping hours, when the brain is programmed to promote sleep, and attempts to sleep during habitual waking hours when the brain is programmed to maintain wakefulness. Since the turn of the century, it has been recognized that complete physiologic adaptation of endogenous circadian rhythms to the required inversion of their sleep wake schedule, even among permanent night shift workers, does not occur even after years of permanent nighttime work [47, 208-213].

Maladaptation of night shift workers' circadian system to their required work schedule results from their exposure to conflicting environmental and behavioral synchronizers. For a commercial motor vehicle driver, this is particularly true on days that they are driving, since drivers are exposed to the solar light-dark cycle to a much greater extent than a person working in an indoor environment. This light exposure synchronizes the biological clock to the solar day, reinforcing a conventional schedule of day activity and night sleep. Therefore, a maladaptive circadian phase relationship with the outside world is maintained for the night commercial motor vehicle driver, promoting sleep at night and wakefulness during the day. This environmental synchronizer is also reinforced by exposure to social and behavioral influences promoting day activity and night sleep, such as the often day-oriented schedules of pickup and drop-off locations. These influences often lead the night shift worker to postpone, interrupt or truncate daytime sleep. Exposure to these environmental, social and behavioral synchronizers can overcome the potential effect of the inverted work-rest schedule on the circadian clock, resulting in misalignment between the biological time programmed into the brain's circadian clock and the work rest schedule required of the night shift worker [47]. Misalignment of the circadian pacemaker with the desired sleep wake schedule is thus a chronic consequence of night shift work, even among permanent night shift workers.

Q: Is there a period during the usual sleep time when night shift workers are especially vulnerable to impaired cognitive performance?

A: Numerous laboratory studies, including those in my own laboratory, have shown that there is a prominent circadian variation in objective and subjective measures of alertness, performance (psychomotor, vigilance, memory) and attention or ability to concentrate with a nadir in the latter half of the usual sleep time [4, 30, 66, 86, 210, 214-226]. Because of the failure of the circadian pacemaker to adapt to the inverted work schedule in most night shift workers, the peak drive for sleep continues to occur during the latter half of the night and into the morning hours while the employee is at work and/or commuting home from work. In 1995, Pack et al. noted that the peak of fatigue-related motor vehicle crashes occurs in the early morning hours between 7–8 a.m. [190]. Extended duration work shifts, in which night workers are also scheduled to work during daytime hours can further increase sleep pressure and lead to increased risk of sleep-related neurobehavioral performance failure [227].

Q: Do individuals differ in their ability to maintain performance during night work?

A: Yes, there are inter-individual differences in the ability to maintain performance during night work. Increased vulnerability to attentional failure during acute sleep deprivation in women depends on menstrual phase [228].

Q: What is Shift Work Disorder and are there effective treatments?

A: Excessive sleepiness during night work or insomnia during day sleep are the cardinal symptoms of Shift Work Disorder [229], which recent research indicates may have a genetic basis in some individuals [230]. A number of countermeasures and treatments can be effective in treating the symptoms of Shift Work Disorder, including improvements in work scheduling, use of properly timed use of light, administration of nutritional supplements such as caffeine and melatonin, and use of pharmacologic agents such as modafinil, as we have demonstrated in my laboratory and our field study investigations [8, 43, 47, 231-236].

J. Night Shift Work Leads to Sleep Deprivation.

Q: How does night shift work lead to sleep deprivation?

A: Several mechanisms are responsible for the sleep deprivation associated with night shift work. The first and most direct effect is that the employees are now awake and working during the hours at which they ordinarily sleep. This can occur when employees work throughout the time of their usual sleep episode (e.g., an overnight work shift), during the first half of the usual sleep episode (e.g., a late evening shift), or during the final half of their usual sleep episode (e.g., an early morning shift). Second, abnormalities in the internal architecture and consolidation of sleep result from the misalignment of their attempted sleep time with the output of their biological clock, causing sleep deprivation, even when there is ample time available for sleep between shifts. Laboratory studies that I and others have conducted have demonstrated conclusively that the length of a sleep episode is dependent on the phase of the circadian system at which the sleep occurs, even when participants are studied in sound-attenuated rooms and shielded from external time cues [28, 29, 66, 67, 237]. Studies have demonstrated that sleep duration is reduced during daytime hours as compared to the night [238, 239]; daytime sleep is accompanied by more frequent arousals and changes in intra-sleep architecture. Even in a soundproofed environment and/or one without time cues, sleep is quantitatively and qualitatively different from that obtained at night, with a deficit of both minutes and types of sleep. Daytime sleep episodes are shorter in duration than nighttime sleep episodes because the night shift worker is attempting to sleep just as the internal biological alarm clock sounds to wake him or her up, a consequence of a misalignment between the circadian pacemaker and the external environment. For example, the daytime sleep of train drivers scheduled to work at night is cut short when sleep is attempted during the daytime at an adverse circadian phase [Foret J and Lantin G, in Aspects of Human Efficiency, W. P. Colquhoun, Ed. (English Univ. Press, London, 1970), pp. 273-282] [66]. The daytime sleep of night shift workers worsens with advancing age [238-240]. When an inadequate amount of time is available between shifts, sleep deprivation will further alter sleep stages. Sleep disruption is more pronounced in middle aged shift workers than in younger shift workers [239, 241]. Nurses commonly admit to falling asleep while working at night, with almost two thirds (65%) of the nurses working the night shift reporting struggling to stay awake at work and 20% falling asleep at work [242].

Q: How do environmental disturbances and social norms contribute to night shift worker sleep deprivation?

A: Environmental disturbances further interrupt the daytime sleep of the night shift worker. Noise from children, road traffic, telephones, doorbells, and other family members are the most commonly reported causes of sleep interruption of the night shift worker [243, 244]. In one survey of 9,000 shift workers, children's noise was mentioned in 77.9 percent of the complaints, road traffic noise in 63.2 percent and telephone ringing in 54.5 percent [243]. Field studies of shift workers worldwide indicate that the majority of workers whose schedule includes night work (midnight to 7 am) experience disturbed day sleep [243, 244].

Furthermore, night workers are often attempting to sleep at a time when not only environmental activities, but also social activities are at a peak. Therefore, many night shift workers voluntarily elect to shorten their sleep in order to attend to social and family obligations. In fact, night shift workers are much more likely than day workers to set alarms to interrupt sleep [245], notwithstanding the increasing sleep debt they are accumulating. Thus, pressure from the demands of society often leads night shift workers to interrupt and even prematurely truncate the sleep that they would be able to achieve during the day. Employees working on call and/or irregular schedules also suffer from poor quality sleep. i.e., sleep that is less restorative for optimal work time functioning.

Q: How much less sleep do night shift workers typically get during the day compared to at night?

A: Overall, night shift workers sleep an average of one to two hours less during the day than at night [47, 239, 244], accumulating approximately one lost full night of sleep for every week of night work. Furthermore, on individual days they are often able to sleep only 1 to 3 hours [244], resulting in acute sleep deprivation. Subjective sleep quality and quantity is also poorer during day sleep [246-248].

Data from field studies collected on shift workers are thus consistent with the conclusion that rotating shift workers are both chronically and acutely sleep deprived when working at night and attempting to sleep during the day. These problems with shorter and poorer quality sleep often persist despite government or industry polices that mandate rest time. Unless sufficient duration and quality sleep occurs, rest alone will have no significant impact on promoting alertness and performance during subsequent working hours. For this reason, it is critical that employers in safety-sensitive industries require employees in general, and night workers in particular, to notify the employer and be relieved of any scheduled work assignment if, for whatever reason, the employee is not fit for duty due to insufficient sleep duration or quality.

K. Worker Survey Data on the Effects of Shift Work

Q: What research have you performed that catalogs the prevalence of sleeping and inattentiveness among shift workers?

A: My own research in the field has provided compelling evidence of the prevalence of sleeping and inattentiveness among shift workers. My colleagues and I have worked with companies from a variety of industries nationwide to evaluate the shift work schedules of workers at those companies using questionnaires designed to evaluate shift work schedules, employee preferences and sleep disorders.

The questionnaires sought information on worker satisfaction, health practices, and adaptation to their existing shift schedules. The questionnaires specifically asked how frequently the employees "nodded off" or fell asleep while at work. Steps were taken to protect worker confidentiality and encourage participation.

Q: What were the results of these questionnaires?

A: The analysis presented below represents results of surveys administered to a total of 2,583 workers from 12 companies. Only those workers who indicated that they currently worked a 3-shift rotation, including day, evening, and night shifts, were included in the analysis. The 12 companies are from a variety of industries and include an urban police department, a paper company, a plant producing rubber for the tire industry, a potash harvesting plant, a tire manufacturing company and a utility with both nuclear and non-nuclear facilities.

Summarized below are the results of a series of questions related to attentiveness and the ability to remain awake at work. The survey data show falling asleep at work and loss of alertness to be common features of shift work. Moreover, the risk of falling asleep at work and loss of alertness is elevated during the night shift. These results are consistent with those obtained by other researchers using similar methods [209, 221, 223, 226, 249-254].

When the shift workers were asked how many times per week of working on the day shift they usually nodded off or fell asleep while at work, 21.6% of the 2402 workers who responded said they fell asleep at least once each week on the day shift, with 2% of those indicating that they fell asleep more than five times per week. When working evening shifts, 15.1% of the 2392 workers surveyed said they nodded off or fell asleep one or more times per week, with 0.7% indicating that they fell asleep more than five times per week. When asked about working the night shift, 55.7% of the 2424 respondents said they fell asleep at least once per week, with 12.1% responding that they fell asleep more than 5 times per week. These inter-individual differences in the severity of symptoms of Shift Work Disorder derived from workers participating in field studies are consistent with laboratory investigations that have revealed considerable differential vulnerability to the deterioration in neurobehavioral performance associated with sleep loss and night shift work [255-260].

Overall, 57.0% of 2363 workers reported falling asleep at least once during a full shift rotation. While results varied by company, at least 40% of the workers from each and every company reported nodding off or falling asleep on the night shift at least once per week.

Q: Can you describe your findings with respect to sleepiness among Nuclear Powered Electric Power Generation plant workers on 8-hour Shifts?

A: There is a common misconception that in critical situations, where individuals have great responsibility for human life, they can voluntarily overcome the effects of sleep loss and misalignment of circadian phase. Our survey data did not support this hypothesis. Even nuclear power plant workers experienced the same debilitating effects of night shift work on alertness and performance.

As with shift workers in the other industries we surveyed, the nuclear plant personnel reported a significant drop in their level of alertness on the night shift. This drop was reported by both licensed and non-licensed nuclear plant personnel. In addition, both licensed and non-licensed personnel reported that they were most tired on the night shift. In fact, 49.4% of the nuclear power plant workers reported that they fell asleep at least once per week on the night shift, with 30.5% reporting that they fell asleep 2 to 5 times per week, and 5.2% reporting 6 to 10 times per week. As in other industries, nodding off or falling asleep at work occurred to a lesser extent on the day and evening shifts. The predominance of reported sleeping on the night shift is consistent with the fact that 71% of the 2,498 workers responding indicated that they were most tired on the night shift. 17.3% indicated they were most tired on the day shift, 4.2% responded that they were most tired on the evening shift, and 7.5% said that they were not more tired on any shift.

Similarly, when asked to rate their alertness on the VAS, the average + S.E.M. alertness score of 2,392 workers on the night shift was 42.0 + 0.54; the average alertness score of 2,322 workers on the day shift was 66.5 + 0.47; and the average alertness score of 2,366 workers on the evening shift was 73.0 + 0.42; and the average alertness score of 2,180 respondents on their days off was 76.9 + 0.43. When asked if they thought that their schedule makes them sleepy, a majority of workers (54.1% of 2,342) answered YES. On a separate question asking if they felt too sleepy during work, 36.8% of 799 workers who were asked this question responded affirmatively.

Q: Can describe the questionnaires' results regarding attentional failures and occupational safety?

A: The impact of the profound fatigue associated with night shift work is highlighted by the responses from employees reporting instances of falling asleep driving to or from work: 17.6% of 1,270 shift workers reported that they had fallen asleep while driving to or from work in the last year and 30.4% of 2,368 shift workers reporting that they had at least one near miss or actual automobile accident due to sleepiness in the past year. A subset of these workers was asked more detailed questions regarding the circumstances of these accidents. 3.6% of all workers responding reported having an actual automobile accident due to sleepiness. Of these 15 workers, ten had accidents on a workday. Two reported accidents that happened while on evening shift rotation, and eight occurred to workers on the night shift.

Of the 428 workers responding to a question about near-miss automobile accidents due to sleepiness, 146 (34.1%) reported having at least one actual or near-miss automobile accident due to sleepiness in the past year. When asked about procedural errors at work due to sleepiness, 19.7% of 233 workers responding reported at least one procedural error, and 33.2% of 214 workers responding reported near-miss procedural errors at work due to sleepiness. When questioned about personal injury accidents at work due to sleepiness, 6.9% of 245 workers responding reported actual personal injury accidents, and 18.4% of 228 workers reported near-miss personal injury accidents due to sleepiness.

Q: There are many studies regarding attentional failures and occupational safety. Can you please briefly describe some of those studies and their results?

A: Yes. First, in 1992, we published data on a study of 876 nurses. We found that 32.4 percent of those who always worked nights reported falling asleep during the night shift at least once a week [261]. Furthermore, we demonstrated that nurses who worked the night shift had 2.24-fold greater odds of a motor vehicle crash and nearly double the risk of a near-crash [261].

In 1996, Novak and Auvil-Novak published data from a cohort of night-working nurses, 95.5 percent of whom report that that they had experienced at least one accident or near-accident driving home from the night shift [262]. In 1999, Stutts et al. reported that working the night shift increases the odds of a sleep-related crash by nearly six times and [263]. In 2007, in a study of nurses, Scott et al. reported that working at night increased the odds of a drowsy driving incident four-fold, such that 79.5 percent of nurses who worked only the night shift had an episode of drowsy driving within a 4-week study interval [264]. Moreover, 3.3 percent of those nurses reported experiencing drowsy driving following every shift worked. In a 2008 study of nurses, Dorrian et al. [265] reported that "nearly half of extreme drowsiness and near-accident reports occurred between 0700 and 0900h. This coincides with the end of the night shift" [265]. These data are consistent with the conclusions from the published literature published by Lyznicki et al. for the Council on Scientific Affairs of the American Medical Association, by Horne [190, 266], by Scott et al. [264], and by Dorrian et al. [265], who concluded that night shift work was associated with a markedly increased risk of fatigue-related motor vehicle crashes. In 2007, Scott et al. concluded: "Given the large numbers of nurses who reported struggling to stay awake when driving home from work and the frequency with which nurses reported drowsy driving, greater attention should be paid to increasing nurse awareness of the risks and to implementing strategies to prevent drowsy driving episodes to ensure public safety. Without mitigation, fatigued nurses will continue to put the public and themselves at risk" [264].

The work schedule itself has a significant effect on the risk of errors and accidents. The number of consecutive work hours; the number of consecutive days of work; the time of day and the frequency of rest breaks have all been found to influence the risk of error and accident [267-270]. A meta-analysis of a number of research studies has revealed that the relative risk of Injury or accident is more than doubled after 12 hours of work [267], comparable to the results of Haneke et al., who reported in 1998 that the relative accident risk increased exponentially after the 9th hour of work to more than double the risk of an 8-hour shift [271]. Rogers and her colleagues found that the risk of error was three times higher when nurses worked shifts of 12.5 hours or longer [270].

When workers experienced with both 8- and 12-hour night shifts were asked which shift resulted in fatigue that decreased their performance at work, 80 percent of respondents felt that the 12-hour workday resulted in the least efficient performance due to fatigue [272]. In a modeling study entitled "The 12-hour Shift Revisited: Recent Trends in the Electric Power Industry" conducted by Ontario Hydro in Toronto, Canada, it was estimated that human error by operators would be doubled by a change from 8-hour to 12-hour shifts, due to fatigue and misalignment of circadian phase. This resulted in a 70 percent increase in their risk assessment of a public accident [273-275]. In addition to (1) night shifts posing a greater risk of injuries and accidents than day shifts, (2) 12-hour shifts posing a greater hazard than 8-hour shifts, (3) the later hours of the night shift posing a much greater hazard than the initial hours of the night shift, and (4) the circadian peak of sleep-related errors and accidents occurring between 6 a.m. to 9 a.m., the number of consecutive days of lengthy shifts also affects the risk of errors and accidents. In 2006, Folkard and Lombardi [267] reported that "there was a significant trend [in the risk of accidents] across four successive night shifts … [such that] risk was about 6% higher on the second night, 17% higher on the third night, and 36% higher on the fourth night."

In 1998, the National Highway Transportation Safety Administration concluded, based on evidence from crash reports and self-reports of sleep behavior and driving performance, that one of the three top population groups at highest risk of drowsy driving crashes was: "Shift workers whose sleep is disrupted by working at night or working long or irregular hours" [276]. The National Highway Transportation Safety Administration noted that "periods of work longer than 8 hours have been shown to impair task performance and increase [the risk of motor vehicle] crashes"[276]. As reported by the Department of Transportation, the relative risk of a fatigue-related crash among truck drivers—which is the leading cause of fatal-to-the-driver truck crashes [102, 277]—increases sharply after 10 hours of driving, such that there is a fifteen-fold increase in the risk of a fatigue-related crash in the group driving more than 13 hours [278] (Figure 16).

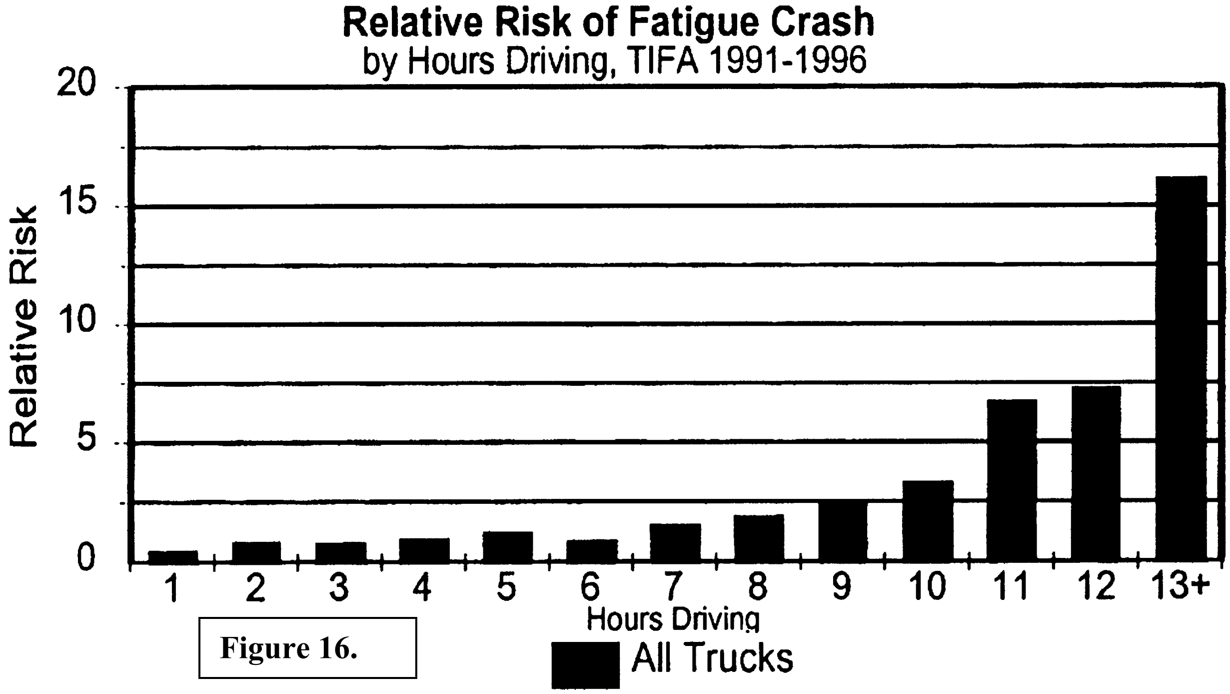


Figure 16.

Figure 16. Figure 16 shows the relative risk of a fatigue-related fatal crash by the number of hours of driving. Data on hours driving up to 1992 came from phone interviews and from the FHWA's form MCS–50T accident reports. Motor carriers involved in certain accidents were required to complete these forms up to 1992. Since elimination of the requirement to file MCS–50T accident reports in 1993, data on hours driving come entirely from phone interviews by University of Michigan Transportation Research Institute researchers. The interview source is the owner of the truck, so the agency expects some under-reporting for hours above the current limits. About one quarter of all respondents refused to answer this question, much higher than the percent missing for any other question. Nonetheless, the data clearly show the impact of extra hours driving on the likelihood of fatigue being cited in a crash. Not surprisingly, risk increases with time driven. Approximately 20 percent of the fatal crashes per year where fatigue is coded as a factor involve the driver being behind the wheel for 13 or more hours [Figure and legend taken from [278]].

In another study, we demonstrated that young physicians in training who were randomized to work 30-hour shifts experienced twice as many attentional failures during nighttime hours as compared to those same physicians randomized to work a schedule in which the longest shift was just over half that duration and was preceded and followed by 13 to 23 hours off [8]. We also found that resident physicians commuting from the hospital after shifts that exceeded 24 hours in duration had a 168 percent greater risk of a motor vehicle crash compared with those same physicians commuting after a shift that averaged approximately 12 hours in duration.

As Harris observed more than forty years ago, truck driving in particular is one of the most demanding vigilance tasks, in which a momentary lapse of attention has the potential for disastrous consequences [104]. Fatigue-related crashes in commercial motor vehicles occur most commonly during night-time hours [103, 104, 279]. Sleep-related fatigue is a major cause of crashes involving heavy trucks due to fatigue-related impairment of driving skills (poor judgment, slowed reaction times, decreased awareness and increased distractibility) [102, 277, 280]. Sleep-related fatigue can be caused by long work hours and lack of sleep and is strongly influenced by time of day [with increased risk in the latter half of the habitual sleep episode and in the mid-afternoon between about 1-5 p.m. [89]]. In May of 1994, two parents in Maine whose son and three of his friends were killed by a truck driver who the parents believe fell asleep at the wheel formed an organization they call "Parents Against Tired Truckers," an organization with the stated goal of reducing heavy truck crashes resulting from truck driver fatigue.

Q: Can you please describe the study that you performed regarding sleepiness among urban police officers working 8-hour Shifts?

A: Thirty years ago, I conducted an evaluation of the impact of the shift work schedule on the alertness and performance of the officers in the Philadelphia Police Department. In order to do so, a survey questionnaire was administered to a representative sample of patrolmen and detectives from all districts and divisions in the City of Philadelphia to obtain information from a cross section of the officers (a horizontal sample). Simultaneously, a single district of patrolmen and detectives was selected for an in-depth evaluation (a vertical sample). In this way, 198 questionnaires were collected from across the City of Philadelphia and 177 questionnaires were collected from members of the 35th District and the Northwest Detectives in the City of Philadelphia, for a total of 375 respondents.

I found that 54.3 percent of the officers reported that they received an inadequate amount of sleep. In fact, the only time that the officers averaged eight hours of sleep per night was during a series of days off. When working, the officers' average daily sleep times were 6.7 hours per 24 hours while on day shift; 7.2 hours while on the evening shift; and 6.3 hours when on the night shift. Significantly, more than 50 percent of the officers reported a moderate to severe problem with poor quality sleep. More than 70 percent of the officers admitted falling asleep on the job (intentional or unintentional) during the night shift; one third of the officers reported falling asleep on the job when working the day shift; and one in seven officers reported falling asleep at work while working the evening shift. Officers who admitted falling asleep at work during the night shift estimated that it happened an average of more than three times per week of night shifts. Officers on the night shift averaged 3.8 of such on-the-job sleep incidents per week, even though falling asleep at work was considered grounds for disciplinary action and/or termination. Furthermore, 41.3 percent of the officers reported feeling tired frequently or most of the time both on and off the job while on the night shift. In fact, one out of every ten officers reported incidents when they actually fell asleep while driving to or from work during the prior year. Nearly one in four officers reported an actual or near miss automobile accident due to sleepiness in the prior year. Thirteen percent of the officers reported three or more such incidents in the prior year. Finally, I found that 75 percent of the officers reported that their schedule did not provide them enough time with their children. Nearly 80 percent reported that their families were dissatisfied with their work schedule. Only 16 percent reported that their families were satisfied with their work schedule.

Q: There have been surveys regarding sleepiness among air traffic controllers on a rapidly rotating shift-work schedules. Can you please provide some of the data from the Federal Aviation Administration's survey?

A: Yes. Survey data reveal that sleep disruption and fatigue are serious problems among air traffic controllers. Data from a Congressionally mandated, FAA-sponsored survey distributed from 1999 to 2000 to all 23,500 FAA personnel with an ATCS designation revealed that 62% of the 4,112 enroute and terminal ATCS respondents reported difficulty sleeping before the midnight shift. In fact, according to a pamphlet published by the FAA in 2001, "67% of ATCS shift workers reported having trouble sleeping because of shift work [and] 46% of ATCS shift workers indicated that they often fall asleep unintentionally." [281]. Reported sleep quality was rated most poorly (averaging only 1.3 on a 1-5 scale in which 5 was high) on the sleep between the day shift and the night shift on the FAA's counterclockwise, rapidly rotating schedule worked by 92 percent of the respondents [281], and the respondents felt least rested (average rating of 1) after the midnight shifts and the least mentally sharp in terms of alertness and memory at the end of the midnight shift, consistent with data from our studies in the laboratory [2]. As the FAA reported in 2001, "Mental sharpness is lowest during the midnight shift because at this time, shift workers must deal with the circadian low point for energy and alertness levels, and the effects of poor quality daytime sleep." [281]. In fact, 77% of the FAA's air traffic controllers on the counterclockwise, rapidly rotating shift work schedule with midnight shifts reported that they had caught themselves about to doze off while at work; 79 percent of the air traffic controllers had sometimes, frequently or always had lapses of attention and 36 percent had actually fallen asleep at the wheel while commuting on the midnight shift [281]. This most often occurred on the commute home from the midnight shift. When asked if the air traffic controllers had any other comments or observations relating to their sleep and fatigue, the most common category of response was: "Quick turn-arounds between shifts cause fatigue and/or are dangerous." This spontaneous response was written in by 164 air traffic controllers. The second most common write-in response category was that "shift work in general causes fatigue, is dangerous, and does not allow a sleep routine," which was noted by 115 respondents.

Q: Can you please provide some objective field data on the effects of shift work across various industries?

A: Yes. The self-reported rate of nodding off or falling asleep at work among nuclear power plant control room operators and police officers seen in our survey data is consistent with survey data on severe sleepiness of train drivers working an irregularly scheduled night shift [282], and with data recently obtained using continuous electroencephalographic (EEG) recordings of power plant operators in Sweden. Dr. Kerstin Dahlgren of the Swedish Nuclear Inspectory has recorded ambulatory polysomnograms on 20 nuclear power plant workers on a rotating shift work schedule and has found that approximately 25 percent of them fall asleep while operating the plant, mainly while on the night shift (Dr. Dahlgren, personal communication). Dr. Dahlgren notes that the operators not only napped when she left them on their own, but they progressed to slow wave sleep, according to the EEG recordings (Dr. Dahlgren, personal communication), a progression which our laboratory studies indicate requires an average of 18.0 + 8.6 minutes (range 9.5 to 33.5 minutes). During her study, she has further personally observed situations in which all five nuclear power plant operators were simultaneously asleep.

Objective field studies have also discovered sleeping among workers subject to circadian rhythm disruptions and/or sleep deprivation in other industries where worker alertness is commonly viewed as a necessary element of successful job performance. For example, studies of airline pilots have revealed instances of pilots asleep while on duty on the flight deck [222, 283] and physicians falling asleep while caring for patients in Intensive Care Units [8]. EEG recordings of the pilots have shown patterns consistent with sleep or inattention. Observers in the cockpit have also seen airline crews take voluntary and involuntary naps. In some cases, the crew discussed who would nap, despite regulations prohibiting such behavior. In fact, a NASA/FAA sponsored study revealed that the pilots of commercial airlines were napping approximately 11% of the time on long haul flights (average flight duration, 10.4 hours) with nap episodes averaging 46 minutes in duration, occurring throughout the flights despite the presence of NASA observers and the knowledge that their EEG patterns were being monitored [284].

Studies of train drivers in the field have shown similar results: EEG and EOG changes consistent with inattention, microsleep, and/or sleep and observer (in the locomotive) recorded instances of inattention or missed signals and other severe performance lapses [252, 254, 285]. One study [252] found that of 2,290 train trips, 1.5% (34 cases) had actual operational misses involving drowsing or napping; 79% of these occurred between midnight and 6 a.m. and 12% between 10 p.m. and midnight. The NASA/FAA field study revealed that alertness of pilots from top of descent to landing can be improved by the use of scheduled cockpit naps [222], similar to the results of a CAMI study. However, we have found that brief (<4 hr) sleep episodes are insufficient for restoring performance in first-year resident physicians working overnight extended-duration work shifts [286].

When the work to be performed is relatively monotonous and routine, then sleepiness may be even more difficult to overcome [226, 287]. Dr. Dahlgren found that workers at the power plants were generally inactive and that there was even less activity on the night shift. The biological factors causing sleep and inattentiveness in shift workers would therefore be even more difficult to overcome in a relatively non-stimulating environment, such as that of monitoring a control room in an electric power plant, driving a motor vehicle on a limited access highway, or piloting a vessel at night from the darkened bridge of a slowly moving cargo ship.

As illustrated in Figure 17, continuous polysomnographic monitoring of 80 licensed commercial drivers without OSA during 7,500 hours of long-haul trucking operations revealed that more than half of the long-haul truck drivers experienced episodes of drowsy driving, mostly during night driving [288]. Predictably, these episodes of drowsy driving were not distributed evenly across the 80 drivers. In fact, more than half of the drowsy driving episodes occurred in just 8 (10%) of the 80 drivers [288], revealing the differential vulnerability of this subset of drivers to the sleep deprivation and circadian misalignment associated with night driving. This is consistent with the differential vulnerability to nocturnal sleep loss observed in laboratory studies [255-260].

Countermeasures such as the use of light exposure of optimal wavelength and intensity to suppress endogenous melatonin secretion, enhance alertness and reset the circadian clock of night shift workers [44, 47, 120, 289], the use of wake-promoting therapeutics during night work [233, 234, 290] and the use of sleep-promoting therapeutics during day sleep [43, 291-293] hold promise for use in overcoming the propensity for the occurrence of lapses of attention and unintended sleep episodes during night shift work.

Overnight Trucking and Drowsy Driving

Figure 17.

- Polysomnographic recordings reveal that truck drivers working between midnight and noon sleep an average of only 3.8 hours per day[1,2]
- Videos recordings revealed that truck drivers are often drowsy while driving
  - Forty-five drivers (56 percent) had at least 1 six-minute interval of drowsiness while driving
  - 1067 of the 1989 six-minute segments (54 percent) that showed drowsy drivers involved just eight drivers

[1]Wylie et al., Commercial Motor Vehicle Driver Fatigue and Alertness Study: Technical Summary. Report No. FHWA-MC-97-001, National Technical Information Service, Springfield, VA, November, 1996.
[2]Mitler, M. M., Miller, J. C., Lipsitz, J. J., Walsh, J. K., and Wylie, C. D. The sleep of long-haul truck drivers. *New England Journal of Medicine* **337**, 755-761. 1997.

As noted in the 1975 FAA study carried out at the FAA Civil Aeromedical Institute in Oklahoma City, Oklahoma that was entitled "The Effects of a 12-Hour Shift in the Wake-Sleep Cycle on Physiological and Biochemical Responses and on Multiple Task Performance," the interaction of sleep loss with misalignment of circadian phase may explain why performance is so significantly degraded at the end of the first night shift [294]. As Higgins and his colleagues at the FAA Civil Aeromedical Institute concluded from their study, "The implications of these findings are as follows: (1) Individuals making a 12-hour alteration in the wake-sleep cycle should not perform critical tasks during the first awake period following the change. Performance decrements observed during this first period might be due to either the sleep loss or the initial adjustment to the new schedule, or both factors could be contributory. (2) After the first full sleep period following the change, subjects appeared to perform well even though the physiological and biochemical parameters measured were still adjusting to the change. …" [294] (pp. 23-24).

More than 30 years later, we have published a paper based on studies sponsored by the National Institute of Occupational Health in my laboratory at the Harvard Medical School/Brigham and Women's Hospital that comes to a similar conclusion, as shown in Figure 18, which is from our publication entitled "Acute Sleep Deprivation and Circadian Misalignment Associated with Transition onto the First Night of Work Impairs Visual Selective Attention" [9]. Moreover, we have demonstrated that the sleep deprivation associated with night shift work resulted in individuals becoming "fast and sloppy" when doing visual searches [41]—with impairment of decision making [295]—and that sleep deprivation interferes with the search for rare targets [296]. Excessive sleepiness is also known to enhance distractibility when performing a routine task [156]. We have also found the degradation of performance on a spatial configuration visual search task to be significantly worse on the first night shift as compared to subsequent night shifts, with participants exhibiting a significantly greater number of attentional failures on the first night of an overnight work episode [9].

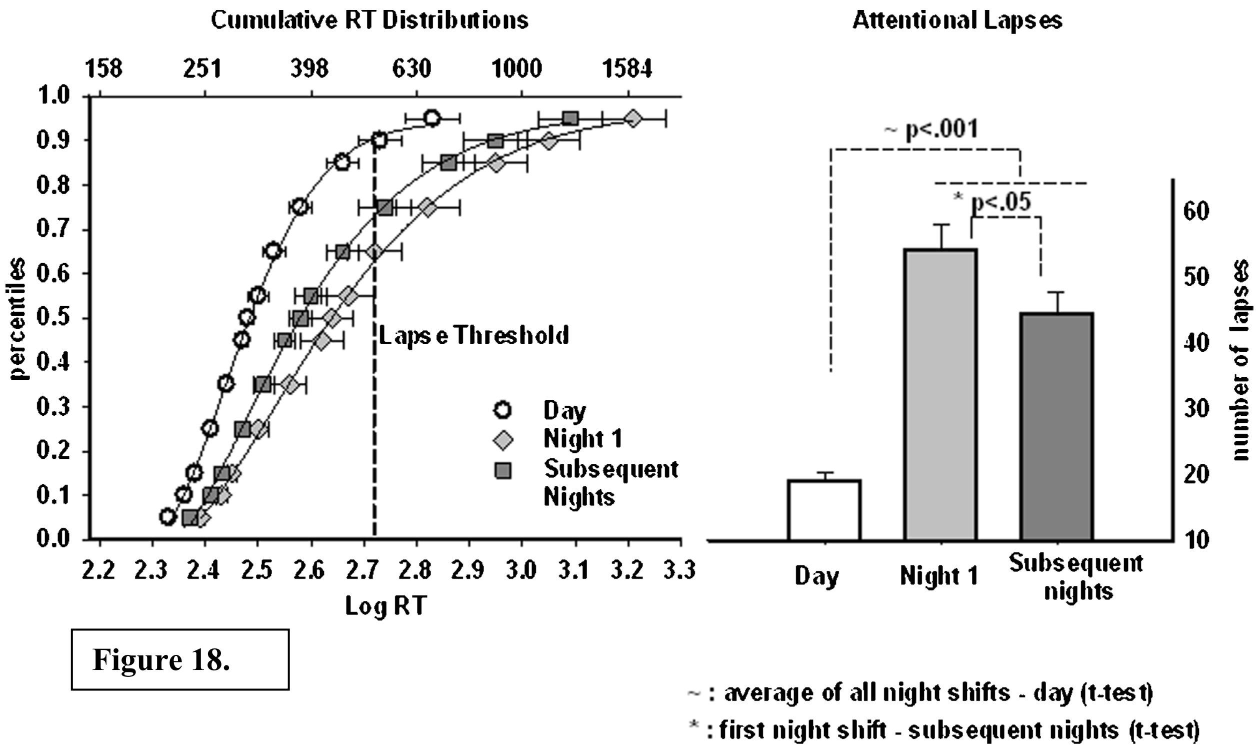


Figure 18.

Figure 18. The Impact of Night Work on Vigilance RT and Attentional Failures. This figure presents results from the Psychomotor Vigilance Task (PVT). The left panel represents the group-averaged cumulative response time (RT) percentile distribution. The x-axis represents response time. The error bars represent the standard error of the mean. The dashed vertical line is plotted at the average attentional lapse threshold (90th percentile of baseline RT). The y-axis represents percentile points. The average cumulative distributions were computed by calculating the RT percentiles for the day (open circles), first night shift (filled diamond) and 'subsequent' night shifts (filled square) for each individual subject, and then averaging them across subjects to compute the final cumulative distributions. For each of the shifts, these cumulative distributions were fitted with a 4-parameter Weibull function. The right panel presents the number of attentional lapses on the three shifts. The error bars represent the standard error of the mean. There was a significant increase in attentional failures during night work, and this was most pronounced on the first night shift. Figure and legend from [9].

Q: Can you please describe in detail the study that you performed finding that routine tasks like driving are impaired just after working an overnight shift?

A: Yes. When sleep pressure is elevated, as occurs just after working the overnight shift, then routine, highly overlearned tasks like driving a motor vehicle are impaired. In collaboration with the Liberty Mutual Research Institute for Safety, we evaluated the impact of actual night shift work on measures of drowsiness and driving performance while operating an actual motor vehicle in sixteen night-shift workers driving during the daytime [297]. Each of those workers completed two 2-hour daytime driving testing sessions on a closed driving track operated by the Liberty Mutual Research Institute for Safety in Hopkinton, Massachusetts. The sessions all began between 9:30 a.m. and 2:30 P.M. and were time-matched for each individual to control for potential time-of-day effects. In one instance, the drive testing session occurred after a prior night of sleep averaging 7.6 ± 2.4 h in duration, without having worked on the night shift (the post-sleep condition). In another instance, the drive testing session occurred after a prior night of work averaging 8.3 ± 4.1 h in duration (the post-night-shift condition). Participants in the post night-shift condition reported obtaining an average (±SD) of 0.4 ± 1.1 h of sleep between the start of their overnight shift and the start of their post-night-shift drive (in three cases this sleep occurred during the night shift, whereas in one case it occurred between the end of the night shift and the start of the post-night shift-drive). As shown in the Figure 19 below, we found that eleven near-crashes occurred in 6 of 16 post night shift drives (37.5%), and that 7 of 16 post night-shift drives (43.8%) were terminated early for safety reasons, compared with zero near-crashes or early drive terminations during 16 post sleep drives (Fishers exact: P=0.0088 and P=0.0034, respectively). No near-crashes occurred during driving after a night of sleep; 11 occurred during driving after night-work [297] (Figure 19).

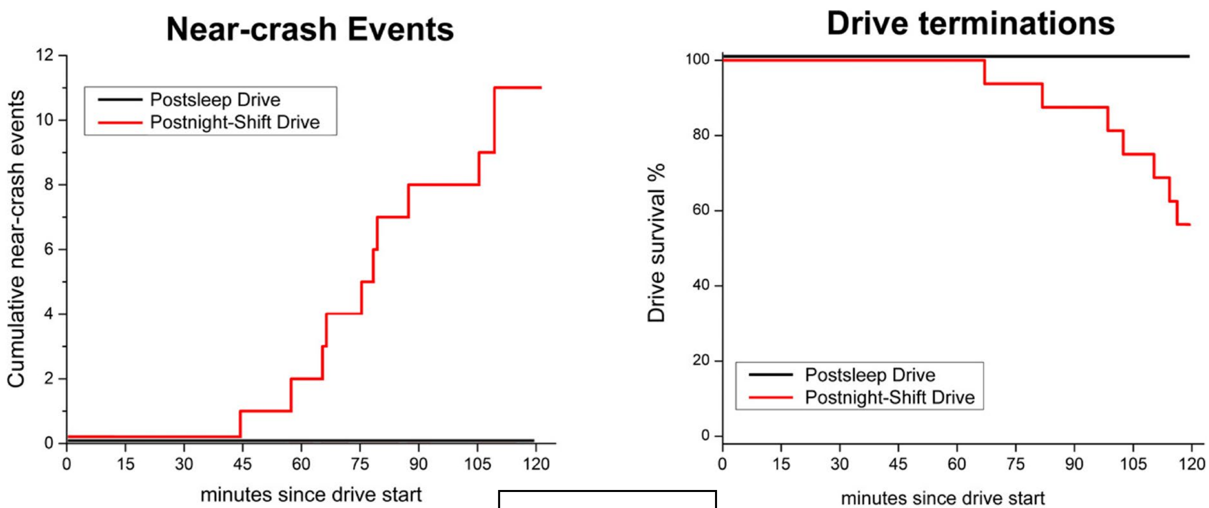


Figure 19.

Figure 19. Near-crash driving events and drive terminations occurred only in post-night-shift drives. (Left) Cumulative histogram of 11 near-crash driving events across time since drives began in each condition. (Right) Kaplan–Meier survival curve of the seven drive terminations since drives began in each condition (P=0.00308). None of the drivers in the post-sleep driving sessions had a near-crash driving event or drive termination, whereas 6 of the 16 participants had a near-crash driving event and 7 of the 16 participants had the drive terminated in the post-night-shift driving sessions (P = 0.0088 and P = 0.0034, respectively). Tick marks on both panels indicate driving breaks that occurred every 15 min to complete sleepiness assessment surveys. Figure 19 and associated legend taken from [297].

Though all near-crashes in this group of 16 participants occurred after at least 45 min of driving, evidence of fatigue-related degradation in the participants' driving performance was evident within the first 15 minutes of the post-night-shift drive. As shown in Figure 20 below, participants had a significantly higher rate of lane excursions, average Johns Drowsiness Scale, blink duration, and number of slow eye movements during post-nightshift drives compared with post-sleep drives (3.09/min vs. 1.49/min; 1.71 vs. 0.97; 125 ms. vs. 100 ms.; 35.8 vs. 19.1; respectively, $P < 0.05$ for all) [297].

This real-vehicle driving study demonstrated increased objective and subjective drowsiness and degraded daytime driving performance in 16 night-shift workers while driving after a night of work, deteriorating with drive duration. We thus found that sleep deficiency induced by nightshift work increased driver drowsiness, degrading driving performance and increasing the risk of near-crash drive events [297]. With more than 9.5 million Americans working overnight or rotating shifts and one-third of United States commutes exceeding 30 min, these results have implications for traffic and occupational safety.

In 2012, while we were in the process of analyzing the data that we had collected in 2011 for the Lee *et al*. study that we published in 2016 [297], ABC News requested that we test the driving performance of ABC News journalist and correspondent Mr. Ron Claiborne after a night without sleep using the same recording methods for the driving test sessions that we used in 2011, to evaluate the impact of increased homeostatic sleep pressure on his ability to drive using the same methods that we used in the experiment described in [297] and that are illustrated in Figure 20 below.

Figure 20.

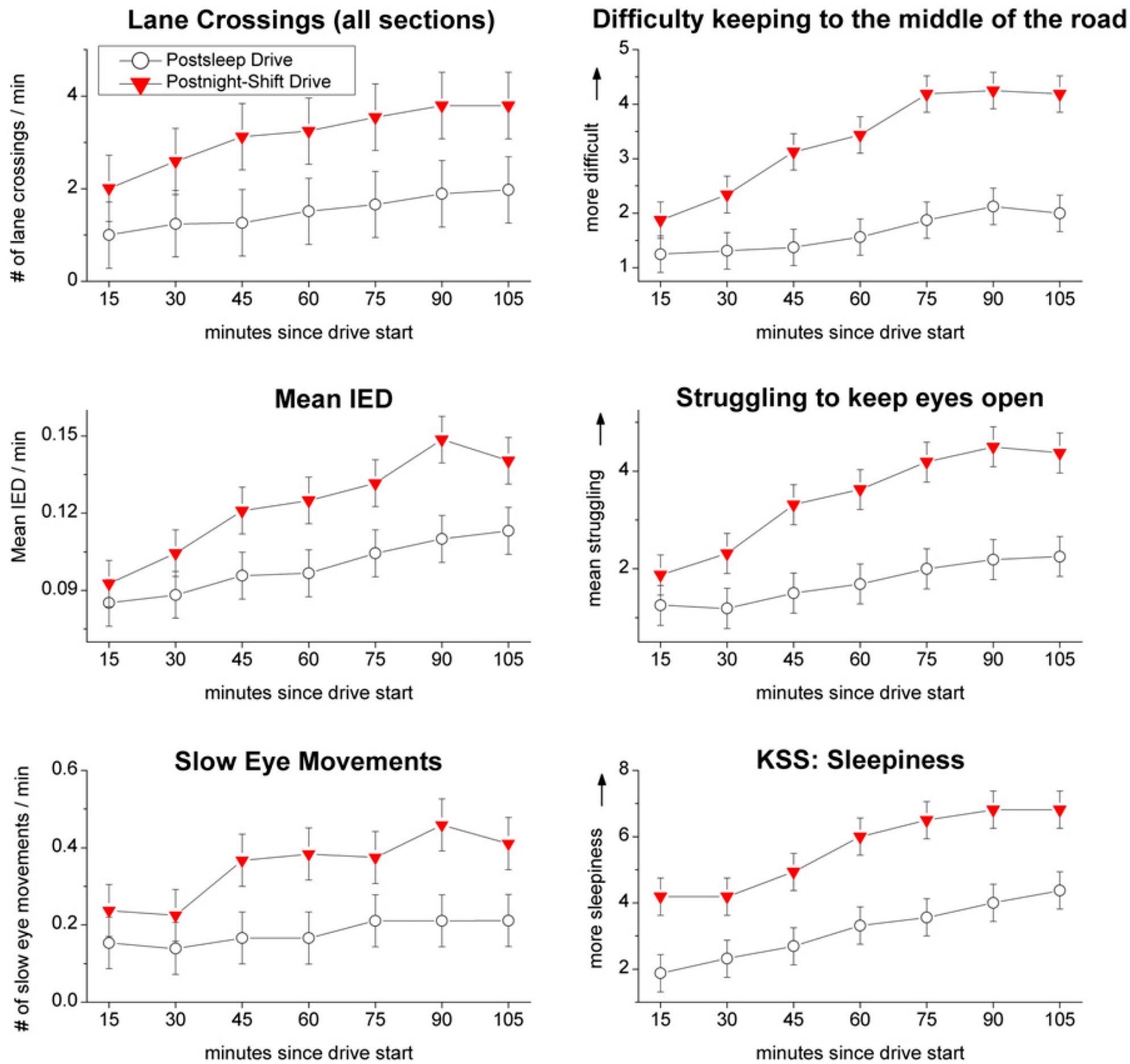


Figure 20. Drowsiness progressively increased across driving sessions. Driving performance, ocular, and survey measures of drowsiness are shown by drive condition and drive duration. Mean values with Standard Error of the Mean bars. For each of these variables except the KSS, there was a significant interaction effect of driving duration (driving block 1–7) by condition ($P < 0.05$). Condition alone had a significant effect on the KSS ($P < 0.05$). Tick marks indicate driving breaks, as in Figure 19. Figure 20 and associated legend taken from [297].

Figure 21. ABC News correspondent Mr. Ronald driving a specially instrumented van during a test driving session while outfitted for polysomnographic recording and eye tracking equipment. Investigator-observer in the front passenger seat can activate emergency braking maneuvers to prevent a crash. Seated in the second row, Dr. Charles Czeisler and Dr. Michael Lee are monitoring Mr. Claiborne's electroencephalogram and electrooculogram during the drive.

As shown in the video report that he filed on ABC News Nightline on December 3, 2012, ABC News, *Sleepy Drivers Can Doze Unknowingly*, YouTube (Dec. 3, 2012), https://www.youtube.com/watch?v=JwCnJZyU70M, and on ABC World News Tonight with Diane Sawyer, *Micro-sleep May be to Blame for Accidents*, https://abcnews.go.com/WNT/video/micro-sleep-blame-accidents-17871728, (accessed May 26, 2018), Mr. Claiborne was very impaired when driving after he had missed a night of sleep. Like most sleep-deprived individuals, Mr. Claiborne reported that he thought he could handle the driving after missing a night of sleep. However, about a half-hour into the drive, Mr. Claiborne fell asleep at the wheel and drove completely off the roadway on the closed track (see Figures 22 and 23 below).

Figure 22. Photograph of ABC News correspondent Mr. Ronald Claiborne when he was asleep at the wheel while driving an instrumented van occupied by himself and three other people on a test track in Hopkinton, MA, while he was being recorded in a driving test session after missing one night sleep.

Figure 23. Photograph from the instrumented van driven by ABC News correspondent Mr. Ronald Claiborne and occupied by himself and three other people as it drove off the roadway completely on a test track in Hopkinton, Massachusetts, while Mr. Claiborne was being recorded by Dr. Charles Czeisler and colleagues in a driving test session after a night without sleep.

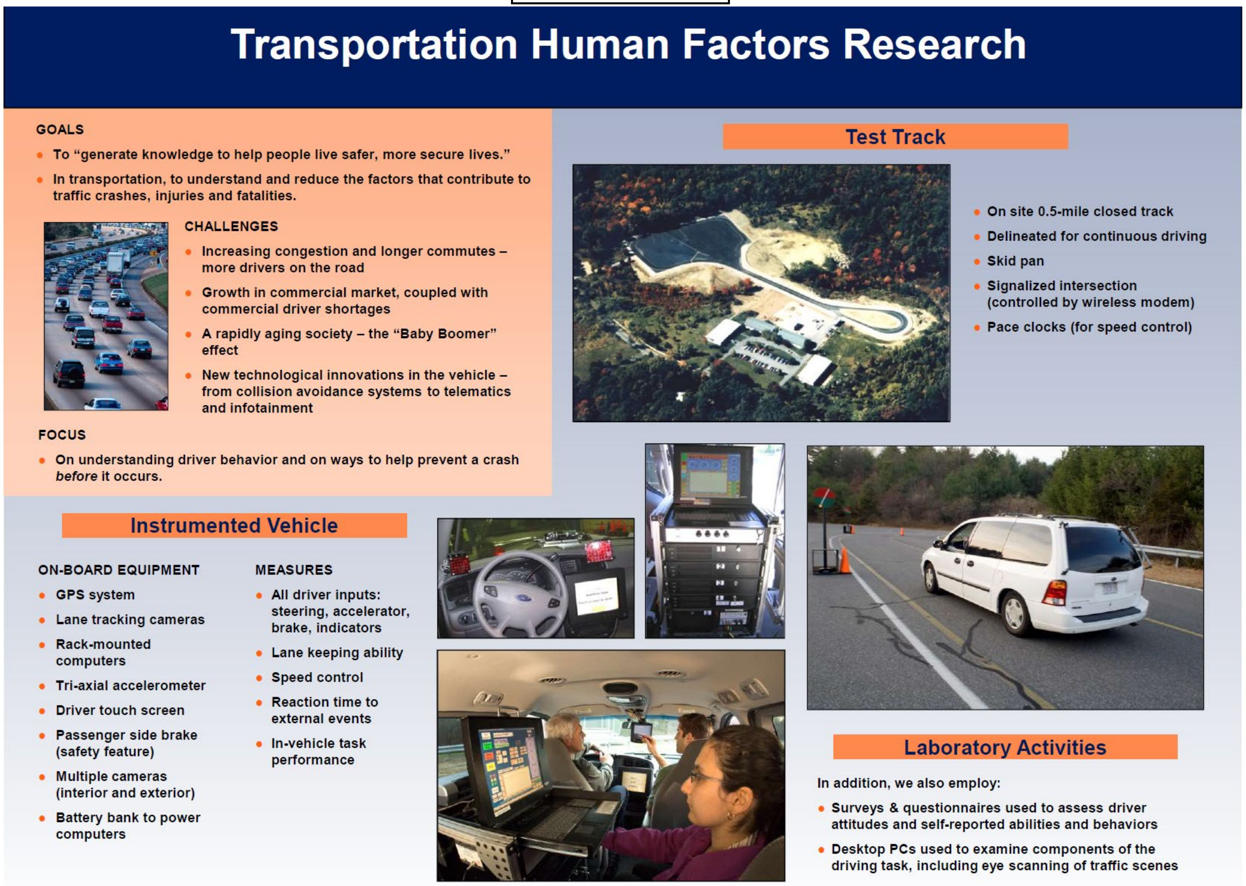
Recognizing that it was unsafe to continue driving, Mr. Claiborne decided to terminate the 2-hour drive testing session early. After terminating the drive testing session, Mr. Claiborne forgot to put the vehicle in "Park," and had to be reminded to do so by an investigator before leaving the driver's seat of the vehicle.

During Mr. Claiborne's half-hour drive testing session, polysomnographic (PSG) recording—including electroencephalographic ("brain wave" or EEG) recording—using electrodes attached to the face and scalp (illustrated in Figure 24 below) revealed that Mr. Claiborne experienced 22 attentional failures and/or micro-sleep episodes, though he remembered only two of them.

Figure 24. Polysomnographic (PSG) recording equipment used to monitor the electroencephalogram (EEG) and electrooculogram (EOG) of ABC News Correspondent Mr. Ronald Claiborne.

Thus, despite being hooked up to all of our monitoring equipment, and despite the presence of television news crews filming at multiple positions along the track, and despite the presence of scientist observers in the car, including myself, Mr. Claiborne recapitulated all of the findings that we observed in the 16 participants that we had carefully evaluated in the randomized study that we later published [297]. The Liberty Mutual Research Institute for Safety test track, located in Hopkinton, Massachusetts, on which we conducted the driving test sessions is illustrated in Figure 25 below.

Figure 25.



L. <u>Sleep Disorders and Crash Risk</u>

Q: Do common sleep disorders increase the risk of motor vehicle crashes?

A: Yes, common sleep disorders increase risk of motor vehicle crashes [25, 298].

Q: Can you please describe how various common sleep disorders affect cognitive performance and driving risks?

A: *Obstructive sleep apnea/hypopnea*. Obstructive sleep apnea/hypopnea (OSA) results in sleep fragmentation and consequent daytime sleepiness. Excessive daytime sleepiness is reported in about 80% of patients with OSA, 80 to 90% of whom remain undiagnosed and untreated; it often takes several years from the time a patient presents to a physician with symptoms until the correct diagnosis is made [1]. Performance related to executive functions such as verbal fluency, planning and sequential thinking—the purview of the frontal cortex, an area of the brain that imaging studies has revealed to be exquisitely sensitive to sleep loss—is very adversely affected by OSA [299]. Vigilance and the ability to sustain attention are also degraded in patients with OSA. Reaction times on a sustained attention task in patients with mild to moderate OSA have been reported to be comparable to or worse than those of a young adult with a blood alcohol concentration of 0.080 g/dL [300].

Untreated patients with OSA perform much more poorly in a driving simulator (in terms of lane deviations, tracking errors, off-road events and collisions with obstacles) and have a markedly increased in risk for having a motor vehicle crash [25, 301-314]. Two systematic reviews reported that the majority of studies found that patients with obstructive sleep apnea had a motor vehicle crash risk that was 2 to 3 times higher than those without obstructive sleep apnea [315, 316], with individual studies estimating the crash risk to be more than 6-fold higher in patients with obstructive sleep apnea [311]. We found that nonadherence with an employer-mandated sleep apnea treatment greatly increased the risk of serious truck crashes [317], and that implementation of a sleep health education and sleep disorders screening and referral for treatment program significantly reduced injury rate and reduced disability day usage by 46% [318, 319].

Insomnia. Insomnia is the most common sleep disorder, with symptoms of disturbed sleep affecting most adults at some time in their lives [1]. The clinical definition of insomnia is a chronic (> 6 months) complaint of latency to sleep onset or awakenings from sleep of at least a half hour occurring at least three times per week. The prevalence of insomnia associated with a daytime complaint of increased sleepiness or fatigue is 8% to 18% [320]. Broadly, insomnia may be psychophysiologic or secondary to the sleep environment, an irregular sleep schedule [321], a sleep-related movement disorder, a psychiatric condition, a medical condition, a medication or substance, or a circadian rhythm sleep disorder such as shift work disorder [1]. Insomnia in non-depressed adults is a risk factor for depression [322]. Insomnia syndrome, which includes increased daytime sleepiness, is associated with an increased rate of work absenteeism, reduced productivity and increased risk of accidents [1, 323].

Shift Work Sleep-Wake Disorder. As reviewed above, night shift work is often associated with insomnia during daytime sleep. Excessive sleepiness during night work or insomnia during day sleep are the cardinal symptoms of a condition known as Circadian Rhythm Sleep Disorder (CRSD), Shift Work Type (Shift Work Disorder, SWD) [229], which recent research indicates may have a genetic basis in some individuals [230]. While most employees nod off or fall asleep regularly while working at night or while commuting to or from night work [233], about 5–10% of such workers suffer chronically from moderate to severe SWD [324]. One-third of nurses who work at night report that they fall asleep in the hospital every week of night work (302), with half admitting that they fall asleep at the wheel while driving to or from the hospital; twice as many night-working nurses reported making medication errors or having motor vehicle crashes as compared to those who worked the day and evening shifts, but did not work at night [261]. Long work weeks and extended duration work shifts that do not allow sufficient time for sleep can elicit attentional failures during work in most if not all employees [8], effectively inducing SWD in all workers in the same way that depriving people of food will eventually induce malnutrition in all people who are starved. Exposure to less extreme work schedules reveals considerable variability in the ability of individuals to cope with the demands of work schedules that require employees to work during times that they would otherwise be asleep.

A number of countermeasures and treatments can be effective in treating the symptoms of Shift Work Disorder, including improvements in work scheduling, use of properly timed use of light, administration of nutritional supplements such as caffeine and melatonin, and use of pharmacologic agents such as modafinil, as we have demonstrated in my laboratory and our field study investigations [8, 43, 47, 231-236], although none eliminate them altogether.

There are a number of other factors that can have an impact on alertness and performance. These include the length of time on task, the level of environmental stimulation, the level of physical activity, posture, the level of task stimulation/novelty, many other medical conditions, and the use of pharmacologic agents with stimulant or hypnotic properties. Caffeine administration can reduce the adverse impact of misalignment of circadian phase as well as increased homeostatic pressure on neurobehavioral performance [234]. It should be noted that caffeine, which has a 6- to 9-hour half-life, may interfere with recovery sleep. Neither caffeine nor other wake-promoting therapeutics are a substitute for sleep. In a study of fatal-to-the-driver truck crashes, the National Transportation Safety Board (NTSB) found that plasma caffeine levels were highest in drivers involved in fatigue-related crashes [102, 277]. The NTSB interpreted high plasma caffeine data from those drivers as indicating that the drivers were taking caffeine to try to combat their fatigue. Unfortunately, even high levels of caffeine were insufficient to save those drivers from the effects of fatigue, which the NTSB found to be the leading cause of fatal crashes in those trucker drivers, accounting for 31 percent of fatalities, equal to the fraction of fatal truck crashes caused by both drugs and alcohol combined [102, 277].

M. A Summary of the Evaluation Performed at the Brigham and Women's Hospital Division of Sleep and Circadian Disorders Evaluating Puget Sound Pilots' Scheduling Efficiency and Making Recommendations for Improvement

Q: Please describe the scope of work performed by you and your colleagues at Brigham and Women's Physicians Organization for the Puget Sound Pilots.

A: Over the course of one year that began with our engagement on June 1, 2021, we reviewed the previous studies of pilot fatigue issues involving the Puget Sound pilots, the PSP Operating Rules, conducted interviews of PSP dispatchers and a series of pilot focus groups involving 68% of the PSP pilot corps, examined large data files provided by PSP, transformed that data into usable databases for analysis and queried PSP management when questions arose regarding the data. During the course of our work, PSP implemented multiple new efficiency measures between the fall of 2021 and spring of 2022. Ultimately, we produced a report with 11 recommendations, all but three of which have already been implemented.

Q: What previous studies had been performed related to fatigue risk management for the Puget Sound Pilots prior to beginning your most recent work for PSP in June 2021?

A: There were two. We reviewed the San Jose State Foundation/NASA Ames Research Center Fatigue Countermeasure Laboratory Puget Sound Pilot Fatigue Study Report (2019) and the previous presentation that I made to the Washington Board of Pilotage Commissioners in 2017. A copy of the 2017 presentation to the Board is Exhibit CAC-03.

Q: How would you describe the nature of the overall effort by the Puget Sound Pilots to address the directive from the Washington Utilities and Transportation Commission to thoroughly examine their scheduling practices in order to improve overall work efficiency?

A: Based upon the time that PSP leadership and its members devoted to examining all of the potential means of improving efficiency and the group's implementation to date of no less than eight efficiency measures, I would characterize PSP's response to the UTC directive as both robust and clearly in good faith.

Q: In an overview fashion, how would you describe the nature of the efficiency measures both recommended and now adopted by PSP?

A: The efficiency measures adopted by PSP over a period of approximately 10 months range from modest incremental efficiency gains to highly significant improvement of non-watch efficiency. The first recommendation in our report is an example of a modest efficiency gain. In this instance, PSP changed its rule requiring rest following attendance at a meeting. The new operating rule allows for direct dispatch of a pilot to a pilotage assignment following the meeting where the combination of the meeting and assignment can be concluded within 13 hours from the start of the meeting. Further, in order to increase the efficiency gain associated with this rule change, PSP began greater utilization of virtual meetings and established hard stops for meetings when possible to facilitate dispatcher awareness of when pilots involved in a meeting will be available for efficient assignment to a follow-on job. An example of a major operating rule change that we believe will deliver significant efficiencies is the adoption by PSP of a rolling start for pilots coming on and going off their watch intervals. For decades, PSP used the scheduling approach that is common among pilot groups to divide their pilot workforce into two watches that changeover on a single day. In other words, one watch of half the pilot corps that is on-duty for a specified period is replaced by the other watch of half the pilot corps that has been off-duty on a single changeover day. Following extensive work back and forth between PSP and me and my colleagues, PSP created and implemented a five-watch rolling start schedule with starts on Tuesdays and Thursdays. Our evaluation of this new rolling start schedule shows that it increases on-watch efficiency significantly. As we note in the report: "On this schedule, there are never fewer people scheduled to be on duty than in the standard non-rolling schedule. We estimate on-duty capacity increases by at least one schedule pilot for 99% of days and by two or more schedule pilots for 29% of days."

Q: The last three recommendations in your report have not yet been implemented. These include 72-hour no assignment shoulders on each side of a pilot's on-watch interval and the pilot's next rolling start, an annual cap on the maximum number of callback jobs and limiting pilot workload by increasing the number of licensed pilots. What is your understanding about why these recommendations have not been implemented?

A: Two of these recommendations—72-hour no assignment shoulders at the beginning and end of each pilot's off-watch interval and placing an annual cap on the number of callbacks any pilot can perform—are both potential new operating rules that PSP could implement, but I am advised by PSP leadership that it is not possible to do so at this time. This is because implementing one or both of these new rules would significantly increase ship delays. At present, PSP is experiencing high levels of callbacks, utilizing off-duty pilots to work in order to avoid ship delays. During the two years preceding the pandemic, callbacks as a percentage of total assignments were at 18% in 2018 and 19.7% in 2019. Callbacks as a percentage of total assignments moderated with lower traffic levels in 2020 and 2021 due to Covid-19, but are now back up with rebounding traffic in 2022 to levels above 15% during the first five months of this year, which I consider to be unsafe from a fatigue risk management standpoint. Given the transportation-critical nature of PSP pilot work, the unpredictable nature of assignments during a pilot's on-watch interval and the prevalence of night work throughout that interval, it is important for each PSP pilot to use their off-watch interval for what it is called "respite" by PSP. In my opinion, the number of callbacks that a pilot group like PSP should experience throughout the year should average 5% or less in order to maximize the level of alertness and rest necessary to perform this challenging work.

Q: Please explain why extensive use of callbacks utilizing off-watch pilots is not acceptable from a fatigue risk best practices standpoint.

A: Over the past decade, research has demonstrated that an extended duration of time off duty, without scheduled work time, is required to recover from the chronic sleep deficiency and disruption of circadian rhythms induced by the types of erratic and demanding schedules required of the Puget Sound Pilots. For example, as demonstrated in 2011 in a study conducted by Van Dongen et al. [325] from the Sleep and Performance Research Center at Washington State University in Spokane and published in the peer-reviewed journal *Sleep*, a 34-hour restart break, which was efficacious for maintaining neurobehavioral functioning from a pre-restart duty cycle to a post-restart duty cycle after daytime work shifts, was not sufficient or efficacious for maintaining neurobehavioral reaction-time performance and other objective neurobehavioral functioning profiles from one duty cycle to the next after nighttime work shifts. Moreover, the scientists found that subjective sleepiness did not reliably track objective neurobehavioral deficits observed in the nighttime duty condition. Thus, extensive use of callbacks utilizing off-watch pilots—especially when this *averages* 15% across more than 50 pilots and is not capped, such that some pilots may be working multiple times during their off-duty recovery intervals—will result in conditions in which maritime pilots will **begin** their next work-shift interval pre-loaded with fatigue, lacking resilience for coping with the very demanding schedule that each sequence of shifts requires. This will increase the risk of a fatigue-related adverse safety event.

Q: Did you receive any comments from PSP regarding your final report?

A: Yes. PSP leadership questioned the accuracy of the following sentence on page 5 of our report: "Given that the PSP management affirmed that one type of assignment is not inherently more dangerous than another, the work hour limit does not need to limit multiple shifts to just harbor assignments." I concur that the reference to one type of assignment not being inherently more dangerous than another is ambiguous. In reality, however, the challenge of any particular pilotage assignment is a function of many different factors such as ship type, weather, current, proximity to other vessel traffic, etc. Hence, the difficulty level of any particular pilotage assignment in Puget Sound is also a function of these many factors. The same holds true for the difficulty that an airline pilot faces on any given flight. There is a significant difference between a flight in perfect weather compared to one with weather or wind factors which substantially increase the difficulty of the pilot's job safely completing a particular flight.

III. <u>CONCLUSION</u>.

Q: Does this conclude your testimony?

A: Yes.

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