A while ago, a jet launched off a carrier deck, and headed home into the night. As was the pilot’s habit, he snapped off his oxygen mask as he climbed to altitude – a violation of established NATOPS flight rules, but nevertheless done for comfort. But while cruising at 24,000 ft. the jet developed a series of malfunctions, which lead to a sudden depressurization of the cabin. The pilot, a squadron commander and experienced aviator, and widely recognized as a “good stick,” failed to perform the emergency actions necessary to rescue the aircraft. The pilot lapsed into unconsciousness, the jet fell from the sky, and both were lost at sea. The NFO ejected from the aircraft and lived to tell the tale. A mishap board was convened and searched exhaustively for mishap causal factors, before coming to the obvious conclusion – hypoxia. Recommendations were made for enforcing the rules for oxygen mask discipline and further training was recommended to ensure other aircrew didn’t repeat the same mistakes in the future. The pilot was beyond discipline, having already paid the price for his mistakes.
A while ago, a carrier and a cruiser were practicing maneuvers at sea. The pace was busy, and bridge and propulsion teams were drilling their training plans, while an airborne helicopter served as plane guard for the carrier. From a cumulative series of errors that the mishap board would subsequently attempt to identify, the two ships collided. Although no lives were lost, substantial damage was sustained. Blame was ascribed to several individuals, including Officers of the Deck on both ships, and senior leadership aboard the cruiser and additional crew, all of whom failed to perform their expected duties in an acceptable manner. The causal factors included failure to assess risk, failure of communication, inaction, lack of coordination and other similar errors of omission. Discipline was meted out and careers were truncated, as examples to other officers to dissuade them from making similar mistakes.

The mission of naval forces is to continually train in preparation for the eventuality of war, if not already so engaged. Technological advances and the ever-increasing capability of our machines and missions dictate more and more complex training scenarios and more highly educated and trained professionals in our service. Our wars are fought to maximize our enemy’s disadvantage. We own the technology of the night, and strike when least expected. The modern sailor and commander must be energetic, intelligent, innovative, highly motivated, highly trained, and resourceful. We spend unlimited hours and resources training, drilling and molding the minds of warriors to succeed in this. And yet, as these mishap scenarios and many others illustrate, these minds do not always perform satisfactorily. Training mishaps and loss of assets take a
much higher toll on our capabilities and readiness than enemy action ever did. We are our own worst enemy.

But the mind of the successful warrior is simply the product of the human brain. The brain is an organ of incredible complexity and wonder, which only now is beginning to yield its secrets to modern science. The human brain is the most complex system in the known universe, yet in its simplest description, it is nothing more that an electro-chemical digital computer. Although massively parallel and composed of the order of 100 billion neurons and trillions of synapses – logic gates – the brain is subject to some very fundamental limitations based on its evolved structure and function. The brain is another weapon system the war fighter must understand in sufficient detail for proficiency, yet it’s so familiar to us that we rarely consider it in such terms.

A short summary of the science of these ubiquitous yet overlooked weapons of warfare reveals the following. While awake, the healthy, well-nourished and rested human brain is capable of prodigious feats of sensory perception, symbol manipulation, logic, analytic thought, language, and problem solving. However, due to its biologic nature, the brain cannot run continuously in the awake conscious mode, but requires scheduled maintenance and recharge cycles for efficient function. The awake functioning brain seems to deplete neurons and biochemical capability, build up toxins and metabolic by-products, and starts to run down. This “running down” is manifest as declines in mental performance, judgment, and complex decision-making, and is associated with a variety of symptoms that we commonly experience as “fatigue.”

¹
We refer to the regular maintenance and recharge cycles that the brain engages in as “sleep.” All animals studied show sleep behavior, cycling around a 24-hour interval. This is simply a product of our evolution and the orbital motion of this planet, and is inseparable from the fabric of our existence. Sleep is as necessary for survival as oxygen, water, and nutrition. Animals deprived of sleep will die within two to three weeks from immune system failure, insulin resistance and massive infection. Animals that cannot enjoy the luxury of unconsciousness during sleep but must remain continually vigilant, such as porpoises, are able to switch their brains into sleep mode half-a-brain at a time, while still functioning sufficiently to avoid drowning.

Sleep is not just a simple “switching off” of the brain, but is a complex activity in its own right, different than, yet equally as mysterious as the electrical activity seen in the awake brain. Most adult human brains require 8 to 8 ¼ hours of efficient sleep activity at night to maintain optimum performance. Sleep onset and awakening are governed by circadian rhythms, which are in turn kept in phase by sunlight exposure as the Earth turns daily on its axis. Light exposure as perceived through the eyes inhibits melatonin secretion from the pineal gland in the center of the brain. Melatonin is a naturally-occurring hormone which induces and assists the brain in switching into sleep modes.

Electroencephalographic study shows that the awake brain displays continual electrical chatter between neurons, with combined frequencies in the order of hundreds of cycles per second. Sleep activity has been discovered to consist of periods of deep, slow
electrical activity known as “non-REM” sleep, alternating with periods of fast electrical activity during which the eyes are seen to move beneath the eyelids, hence the term “rapid eye movement,” or REM, sleep. Dreams occur during REM sleep, but in this phase the brain in essence disconnects itself from the rest of the body and, with the exception of respiratory muscle activity, no signals are sent to the muscles of action so dreams are not translated into body activity. The alternating cycles of REM and non-REM sleep occur at roughly 90-minute intervals, known as the ultradian rhythm.\textsuperscript{5}

The majority of non-REM sleep is obtained in the first half of the night’s sleep, whereas REM predominates in the latter half of the sleep period. Depriving the brain of REM sleep by shortening the nightly sleep period from 8 to 6 hours may significantly affect learning and retention.\textsuperscript{6} It is apparent that both are necessary for brain health and function, and if the human brain is deprived of either type of sleep, it will actively seek that type in greater amount. Inefficient or fragmented sleep will result in increased fatigue levels and again, declining performance.

All this fatigue and sleep physiology would be of mere academic interest to the war fighter were it not for the simple fact that the sleep-deprived and fatigued brain suffers increasing performance deterioration as sleep deficits accrue. The signs and symptoms evident in individuals in a fatigued state include deterioration in mood, impairment in complex reasoning and decision-making, increased tolerance for error and risk, task fixation, reduced communication, reduced vigilance and motivation, and increased
reaction times, among others. These are objective and measurable deficits, demonstrated in a variety of studies.\(^7\) Another problem with accumulating fatigue is that the pressure for sleep increases and the brain will unpredictably try to insert snatches of sleep – lapses or “microsleeps.” These typically last 5-15 seconds or longer, during which the individual may even appear awake with eyes open, but is actually asleep. The brain has switched to sleep mode and is not processing external stimuli. Performance deteriorates due to fatigue, but during these lapses, performance drops to zero. These lapses become more frequent as fatigue accumulates. What’s most dangerous is that individuals are often unaware that these are occurring. External events – radio calls, warning lights, sudden threats, or mandatory responses – aren’t processed during lapses. Thus fatigue produces both predictable declines in performance interspersed with sudden lapses, an especially dangerous combination of deficits where vigilance is required.

The declines in performance resulting from sleep deprivation have been demonstrated in a variety of studies. In one study conducted at the Walter Reed Army Institute of Research, groups of subjects were restricted to 9, 7, 5 or 3 hours of sleep a night for a week. Performance on a simple vigilance test declined in a dose-response fashion, such that even the 7-hour group showed statistical declines in performance, and the 3-hours’ sleep a night group suffered a 40% decline from baseline by the end of the testing period. Furthermore, performance was not restored to baseline even after subjects were allowed three nights of unrestricted recovery sleep. Most insidiously, although the recovering
subjects were testing at only 80-85% of their baseline performance, they were unaware of their impairment, and felt that they were functioning normally. Other studies confirm predictable declines in performance as a result of sub-optimal sleep, coupled with poor assessment or appreciation by the subjects of their deteriorated functioning.

Although fatigue affects all areas of the brain, the areas most susceptible to fatigue’s early effects are in the “prefrontal cortex,” behind the forehead. This area of the brain is most recent in evolutionary history, and is the origin of those qualities that make us uniquely human – personality, mood, reasoning, and decision-making. Multitasking ability also resides here. Deeper areas of the brain are affected relatively later by fatigue, and well-rehearsed motor skills, semi-automatic actions, and simple tasks are less affected by fatigue early on. We may still be able to fly the plane, pilot the ship, or drive the car, however the ability to deal with novel situations, depart from habits or react to emergencies may be seriously degraded. We ignore our simple need for sleep at our peril.

The performance deterioration produced by fatigue is hard to conceptualize for the lay operator, but the impairment that results from alcohol intoxication isn’t. Road accidents, wrecked lives and careers, and Mothers Against Drunk Driving have all served to educate society to the impairment of critical functions that alcohol induces. A study, reported in Nature in 1997, was the first to compare the effects of alcohol intoxication to the effects caused by fatigue, and reached a surprising conclusion – they are comparable. A measured performance decrement of 30% due to fatigue, which is seen in subjects kept
awake for 22 hours, equates to the same deterioration that would be seen if subjects had a blood alcohol concentration of 0.08%. In other words, the driver on the road who has been continuously awake for 22 hours is as great a threat to public safety as the legally drunk driver in all 50 states. Subsequent researchers have shown similar performance effects from fatigue as those seen with alcohol use, and although the degree of impairment may differ depending on the type of test of performance used, there is a global correlation showing that fatigue and alcohol produce similar declines in performance in a dose-response fashion. ¹¹ There’s more, but the crux of all this is that fatigue and performance decay is a function of real physiology. It’s the way these digital computers operate.

It would be understandable at this point for the war fighter to respond, “so what – we have to train and fight wars in a fatigued state and we manage to deal with it. We can’t eliminate fatigue. Crews must be vigilant and capable 24 hours a day. Wars are fought at 0400. The luxury of 8 hours’ sleep a night can’t be afforded in the military. If the problem is so serious, where’s the evidence?”

Dr. Nita Miller, fatigue research professor at the Naval Postgraduate School, has studied naval populations on ships, in submarines, and at training institutions. Significant sleep deficits in study subjects are common, and resultant deterioration in performance and learning are evident. Our culture, especially in the military, holds that somehow training, habit, motivation and/or attitude can overcome all this. Mishap statistics suggest otherwise.
As part of many mishap investigations, particularly aviation mishaps, we routinely measure for glucose, alcohol, drugs, carbon monoxide, lactic acid, cyanide, and a variety of other biological markers and agents, both in the living and the dead. But we have no good measure for fatigue, so we’ve historically missed it as a causal factor.

Sentinel mishaps such as Challenger, Exxon Valdez, Chernobyl, Three Mile Island, and others have been shown to have fatigue as the root cause, just as fatigue was the root cause for the two mishaps examples cited here, despite the fact that the mishap boards failed to discover or address it. Fatigue is so prevalent and such a part of our culture that we scarcely see or recognize it. It’s the big gray elephant we muscle out of the cockpit when we fly, step around when we enter the bridge, and push aside when we peer into the periscope.

We can measure the performance deterioration that results from fatigue, and observe for the signs and symptoms of fatigue, but we don’t have any ready measure of the brain’s fatigue level itself. But can we predict fatigue levels based on knowledge of work and sleep cycles, time of day and circadian rhythms? It turns out that we can, and with surprisingly good accuracy. The elephant’s been invisible - until now.

Several teams of researchers have attempted to take the known physiology of work and sleep cycles, sleep deprivation and circadian rhythms, and develop computer models to predict the accumulation of fatigue and the level of performance deterioration that results.
These computer programs were recently compared with each other on standard data sets of performance in sleep-deprived subjects in a “shootout” of which program performed best. The full report of this evaluation was published in Aviation, Space and Environmental Medicine in a March 2004 Supplement. The “winner,” named the Fatigue Avoidance Scheduling Tool (FAST\textsuperscript{TM}), was a program developed with Department of Defense sponsorship and is licensed for military use in official applications. The FAST program predicts a running plot over time of human performance on a scale of “effectiveness” from 100% to zero.

The FAST program is based on a mathematical model developed by Dr. Steven Hursh, then at the Science Applications International Corporation, and is specifically designed to help optimize the operational management and scheduling of aviation flight and ground crews. It displays a graphical plot of predicted performance after sleep and work times are specified, and will accept events such as transmeridian travel, and calculate the phase of the circadian rhythm and anticipate how it adjusts to travel over time zones. It calculates light and dark cycles depending on latitude and longitude, and will recommend sleep intervals once duty periods are specified. FAST can also display performance effectiveness against the similar decrements seen from alcohol’s effects. The correlation between predicted and actual measured performance as a result of fatigue has been shown to be as high as 94% - surprisingly good agreement in modeling something as notoriously variable as human behavior.
It’s time to change the culture in the Navy regarding sleep deprivation and fatigue. We would never tolerate the profound deterioration in performance that would result if a large number of our sailors and commanders were routinely intoxicated on duty, yet we accept the same levels of impairment in performance from fatigue without recognition. In fact our military culture often rewards sleeplessness as a badge of honor. The science is now sufficient to illustrate the truth. Dr. Jonathan Shay, in his article “Ethical Standing for Commander Self-Care: The Need for Sleep,” expresses it best:  

“That pretending to be superhuman is very dangerous... It is time to critically reexamine our love affair with stoic self-denial... If an adversary can turn our commanders into sleepwalking zombies, from a moral point of view the adversary has done nothing fundamentally different than destroying supplies of food, water, or ammunition. Such could be the outcome, despite our best efforts to counter it. But we must stop doing it to ourselves and handing the enemy a dangerous and unearned advantage.”

The war fighter is right – we cannot eliminate fatigue. But we have increasingly sophisticated tools and scientific evidence to recognize the true cost of fatigue on naval operations. We can provide the commander with better risk assessment strategies and countermeasures. We need to spot the elephant. Perhaps we don’t need more training, more discipline, more regulation, more safeguards, or bigger instructions. Perhaps we just need more sleep.
Note: The opinions or assertions contained in this article are the private views of the author, and are not to be construed as official or reflecting the opinions of the Department of the Navy or the Department of Defense. The author has no material interest, financial interest, or other relationship, with Science Applications International Corp. (SAIC) or the Fatigue Avoidance Scheduling Tool (FAST™).

The author expresses sincere appreciation to Dr. Nita Lewis Miller, PhD, Director, Human Systems Integration Program, and Operations Research/Systems Engineering Depts. at the Naval Postgraduate School, for her continual enthusiasm, encouragement, and support; and her dedication to studying fatigue and sleep deprivation and its effects on naval personnel.


3. P&P of Sleep Medicine, Ch. 21 – Host Defense.

4. P&P of Sleep Medicine, Ch. 32 – Melatonin in the Regulation of Sleep & Circadian Rhythms.

5. P&P of Sleep Medicine, Ch. 14 – Physiologic Regulation in Sleep.


12. P&P of Sleep Medicine, Ch. 53 – Sleep Medicine, Public Policy, & Public Health.


14. “*The SAFTE™ Model and Fatigue Avoidance Scheduling Tool (FAST™).* Hursh, Steven R.; Program Manager, Biomedical Modeling and Analysis, Science Applications International Corp.
