Title
[Recent evidence on fatigue and sleep deprivation in both the medical and military aviation professions].

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Abstract.

Objective: The Accreditation Council on Graduate Medical Education, ACGME, duty hour limitations have been resisted for various reasons, including the belief that fatigue does not affect our profession's core skills; duty hour limitations will affect patient safety due to increased handoffs and decreased training and patient care opportunities for residents. This paper will examine the recent evidence on fatigue and sleep deprivation in both the medical and military aviation professions. These professions have been compared and contrasted before because of their requirement for a high level of training and competence as well as their profound responsibility for the lives of others. It is our desire to highlight recent literature in both professions so that one may inform the other.

Method: The authors conducted a search on MEDLINE for English-language literature from 2007-2012 for articles about the effects of fatigue on medical residents. The articles were limited to those from North American, Australian, and European programs. In addition, inclusion criteria included the measurement of physical and/or cognitive function as a reported outcome. Articles regarding military aviation were limited to those from the United States Navy.

Results: The search found 157 articles on the effects of resident fatigue and 22 met inclusion criteria. Of the 22 reviewed articles, 13 showed a significant effect of fatigue on technical skills, cognitive function or medical error rates while 9 articles found no statistically significant effect. Articles involving Naval Aviation included relevant research and regulations. The review found a longstanding organizational acceptance of the effects of fatigue, accident data that reported fatigue as a causal factor in nearly 25% of aviation mishaps, and increased scientific understanding of the complex nature of fatigue when compared to medical research.

Conclusions: To our knowledge, this is the first review to compare medical and aviation research and regulations regarding fatigue. The review showed that a majority of articles demonstrated a significant relationship between fatigue and residents' abilities, especially concerning cognitive function. However a relatively large minority of articles did not find a significant effect. A review of the naval aviation literature appeared to reveal a much more sophisticated understanding of fatigue, its effect on flight crews, and the general area of error prevention.

Background

Sleep is an important part of our lives, and we all appreciate it most when we are deprived of it. It has long been believed that we are adversely affected by increasing levels of daytime sleepiness. Decades of studies have linked increasing levels of sleep deprivation to decreased cognitive reasoning, vigilance, memory, and increased reaction time and error rates. The increased reaction time caused by sleep deprivation has even been shown to approach the level of legal intoxication in several studies.[1] Professions like medicine and aviation are entrusted with the public safety and expected to minimize the risk of error. This implies a responsibility to understand and diminish the risk associated with fatigue and sleep deprivation. The response of each profession has followed varying timelines, acceptance from group members and success.

In 1984, the highly publicized death of Libby Zion brought to public light the possible connection between medical resident fatigue and patient safety. While there were certainly multiple factors, the public outcry focused on what it considered excessive duty hours and a resultant cascade of fatigue-induced errors. As a result, New York State adopted an 80hr work week limit and 24hr shift limits in 1989.[2] A decade later, in 1999, an Institute of Medicine (IOM) report estimated that between 44,000 and 98,000 US hospital patients die each year due to medical error. Fatigue has been cited as a preventable causes of error.[3]

The IOM report, as well as the threat of federal regulation by the Occupational Safety and Health Administration, OSHA, prompted the Accreditation Council on Graduate Medical Education, ACGME, to reduce residency work hours to 80 hours per week in 2003. The ACGME further limited maximum continuous shifts to 16 hours for all first year residents in 2010.[2] These changes have met resistance because many medical educators feel that fatigue does not affect their core skill sets and duty hour limitations will affect patient safely due to increased handoffs and decreased resident training. In addition, medical research into the effects of fatigue has resulted in largely mixed conclusions. These factors have made regulation more difficult.

If US commercial and military aviation reported the same incidence of fatalities due to human error as cited in the 1999 IOM report, it would be the equivalent of one Boeing-737 crashing every single day and killing all on board. Fortunately they are highly regulated organizations with centralized and empowered governing bodies that focus on error and risk mitigation. With regard to fatigue, the FAA began limiting work and flight hours in the 1940's, and most recently began the process of updating regulations in 2009 based on current scientific understandings.[4]

The US Navy implemented the Naval Air Training and Operating Procedures Standardization, (NATOPS) in 1961 as a means to reduce the aircraft mishap rate. These regulations cover training requirements, flight procedure recommendations, aircraft limitations and technical information, emergency procedures, crew resource management, annual medical screening, annual flight examinations, alcohol consumption limitations, medical limitations, safety reviews for aircraft mishaps and fatigue mitigation. For fatigue mitigation under normal flight operations, NATOPS limits duty hours involving any flight time to 18 hours per 24 hour period and "aircrew must be allotted free time for meals, transportation and rest and must include an opportunity for 8 hours of uninterrupted sleep time for every 24-hour period." Individual squadrons can further restrict flight hours and increase crew rest. Of particular note, these flight hour restrictions and crew rest requirements apply to all pilots and aircrew regardless of experience or seniority.[5]

While Aviation has attempted to control fatigue for the better part of a century, Medicine began barely 10 years ago. Why the difference in response? Both require a high level of training and cognitive function as well as a profound responsibility for the lives of others. They should both be similarly affected by fatigue and equally concerned about safety. Yet a review of the medical literature on fatigue has shown mixed results regarding its effects on residents;[6] while the aviation community embraces the fairly conclusive research on pilots,[7] locomotive operators[8] and truck drivers.[9] This review paper examines the current medical literature on the effects of fatigue on residents for trends and possible methodology errors. Aviation research, regulations and flight accident data were also used to help guide recommendations for the future.

Definitions:

One of the possible causes of the mixed results found in medical literature is lack of a standardized definition of fatigue and the factors that cause it. This article will use the following definitions:

Acute Sleep Deprivation: Little to no sleep, often < 4 hours, usually during a one day period.

Chronic Sleep Deprivation: Consistently sleeping less than required for optimal functioning, usually < 6 hours per night for a week or more.

Circadian Disruption: When the environmental wake/sleep cycle causes deviation from the persons internal circadian rhythm. Night shifts and jet lag are examples.

Fatigue: The decreased ability to function normally due to excessive mental or physical stimulation.

Methods

A search was completed on MEDLINE for English-language literature from 2007-2012 for articles about the effects of fatigue on residents. Search terms used were: (((Fatigue OR Sleep Deprivation OR "Fatigue/prevention and control"[Mesh] OR "Sleep Deprivation"[Mesh]) AND (Residents OR "Education, Medical, Graduate"[Mesh]) AND ("last 5 years"[PDat] AND English[lang]))) NOT (nursing home)). Only articles from Australia, Europe and North America were included due to similarities in medical training. In addition, inclusion required physical and/or cognitive function to be the main reported outcome. It was felt that articles reporting only survey results, especially on the topic of duty hour limitation, would be exposed to significant biases and would reflect the opinion of the medical culture rather than scientific evidence. Any article reporting retrospective macro-scale safety measures was also excluded as morbidity and mortality measures were too multifactorial to accurately reflect the effect of changing one aspect of a small portion of the medical system. To limit discussion with regard to aviation, only regulations, research articles, accident data, and flight surgeon references from the US Navy were reviewed.

Results: The MEDLINE search found 157 articles on the effects of resident fatigue with 22 meeting inclusion criteria for this review. Of the reviewed articles, 13 showed a significant effect of fatigue on technical skills, cognitive function or medical error rates, while the remaining 9 articles found no statistically significant effect. Summary of results can be found in Table 1.

Table 1: Results of Articles Evaluating the Effects of Fatigue on Medical Residents

Study Author	Program	Number of Participants	Fatigue Measure	Results	Comments
Ayalon et al 2008	OB/Gyn	28	Fine motor coordination	Decreased performance	
Brandenberger et al 2010	General Surgery	14	Fine motor coordination, time to completion, memory, error rate	Decreased performance in all measures. NS - 30% increase in errors, DS - 19% increase in errors	Compaired day shift (DS) and night shift (NS)
Davies et al 2012	Neurology	35	Rapid number naming	Decrease in time improvement	
Erie et al 2011	Ophtamology	9	Fine motor coordination	No significant change	
Ganju et al 2012	Neurosurgery	7	Fine motor coordination, time to completion, memory, error rate	No significant change	Method similar to Kahol et al
Gerdes et al 2008	General Surgery	14	Fine motor coordination, time to completion, memory, error rate	Increase in cognitive errors	Residents and attendings, Method similar to Kahol et al.
Gohar et al 2009	Internal Medicine	39	Working memory capacity	Decreased working memory, increased errors	Recovery to baseline performance took 4 days
Gordon et al 2010	Internal Medicine	25	Patient simulator scenario performance	Decreased performance score	
Hayter et al 2010	Anaesthesia	29	Epidural catheter placement score	No significant change	Performed on actual patients
Hegar at al 2011	General Surgery	14	Fine motor coordination	Increased performance	
Kahol et al 2008	Gen Surg/OB	37	Fine motor coordination, time to completion, memory, error rate	Decreased performance, 32% increase in cognitive errors	
Kahol et al 2011	General Surgery	7	Fine motor coordination, time to completion, memory, error rate, EEG	Decreaase performance, Increase in Cognitive errors, Decrease in EEG attention score	
Leff et al 2008	General Surgery	21	Fine motor coordination, time to completion, error rate	Decreased performance, increase in cognitive errors after 1st night shift	Examined night float schedule
Leff at al 2010	General Surgery	7	Fine motor coordination, Arithmetic calculations, functional near-infared spectroscopy	No change in performance, increase in cortical activation	Showed increase in workload with simple activities
Lehmann et al 2010	General Surgery	30	Fine motor coordination, time to completion, attention and concentration	No change in performance	Psycomotor and cognitive tests separated, Conducted in Germany with 60 hour work week limitation
McCormick et al 2012	Orthopedics	27	Wakefullness measure by actigraphy watch	Predicted 22% increase in medical errors	
Naughton et al 2011	Vascular Surgery	20	Procedure performance score, Memory and	No change in performance score, decrease in memory	Psychomotor and cognitive tests separated

			attention	and attention	
O'Brien et al 2012	General Surgery	32	Fine motor coordination, memory, attention, reaction time and spatial processing	43% increase in overall errors, 72% increase in memory errors	Residents and attendings
Reimann et al 2009	Neurology	38	Pupilary sleepiness test, Arithmetic calculations	No increase in arithmetic errors, increase in pupilary unrest index	Conducted in Germany with 60 hour work week limitation
Schlosser et al 2012	General Surgery	38	Fine motor coordination, Saliva cortisol concentration, pupilary activity	No change in performance, saliva cortisol concentration or pupilary response	Conducted in Germany with 60 hour work week limitation
Sharpe et al 2010	Internal Medicine	12	Patient simulator scenario performance	Increas in errors, decrease in performance score	
Tomasko et al 2012	General Surgery	31	Fine motor coordination, learning, workload index	No change in performance, increase in workload	

The 13 articles found a significant fatigue effect on performance in simulated clinical scenarios[10,11], fine motor coordination[12,13], retention of learned skills[14,15], working memory capacity[16], psychomotor and cognitive skills[17–20], EEG-based attention scores[21], and error rates[22]. These studies represented many different specialties including orthopedic surgery, vascular surgery, general surgery, trauma surgery, internal medicine, OB/GYN and neurology. Most examined small sample sizes of residents in a single specialty at a single center. Two studies that tested both residents and attending physicians found significant decrements in performance for both.[17,20] The 13 articles utilized various measurements including patient simulators, skill simulators, virtual reality simulation, neurocognitive tests and error prediction models using actigraphy watches – devices that measure wrist movement and offer an objective measure of wakefulness.

The more recent addition of simulators to medical education techniques allowed Sharpe et al. and Gordon et al. to expose test subjects to realistic ICU scenarios under rested and fatigued states. Sharpe et al. tested 12 internal medicine residents over 26 hours of continuous wakefulness using multiple advance cardiac life support (ACLS) scenarios and complex medical ICU scenarios. Reviewers watched video tapes of the session so they were blinded to the fatigue state of the subject. Residents were given an overall performance score and medical errors were also tallied for each scenario. Sharpe et al. found a significant decrease in overall performance score, but only a trended increase in medical error rates. Subjects actually showed a significant improvement of error rates in the ACLS scenarios between the 1st and 2nd session followed by stabilization at the 3rd and 4th session. This led the authors to conclude this was largely a learning effect. The complex medical ICU scenarios revealed a steady increase in error rates between the 2nd, 3rd and 4th sessions, but after correcting for resident experience the trend was not significant.[11]

Similarly, Gordon et all utilized patient simulation scenarios to test 17 internal medicine residents in a rested (n=17), post-16 hour shift, (n=16), and post-24 hour shift (n=16). In this study only one reviewer was blinded and used as a control for the in-person graders. They again found a significant decrease in the global score for both post shift groups, but it was noted there was less of a decline in performance in the post-16 hour group.[10]

Kahol et al. developed a series of 8 virtual reality simulations that evaluated both psychomotor (fine motor control, hand-eye coordination) and cognitive skills (memory, spatial manipulation, problem solving) of general surgery residents. In addition to testing virtual laparoscopic skills to manipulate items, the series also tested memory, attention and spatial orientation. They found that cognitive errors increased 47% in the post-call state when compared to pre-call.[19] For the simulations that tested both psychomotor and cognitive skills, psychomotor skills also experience a significant decrease, as measured by movement smoothness and gesture proficiency. The single simulation that tested only psychomotor skills showed no significant effect due to fatigue, suggesting that psychomotor skills by themselves are more immune to fatigue. The system developed by Kahol et al. was also reproduced in 4 other reviewed articles.[17,18,21,23] Of these 4 articles, 3 supported the finding of a significant fatigue effect on cognitive errors and psychomotor skills, while one only measured a statistically insignificant trend.[23]

While most studies only examined medical resident performance, Gerdes et al. and O'Brien et al. subjected both residents and attending physicians to virtual reality simulation and neurocognitive testing. In virtual reality simulations testing psychomotor and cognitive skills, Gerdes et al. found a significant decrement in movement smoothness and efficiency and a significant increase in cognitive errors for both fatigued residents and attendings. The detrimental effects were 25% less for attendings, but still represented a significant change.[17] While attending physicians might feel less vulnerable to fatigue because of their extensive clinical experience, these studies should cause the medical community to consider expanding work hour limits beyond residents.

Many residency programs have moved to night float systems in order to meet ACGME work hour requirements. Residents typically work 12-14 hour night shifts over 5-6 consecutive days followed by 1-2 days off. This weekly schedule can repeat itself for 1-4 weeks. Although this is the common solution to the elimination of overnight calls, it is not without shortcomings. Naughton et al. and Leff et al. found statistically significant limitations to learning and maintaining proficiency for residents on night float. Naughton et al. tested proficiency while learning endovascular skills on a virtual reality simulator on day shift and night shift residents. They were tested at the end of each day or night shift for a 7 day period. Both groups showed similar proficiency by the end of the 7th session, but the night group took an extra day to reach plateau for all measures of performance. They also found that the night group slept significantly fewer hours (6.0 vs 7.0 hours) and performed significantly worse on cognitive assessment of attention and memory throughout the week of testing.[14]

Leff et al. also studied the effect of night shift schedules on learning and skill retention. Twenty-one surgical residents were trained to proficiency on virtual reality laparoscopic skills prior to starting a week-long night shift schedule. They discovered a significant decline in performance skills and a significant increase in errors and time to completion after the first night shift. Economy of movement also suffered on the first and second night. On subsequent nights all parameters returned to baseline and some showed continued learning.[15] The authors concluded that learning can occur on night shifts, which had been a concern for medical educators once the night float system was adopted. However, medical educators and attendings should be aware that acquisition of skills might take longer; cognitive skills are still affected, and these skills will be most affected on the first night of a night float rotation.

In a very novel approach, McCormick et al. used validated relationships between wrist movement and fatigue and fatigue and error rates. The authors recorded sleep-wake cycles and sleep quality using actigraphy watches for 27 orthopedic residents over a 2-week period. The watches continuously measured wrist movement which was then extrapolated to determine validated wakefulness. From this data they predicted performance degradation and error rate using the validated Sleep, Activity, Fatigue and Task Effectiveness (SAFTE) model. This model was developed by the National Transportation Safety Board (NTSB) and used by all branches of the US military and the Federal Railroad Association. Using these relationships, McCormick et al. found that residents averaged 5.3 hours of sleep daily, were fatigued 48% and impaired 27% of their wake time. These fatigue and impairment rates resulted in a predicted increase in medical error rates of 22%.[22]

The remaining 9 articles found no statistically significant effect of fatigue on procedural skill,[24] psychomotor skills,[25–29] cognitive errors,[23,30] or physiologic signs associated with sleep deprivation.[29,31] These studies primarily took place in programs of general surgery, in addition to ophthalmology, anesthesia, neurosurgery and neurology. The articles also involved small sample sizes of residents in a single specialty at a single center. They primarily utilized virtual reality simulation scenarios that tested only psychomotor skills.

Since most sleep deprivation studies use simulations or neurocognitive testing to determine the effects of fatigue, their generalizability to actual patient encounters is often questioned. Only one of the reviewed articles, Hayter et al., developed an IRB approved study that tested fatigue effects on actual patients. The authors tested anesthesia resident’s skill at placing an epidural catheter in actual patients in labor. The study found no statistically significant decrease in performance measured by hand motion, checklist score and global rating scale score between rested and fatigued states.[24] The study controlled for caffeine intake, measured sleep time using actigraphy watches and blinded reviewers by using a video recording for evaluation. They did; however, exclude difficult patients including the morbidly obese, those with spinal deformities and those who had excessive labor pain. The authors pointed out that eliminating these more difficult patients and failing to measure the effectiveness of the epidural placement might have reduced the power of this study.

Ganju et al. was the only study utilizing the VR simulation system developed by Kahol et al. that showed no statistically significant decrement in psychomotor or cognitive skills. They did find a 13.1% decrease in overall performance, but this was not statistically significant.[23] Given that they only tested 7 neurosurgery residents (PGY2-PGY5) the study may have been underpowered. Also, it appears that they did not allow for subjects to achieve proficiency in the VR simulator prior to testing, which might have allowed for a learning effect to overcome the detrimental effect of fatigue. Finally, the duration of each session was 10-15 min thus requiring only a short activation time for successful completion thus possibly masking their fatigued states.

The remaining 5 articles that used VR simulation as a testing modality also found no statistically significant fatigue effect.[25–28] One article even noted a significant improvement in completion time with a preservation of movement accuracy and efficiency.[29] However, these articles were found to have serious design flaws. Their most significant shortcoming was that they universally utilized simulation scenarios that tested only psychomotor skills since they only measured time to completion and movement efficiency and accuracy. Several studies have shown that fatigue affects cognitive function more that psychomotor and Kahol et al. demonstrated that psychomotor skills were only effected when they were combined with cognitive challenges.[19] With the exception of one study, [28], none trained subjects to proficiency on simulated tasks thus allowing for the learning effect to blunt the effect of fatigue. Lack of understanding of the circadian rhythm caused all but one study,[27] to test at the circadian upswing from 6am-10am. Finally, two of the studies were conducted in Germany where residents were restricted to 60 hour work week and overnight call every 5 days, therefore chronic fatigue may not have been as significant a factor.[25,29]

Leff et al. and Tomasko et al. subjected participants to neurocognitive testing and VR simulation, respectively. In addition to these primary tests, they also examined cognitive workload using functional near-infrared spectroscopy and a validated mental workload questionnaire. While they found no decrease in performance in their primary test, they did note a significant increase in cognitive workload in the fatigued state.[26,30] As a concept, workload is the overall mental "cost" for a person to perform a particular function accurately. When the task difficulty increases the workload follows suit until a person is unable to increase workload further in order to deal with unexpected events. Since increased workload is associated with increased errors, it should be noted that these two studies demonstrated that fatigue can cause increased workload for even simple tasks.

Fatigue has been thought to have measurable physiologic effects on the body such as increased cortisol levels, change in brain activity measured by EEG and decreased pupillary responses. A fatigue study by Schlosser et al. tested performance in VR simulation of simple psychomotor tasks and included saliva cortisol concentrations and pupillary activity in their evaluation. Even though subjects received significantly less sleep prior to the post call test compared to the pre call state (4.09 hours vs 6.7 hours) all performance measures on the VR tasks improved.[29] This was the only study that showed such marked improvement in outcome measures. This irregularity might be explained by an insufficient training process that allowed for a learning effect. Also, as with most of the VR studies that found no fatigue effect, the tests involved only short duration psychomotor challenges.

Saliva cortisol concentration and pupillary response also showed no significant change due to fatigue. They did show that cortisol levels were significantly higher in medical interns at all test points when compared to junior and senior residents.[29] The uses of cortisol concentrations to infer fatigue is controversial since it does not directly measure fatigue, but rather stress. The finding in this study could indicate that intense medical training habituates residents to the stress response and therefore normalizes physiologic signs. Reimann et al. also tested pupillary response and found a significant increase in the pupillary unrest index (PUI) for residents on overnight call and nightshift compared to that control group. Studies have shown that the PUI increase with progressive fatigue. They did not however find a change in performance on neurocognitive mathematical addition testing.[31]

A search of Naval Aviation research articles for the previous 5 years yielded only two review articles, one from the Naval Medical Research Unit in Dayton, OH, and the other from the Naval Postgraduate School in Monterey, CA. At first this was surprising, but after examination, the dearth of research articles was likely due to the Navy's acceptance of the effects of fatigue. It was now focused on prevention and management of fatigue.

Caldwell, Chandler and Hartzler reported that the "detrimental effects of sleep loss in aviation have been documented for over 60 years." At the same time they acknowledged that despite this understanding, "the lack of adequate sleep represents a major threat to the health, safety and effectiveness of aircrew and passengers." Similarly to many medical papers, they concluded that fatigue affects attention, vigilance, mood, the body's immune response, judgment and error rate. In addition it was noted that physical performance, such as basic flying skills, was more resistant to the effect of fatigue. [32]

Although most of the medical research focused on acute sleep deprivation, these two Navy articles reviewed other recognized factors that cause fatigue. Chronic sleep deprivation of 4-6 hours per night caused decrease in attention and vigilance and an increase in cognitive errors. Also, this chronic sleep deprivation results in a steady but reduced performance level that may not be noticed by the fatigued individual. The recovery from chronic sleep deprivation was also noted to take up to 7 days.[32] Circadian disruption caused by shift and night work was also reported to produce decreased attention, psychomotor vigilance and error rates.[33]

Miller et al. recognized that many military leaders felt that fatigue could be overcome by motivation and plenty of coffee. However, motivation was shown to only partially compensate for sleep deprivation and only for a short period of time.[34] Coffee was only mildly stimulating in caffeine naive subjects, and again only for short duration. The review also reported that complexity and duration of the task were also important factors with tasks requiring continuous, sustained alertness being the most susceptible to fatigue.[35]

An examination of Naval Aviation regulations found a longstanding organizational acceptance of the effects of fatigue based on the history of flight hour and crew rest regulations.[5] The Navy recognized that pilots are often unaware of the effects of fatigue and developed a fatigue education curriculum. Fatigue education is now part of mandatory annual General Military Training (GMT), aviation physiology training and quarterly safety seminars. The education includes summarizing the harmful effects of fatigue, reinforcing the regulations combating fatigue and teaching appropriate sleep hygiene and techniques for adapting to shift work and night operations.[5]

The Navy also has a system in place to investigate every mishap and quickly incorporate new “lessons learned” into regulations, training and guidelines. This is accomplished through a Safety Review Board, SRB, a unique entity isolated from disciplinary investigations, which looks at causal factors of accidents and makes recommendations for future prevention. Because of the SRB, the Naval Safety Center is aware that fatigue was a factor in nearly 25% of all aviation mishaps from 1997-2002.[36] Clearly fatigue is still a serious problem, but because the Navy is aware of this, it is able to take steps like fatigue education to improve outcomes.

Even regulations and education cannot overcome the challenges posed by continuous operations. Because of this, the Navy allows for controlled use of pharmacological augmentation of pilots. All branches of the military allow for some use of dextoamphetamine and Modafinil as stimulants and zolpidem and temazepam as sleep aids during continuous operations. The risk of use is taken seriously and the use of stimulants and sleep aids during flight operations requires the agreement of multiple leaders, including a flight surgeon. [37]

The Navy’s approach to fatigue mirrors its response to the many risk factors affecting Naval Aviation. Overall, the combination of regulation, education, and pharmacological augmentation has proven to be successful. Naval Safety Center data show that since the introduction of the NATOPS program the aircraft Class “A” mishap rate has been reduced from 17/100,000 flight hours in 1961 to 3/100,000 flight hours in 1995.[38] While it is impossible to determine the contribution of fatigue mitigation to this improvement, this does demonstrate the results an organization can achieve by tracking errors and embracing risk mitigation practices.

Discussion: The results from this review of the effects of fatigue on medical residents found a significant detrimental effect of fatigue on performance. The relatively large minority articles that found no significant fatigue effect cause the medical profession to question the need for duty hour restrictions. However, several of these articles recognized that their results run counter to the scientific understanding and personal experiences. Why is this? After reviewing the scientific understanding of the US Navy as an outside source, the authors feel that the medical research lacked a comprehensive understanding of fatigue. Most medical studies looked only at acute sleep deprivation; however, both doctors and pilots experience acute sleep deprivation, chronic sleep deprivation, and circadian disruption in combination. These oversights produced numerous studies that failed to control for chronic fatigue and often tested at the circadian up swing. Furthermore, failing to recognize that fatigue affects cognitive skills considerably more than psychomotor skills caused many medical researchers to measure the least sensitive fatigue outcome - psychomotor skills. In general the medical literature on the subject of fatigue was found to be extremely heterogeneous, usually study resident physicians, measure a widely varied set of objective variables, involve numerous specialties and clinical environments, are generally small, and employ methodologies generally of fair to marginal quality.

Naval aviation was chosen for comparison because its similarities in training, required psychomotor and cognitive skill sets and shared responsibility for human lives. Pilots, much like doctors, are expected to perform continuously and are prone to all the factors that cause fatigue. Both professions must also be able to operate effectively under adverse conditions with limited manpower and equipment. Unlike the medical community, leaders in naval aviation now acknowledge the detrimental effects of fatigue and try to manage them. This is supported by the reported regulations, fatigue education programs and other fatigue countermeasures employed by the Navy. The US Navy's success in a systemic response to risk mitigation is also supported by the presented data.

While both professions now have work hour limitations in place, the scope and the attitude toward the limitations differ. First and foremost, A survey of pilots and surgeons found that only 26% of pilots denied the effects of fatigue on performance compared to 70% of surgeons.[39] Even with hundreds of articles demonstrating the effect of fatigue on humans from all walks of life, the medical community still debates whether fatigue affects clinical performance.

Naval aviation recognized the problem of fatigue far earlier than medicine, has been working on it longer, and perhaps because of the more hierarchical structure of the military, has been able to take more forceful and comprehensive measures to combat it. Pilots may also accept the effects of fatigue more readily since their personal safety, not just the safety of the crew and passengers, is on the line. Regardless, it it's the desire of the authors to refocus the medical community on solutions for combating fatigue by presenting the successes of a similar profession.

There will certainly be flaws in regulations but this should not prevent us from implementing regulations now. The FAA and the branches of the military frequently reevaluate regulations base on scientific evidence. Currently, the FAA is considering limiting night flight hours more than day flight hours in recognition of the effects of circadian disruption.[40] Regulations can be adjusted but ultimately we have to admit a problem exists before it can be prevented effectively.

Recommendations:

1. System-wide regulations – Fatigue affects more than just residents; research presented here showed senior physicians experience decreases in cognitive skills due to fatigue as well. Work hour regulations should be applied to the medical profession as a whole.
2. Education on fatigue – Teach medical students, residents and attendings the causes and effects of fatigue, appropriate sleep hygiene, effective adjustment for night shifts and effective countermeasures for fatigue reduction.
3. Manpower increases – Fewer individual work hours require more resident and attending positions to fill the gaps otherwise workload increases and risks patient safety. GME positions and funding must be increased.
4. System flexibility – Grant individual program waivers for exploring different approaches for achieving improvement in patient safety and provider quality of life.
5. Nationwide medical error database – Empower an independent group to investigate medical errors and maintain a system wide database for analysis and dissemination to the medical profession.

Conclusions: To our knowledge, this is the first article comparing medical and aviation research and regulations regarding fatigue. The majority of articles measured a significant effect of fatigue on resident's abilities, especially concerning cognitive function. Several studies however did not find a significant effect. Based on the reviewed articles and regulations, US Naval Aviation has concluded that fatigue has an adverse effect on performance and is actively managing fatigue with a more sophisticated understanding of the components of fatigue. We conclude that current ACGME regulations are a plausible initial solution to resident fatigue. However more standardized research is needed in order to develop a consistent consensus and explore more effective solutions for fatigue prevention.

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