

Fatigue Optimization Scheduling in Graduate Medical Education: Reducing Fatigue and Improving Patient Safety

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Abstract

Background Medical error is a major cause of preventable morbidity and mortality. Resident fatigue is likely to be a significant contributor.

Objectives We calculated and compared predicted fatigue impairment in surgical residents on varying schedules by using the validated Sleep, Activity, Fatigue, and Task Effectiveness model and Fatigue Avoidance Scheduling Tool; we identified specific times of day and rotations during which residents were most affected, instituted countermeasures, and measured the predicted response.

Methods We compared 4 scheduling patterns: day shift, trauma shift, night shift, and prework hour restriction Q3 call (or every-third-night call). The dependent variables were mean daily effectiveness while at work and the percentage of time residents worked with critical fatigue impairment (defined as an effectiveness score of less than 70 correlated with an increased risk for error and a blood alcohol content of 0.08). Fatigue countermeasures

(ie, a 30-minute nap, eliminating 24-hour shifts) were applied to rotations with significant impairment to determine impairment plasticity.

Results Calculated mean effectiveness scores and percentage of time spent impaired at work were as follows: day shift, 90.3, 0%; trauma shift, 82.0, 7.5%; prework hour restriction Q3 call shift, 80.7, 23%; and night shift, 68.0, 50% ($P < .001$). Fatigue optimization countermeasures for night shift rotation improved mean daily effectiveness to 87.1 with only 1.9% of time working while impaired ($P < .001$).

Conclusions There is a significant potential for fatigue impairment in residents, with work schedule a significant factor. Once targeted, fatigue impairment may be minimized with specific countermeasures. Fatigue optimization tools provide data for targeted scheduling interventions, which reduce fatigue and may mitigate medical error.

Introduction

The Institute of Medicine's *To Err Is Human: Building a Safer Health System*¹ ranked medical error as one of the leading causes of death in the United States. Medical error continues to be a significant problem worldwide²⁻⁷ and does not appear to be abating.⁸ Errors due to health care

worker fatigue may play a substantial role.^{9,10} In 2008, the Institute of Medicine's report *Resident Duty Hours: Enhancing Sleep, Supervision, and Safety* concluded that "the science on sleep and human performance is clear that fatigue makes errors more likely to occur."¹⁰

Concomitantly, the Accreditation Council for Graduate Medical Education (ACGME) limited resident work hours to an average 80-hour work week in 2003 and implemented further work hour restrictions in 2011. The link between patient safety and ACGME work hour changes is controversial; recent reviews demonstrate no benefit to both patient safety and educational outcomes,^{11,12} while the ACGME changes are projected to cost \$1.6 billion annually. However, if effective, the benefits of reduced errors and harm resulting from the ACGME duty hour limits could offset these costs.¹³

Fatigue risk management systems (FRMS) have emerged in many other industries as an effective way to manage and reduce employee fatigue. These systems use fatigue optimization scheduling simulations to optimize the

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Funding: The authors report no external funding source for this study.

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Received January 21, 2012; revisions received July 22 and September 17, 2012; accepted September 26, 2012.

DOI: <http://dx.doi.org/10.4300/JGME-D-12-00021.1>

work schedule, investigate fatigue-related accidents, and improve worker lifestyle. Fatigue optimization scheduling allows for the identification of specific time periods when performance may be compromised. It also establishes the cumulative effects of different work and rest schedules on overall performance capability and accident risk.¹⁴ Recent advances allow for accurate prediction of fatigue-related impairment and risk for error.¹⁵ The Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) model and Fatigue Avoidance Scheduling Tool (FAST; Fatigue Science, Honolulu, HI) are used for this purpose in other safety-sensitive occupational settings.^{16–20}

Fatigue optimization scheduling simulation will likely be a valuable tool for residency programs and program directors in managing resident fatigue. The purpose of this study is to apply fatigue optimization scheduling to various surgical resident schedules to calculate and compare predicted fatigue impairment and associated risk for error. A secondary aim is to identify specific times of day and rotations during which residents are most affected by fatigue, then institute countermeasures and measure the predicted response. Our null hypothesis is that there will be no difference between predicted effectiveness, based on the different schedules. This study was exempt from institutional review board approval.

Methods

Study Design

We performed a computer simulation experimental study by using 3 typical modern orthopedic surgery rotations (day shift, trauma shift, night shift) and a prework hour restriction schedule with overnight call every third night (Q3

TABLE 1 CHARACTERISTICS OF SIMULATED RESIDENT SCHEDULES BASED ON ACTUAL ROTATIONS	
Rotation	Rotation Characteristics
Day shift	Shift from 6 AM to 8 PM 5 days a week (14 h/d) with daytime shift call every other weekend, 6 h of excellent sleep nightly.
Trauma shift	Shift from 4:30 AM to 6:30 PM 4 days a week (14 h/d), 1 day 30-h extended shift, 1 day off each week, 6 h of excellent sleep nightly, brief nap post call.
Night shift	Shift from 6 PM to 8 AM 4 days a week, 1 day 26-h extended shift, 1 day off each week, 6 h of good sleep daily.
Prework hour Q3 shift	Shift from 6 AM to 6 PM when not on call, 6 AM to 6 PM the following day when on call, Q3 call schedule, no days off, average 6 h daily excellent sleep (day 1 = 0 h, day 2 = 8 h, day 3 = 9 h).

Abbreviation: Q3, every-third-night.

What was known

The 2008 Institute of Medicine’s report on resident duty hours implicated fatigue in human error in teaching settings.

What is new

A fatigue avoidance model (SAFTE) and a scheduling tool (FAST) showed that countermeasures applied to night shift rotations would improve mean daily effectiveness and reduce the percentage of time the simulation indicated residents would be working while fatigued.

Limitations

The SAFTE model did not measure fatigue in residents, could not account for schedule and sleep variability among individuals and institutions, and has not been validated in the medical field.

Bottom line

Fatigue optimization tools can provide data for targeted scheduling interventions to reduce resident fatigue. This has the potential to mitigate medical error due to fatigue.

call) as a historical control. Over a randomly generated 28-day continuous work period, proposed resident wake/rest schedules, sleep quantity, and sleep quality were entered into the FAST computer application and processed through the SAFTE model, from specific rotation schedules. The dependent variables addressed were rotation mean daily effectiveness and the percentage of time at critical fatigue impairment. Effectiveness is defined as the percentage of one’s maximal capacity of cognitive performance.¹⁸ Impairment was defined as an effectiveness score of less than 70. This is correlated with an increased risk for error and a blood alcohol content of 0.08.^{15,21–23} Schedules identified with significant fatigue profiles (mean effectiveness score of less than 70) were subjected to fatigue countermeasure imple-

TABLE 2 IMPLEMENTATION OF FATIGUE COUNTERMEASURES TO THE NIGHT SHIFT ROTATION TO POTENTIALLY MINIMIZE THE INCIDENCE OF RESIDENT FATIGUE AND ERROR	
Fatigue Countermeasures	
1. Taking a 30-min nap at 3:00 AM.	
2. Changing 24-h shift to two 12-h shifts.	
3. Sleeping in on day off.	
4. Prioritizing sleeping during darkness rather than day when post call.	
5. Improving sleep hygiene when sleeping during day (ie, dark environment, no caffeine/alcohol, minimize interruptions).	
6. Encouraging 1 h or more of sleep daily, from 6 to 7 h during the week.	
7. Taking a nap before first night shift.	

TABLE 3 DESCRIPTIVE STATISTICS FOR EACH OF THE 5 ROTATIONS ANALYZED

Rotation	N	Mean	SD
Day shift	24	90.32	1.24
Trauma	20	83.66	4.43
"Old school" (Q3)	18	80.77	5.07
Night shift	19	67.98	4.77
Night shift with countermeasures	47	87.17	9.05

Abbreviation: Q3, every third night.

mentation to determine the plasticity of the fatigue and identify solutions to minimize potential patient harm.

Tools

The FAST tool is a computer application of the SAFTE model that allows a continuous calculation of predicted performance during periods of measurement, based on the following inputs: wake/rest schedules, sleep quantity, sleep quality, time zone, geographic changes, and sunlight exposure.²⁴ The SAFTE model has been validated against laboratory-controlled assessments and is able to predict performance degradation effects of fatigue and the rate of recovery with excellent reliability in published scientific studies (R^2 of 0.94, 0.89, and 0.98).^{16,17,19}

Independent Variables

Schedules selected were based on actual rotations at a large academic orthopedic surgery residency program (TABLE 1). Emphasis was placed on rotations with defined schedules, heavy workloads, compliance with ACGME work hour restrictions, and variability with regard to circadian rhythm disruption and rest opportunities to enhance the ability to generalize to other surgical residency programs. The prework hour restriction Q3 call shift was used as a historical control for comparison. We assumed

daily sleep across rotations was an average of 6 hours, from published studies.^{25,26} We also assumed 1 hour for commuting, 1 hour for reading and case preparation, and 2 hours for fitness, eating, hygiene, and family (for a total of 4 hours). Any periods not accounted for by scheduled shifts or the daily 4 hours were imputed as naps.

Dependent Variables

The outcome measurements were each rotation's mean daily effectiveness and the percentage of time at work with critical fatigue impairment. Details of this effectiveness calculation were previously published.^{18,20} The percentage of time working with critical fatigue impairment was calculated by measuring the duration of predicted effectiveness below a score of 70 for the 28-day period, dividing this time by the total time spent at work for the 28-day period, and converted into a percentage.

Statistical Analysis

Average effectiveness scores for time at work were recorded for each period the subject was awake and at work. Descriptive statistics were reported. Means between all groups were compared by using an analysis of variance. Means between the night shift and the modified night shift schedules were compared with Student *t* test.

Fatigue Optimization Scheduling Countermeasures

Modern rotations with significant performance degradation were identified (rotations with a mean effectiveness score of less than 70). Countermeasures were added to the schedule (TABLE 2) and the schedule was analyzed by using FAST.

Results

Each session was for a 28-day period, generating a daily effectiveness score, both at work and awake. A random time period was generated, with selection of January 5, 2011, to January 28, 2011, in Chicago, Illinois, as the time period to be analyzed. TABLE 3 summarizes the descriptive statistics for each rotation. The predicted effectiveness results for residents on each rotation are summarized in TABLE 4.

TABLE 4 SUMMARY AND COMPARISON OF EFFECTIVENESS SCORES FOR EACH ROTATION

Rotation	Mean Daily Effectiveness at Work	Mean Daily Effectiveness While Awake	P Value (Compared to Day Shift)	Time at Work With Effectiveness Score <70, %
Day shift	90.32	89.32	...	0
Trauma	81.97	82.51	<.001	7.5
"Old school" (Q3)	78.37	79.20	<.001	23
Night shift	68.00	72.36	<.001	50

Abbreviation: Q3, every third night.

TABLE 5 COMPARISON OF NIGHT SHIFT AND MODIFIED NIGHT SHIFT SCHEDULES				
Rotation	Mean Daily Effectiveness at Work	Mean Daily Effectiveness Awake	P Value	Time at Work With Effectiveness Score <70, %
Night shift	68.0	72.36	...	50
Modified night shift	87.0	89.78	<.001	1.9

The night shift schedule was associated with significant fatigue, with critical fatigue levels for more than 50% of the time spent at work. Implementation of fatigue countermeasures reduced the critical fatigue levels from 50% of the time to 1.9% of the time at work ($P < .001$) (TABLE 5).

Discussion

We found significant differences between mean daily effectiveness scores among the various schedule simulations. Thus, our simulation shows resident fatigue may be influenced by work hours, but also by the quantity and quality of sleep and circadian rhythms.

A critical finding is the significant impairment from fatigue that a resident may encounter while working the night shift schedule. We found a mean effectiveness score of 68.0, indicating that more than 50% of the time residents are potentially working while impaired. A fatigue impairment score below 70 suggests an increased risk for error as well as its severity.²⁷ The extended shift and circadian rhythm disruption are the primary drivers of resident fatigue impairment on night shift. These drivers are so powerful that they result in twice the impairment predicted for the prework hour shift where residents were on call every third night with no work limitations or days off.

A secondary aim was to quantify the effectiveness of fatigue countermeasures. We found that the predicted impairment from fatigue on the night shift can be significantly reduced by instituting fatigue countermeasures. Implementing the day shift and modified night shift would essentially eliminate predicted critical resident fatigue impairment.

Our findings demonstrate the potential value of fatigue optimization scheduling and fatigue optimization countermeasures. Sometimes resident fatigue is unavoidable, but by identifying those scenarios, alternative safety checks can be implemented to prevent errors from reaching the patient. Fatigue optimization scheduling is currently used in aviation and by the US Military and Federal Transportation Association.²⁸ Despite use within these large industries, the role of fatigue optimization scheduling in reducing medical error has had limited exploration to date.^{29,30} Fatigue optimization scheduling has significant potential value for

use in residency programs and in large practices for minimizing medical error and improving patient safety.

This study has several limitations. Primarily, the results are based on a computer simulation and do not measure actual fatigue. There is likely to be significant schedule and sleep variability between institutions, individuals, and workdays, affecting the generalizability to other programs. Moreover, the schedules are based on assumptions (ie, sleep quality and quantity, and adherence to the work schedule). There may be significant variability within these measures in real-world application. Also, this study does not account for the safety checks or other countermeasures that are already in place to prevent fatigue-related error from bringing harm to the patient. Finally, the SAFTE model is predictive; it does not directly measure fatigue or medical error, nor has it been validated in the medical field.

Conclusion

There is significant potential for fatigue impairment in residents. Work schedule may be a significant factor in predicted effectiveness. Once targeted, impairment due to fatigue can be minimized with countermeasures. Fatigue optimization tools provide data for targeted scheduling interventions, which reduce fatigue and may mitigate medical error.

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