

## OPINION

# Addressing fatigue in medical residents with biomathematical fatigue modeling

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## Abstract

Fatigue in resident physicians has been identified as a factor that contributes to burnout and a decline in overall wellbeing. Fatigue risk exists because of poor sleep habits and demanding work schedules that have only increased due to the COVID-19 pandemic. At this time, it is important not to lose sight of how fatigue can impact residents and how fatigue risk can be mitigated. While fatigue mitigation is currently addressed by duty hour restrictions and education about fatigue, Fatigue Risk Management Systems (FRMSs) offer a more comprehensive strategy for addressing these issues. An important component of FRMS in other shiftwork industries, such as aviation and trucking, is the use of biomathematical models to prospectively identify fatigue risk in work schedules. Such an approach incorporates decades of knowledge of sleep and circadian rhythm research into shift schedules, taking into account not just duty hour restrictions but the temporal placement of work schedules. Recent research has shown that biomathematical models of fatigue can be adapted to a resident physician population and can help address fatigue risk. Such models do not require subject matter experts and can be applied in graduate medical education program shift scheduling. It is important for graduate medical education program providers to consider these alternative methods of fatigue mitigation. These tools can help reduce fatigue risk and may improve wellness as they allow for a more precise fatigue management strategy without reducing overall work hours.

## KEYWORDS

biomathematical modeling, fatigue, medical residents

## 1 | FATIGUE MODELING AND FATIGUE RISK MANAGEMENT

Due to the intensity of post-graduate training programs and barriers to work-life balance, diminished wellbeing and burnout are highly prevalent among resident physicians.<sup>1</sup> Fatigue due to poor sleep habits and demanding work

schedules has been identified as a factor that contributes significantly to the observed decline in wellbeing among residents.<sup>2</sup> Fatigue Risk Management Systems (FRMSs) used in other safety-sensitive industries are a potential solution to combat fatigue in medical residency programs.<sup>2,3</sup> A FRMS is a set of policies, procedures, and best-practices developed by operational personnel in order to manage

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situations which are known to increase the risk of on-the-job fatigue. Administrations may tailor their FRMS to their specific operational environment. In industries such as aviation or rail, the systems developed by operators require approval by a regulatory body, such as the FAA. While the US has provided prescriptive limits on duty time for rail and aviation since the early 20th century, FRMS have evolved as sleep and fatigue science has expanded our understanding of the causes and consequences of fatigue-related impairment.<sup>4</sup> An FRMS complements prescriptive duty hours limits by using measures and estimates of actual performance to address fatigue and alertness. Agencies such as the Federal Aviation Administration (FAA), International Civil Aviation Organization, and the Civil Aviation Safety Authority of Australia, have promoted the use of FRMS systems, with the FAA describing it as "... a data driven and scientifically based process that allows for continuous monitoring and management of safety risks associated with fatigue-related error. It is part of a repeating performance improvement process. This process leads to continuous safety enhancements by identifying and addressing fatigue factors..."<sup>5</sup> FRMS use a variety of approaches including napping, rest facilities, rotating shifts, voluntary reporting of fatigue, and biomathematical models of fatigue to address fatigue risk both proactively and reactively.<sup>6</sup> While such systems are applied to other safety-sensitive industries such as aviation and railroad, they are not formally used in medical fields, which still use prescriptive limits on duty time.

A major component of current FRMS is the use of biomathematical models of fatigue to assess schedules prospectively. Mathematical models of sleep regulation assert that the timing of sleep arises from a combination of sleep pressure (or how long it has been since an individual last rested) and the circadian rhythm, ie, the body's estimate of time of day based on environmental cues like daylight.<sup>7-11</sup> Fatigue models take these factors into account to predict the restorative benefit of sleep opportunities within the context of time of day and work history. Several biomathematical models of fatigue exist and are commonly used in transportation and/or shiftwork industries.<sup>7,8,12-18</sup> These models may differ with regard to their design, capabilities, or stated goals, but generally rely on work schedule data, circadian factors, and a model of sleep regulation to predict performance and alertness on the job.<sup>6,14</sup> In contrast to duty-hour restrictions, fatigue modeling considers when work hours are scheduled in relation to time of day as well as proximity of a work shift to previous and subsequent work periods; this allows for the assessment of the cumulative effects of multiple days of sleep restriction.

Available and widely-used models have undergone validation of their alertness predictions<sup>19</sup> and, in some models, sleep pattern predictions.<sup>20-22</sup> As a result, fatigue modeling has been incorporated into the FRMS of multiple shiftwork

industries. For example, fatigue modeling is commonly used in commercial aviation as a prospective scheduling tool and for accident investigation.<sup>23</sup> The FAA has identified scheduling factors known to affect sleep and alertness, including early start times, extended work periods, and insufficient time off between work periods.<sup>24</sup> The aviation industry has focused on mitigating fatigue risk using modeling, going beyond simple duty-hour restrictions, by implementing duty and rest requirements based in part on modeling results as evidence for its recommendation. The FAA considers fatigue modeling as a component of an FRMS that "incorporates the latest scientific research on human circadian systems, sleep, and performance capability, and can be useful for rapidly estimating fatigue levels associated with proposed new routes or schedule changes."<sup>25,26</sup>

Prospective fatigue modeling is also used in railroad operations and long-haul trucking. Research has shown fatigue models could accurately predict risk that was correlated with real-life human factors-related accidents.<sup>16,27</sup> The Federal Railroad Association (FRA) now mandates hours of service rules for employees working in commuter rail and intercity rail transportation and requires some passenger train employees' work schedules to be analyzed with an FRA-approved fatigue model.<sup>28</sup>

## 2 | BIOMATHEMATICAL FATIGUE MODELING FOR GRADUATE MEDICAL EDUCATION

While there are differences between pilots, railroad engineers, and medical residents in terms of job duties and specific schedules, all of these occupations involve shiftwork, long duty hours, rotating schedules, and night shifts. Additionally, each of these occupations are safety-sensitive, meaning that the worker is responsible for his/her own safety or the safety of other people. Fatigue in a safety-sensitive work environment has the potential to increase the risk of making an error or having an accident with potentially fatal consequences.

The growing body of evidence demonstrating the effect of sleep deprivation on performance has led the Accreditation Council for Graduate Medical Education (ACGME) to create guidelines and restrictions on resident duty hours.<sup>29</sup> The restrictions were designed to reduce both acute sleep deprivation and chronic sleep debt, but this approach has been met with mixed results: restricted duty hours have had minimal or no benefit.<sup>30,31</sup> There has also been controversy about balancing fatigue-mitigating restrictions with resident education, patient care, continuity and transitions of care, and program costs.<sup>32-35</sup> Reviews of the 2003 limits generally found no effect on resident experiential learning or patient safety, but improvements in resident quality of life, resulting in the maintenance and occasional update of many of the duty-hour

limits.<sup>36</sup> Resident physician schedules and fatigue have most likely become even more intensive during the COVID-19 pandemic.

A comprehensive risk management system requires a pivot from duty-hour limitations to alternative methods of fatigue mitigation, including the manipulation of scheduling patterns that incorporate consideration of sleep and circadian science. While duty-hour requirements focus on the maximum number of hours that residents can work, they do not address the temporal placement of work within those limitations and fail to incorporate what we know about the circadian rhythm, the cumulative effects of sleep deprivation, and fatigue's effect on cognitive performance. In addition, highly fatiguing service lines could be interspersed with less strenuous ones in the year-long block rotation schedule, or shifting start and end times to maximize the benefits of nighttime sleep during a particular rotation. Such approaches would be ideal for residency programs as they provide more flexibility than total duty hour restrictions while not requiring any additional work hours.

There are certain barriers and limitations that have prevented the implementation of FRMS in healthcare settings. First, manipulating schedules can often not be done in isolation and would likely require disruption at the department or even hospital level. However, many software programs that use fatigue modeling are well equipped for large-scale operations, like major airlines. Second, there is considerable emphasis in the graduate medical education field on substantial resident hours needed with patients for education – there may be resistance to reduction of hours. However, fatigue modeling can be beneficial in altering schedules in a way that does not reduce overall work hours. Finally, there are misrepresentations about the limitations of fatigue modeling in FRMS. Fatigue models are designed to predict a measure of alertness based on time asleep and awake, while incorporating information about time of day and circadian rhythms. However, they do not depend, at present, on workload. This is beneficial in that they can be used across different fields of work, but a limitation in that they do not account for differences in workload across these fields. Despite this limitation, the use of fatigue modeling can maximize performance based on non-workload factors, which can put an individual in a better position to do whatever their work type requires. For example, while a pilot and medical resident may have very different job requirements, both fields demand a high degree of cognitive capacity to handle job demands, and both fields require extensive simulator and real-world training to be licensed. An FRMS using modeling to guide duty scheduling will maximize alertness to meet those demanding cognitive job requirements. A final limitation includes uncertainty about the estimated sleep patterns that performance predictions are based on. While average performance can be predicted using estimated sleep (a parametrized estimator

based on shift worker sleep can do this), or actual sleep from a sample population, the estimate may not be accurate for each individual, if, for example, the individual's sleep is unexpectedly disrupted. Modeling estimates should, therefore, be understood to be probabilistic risk assessments, not definitive predictions of individual performance. Nevertheless, sleep estimates can be guided by actual sleep measurements so that, on average, the predictions are accurate.

Existing biomathematical models originally designed for other shiftwork industries can be adapted for use by physician populations. There have been several studies modeling sleep and schedules in hospital settings to predict performance or fatigue risk in both residents<sup>37,38</sup> and nurses.<sup>39</sup> A recent line of research by our group has focused on modifying a biomathematical model of fatigue based on residents' own sleep patterns with the intent to create schedule mitigations which are tailored to the needs of the medical resident. These articles by Schwartz et al<sup>40,41</sup> and Devine et al<sup>42</sup> demonstrate the utility of fatigue modeling to identify areas of fatigue risk and evaluate how schedule changes could impact fatigue and performance. Devine et al, characterized the trends and patterns in medical resident sleep using actigraph-collected sleep data over two months. From this, they were able to determine how and when residents slept and when and for how long they napped. Both Schwartz et al papers modeled resident schedules to assess their performance based on when and how long they worked. However, in the second paper,<sup>41</sup> they used the exact sleep data from Devine et al to adjust the model so that estimated sleep closely matched actual resident sleep. Performance data will best represent residents when it is based off of estimated sleep times closely matched to actual sleep times. In sum, the fatigue model used was able to closely predict the sleep patterns of general surgery residents and help estimate the level of fatigue risk across multiple schedules.

The authors have also conducted simulations of changes to general surgery resident schedules and their predicted impacts on performance (unpublished data). When shifts were adjusted so that no 24-hour long duties started between 12AM and 8AM and that no shifts, regardless of length, began between 12AM and 6AM, predicted performance was significantly increased compared to the original schedules. Importantly, these simulated mitigations (ie, modeling of changed schedules) did not require any changes to existing resources, such as additional staff, nor did they require a change in the number of duty hours worked by each individual.

While there is promise of using fatigue modeling in healthcare industry, robust trials are necessary to assess the impact of fatigue-modeling-based schedule mitigations on resident fatigue, wellness, or accident-costs. This next step is essential in implementing fatigue modeling as a risk management tool. The authors propose that graduate medical education programs conduct such trials where possible. For

example, residency programs can use a biomathematical model of fatigue to assess fatigue risk in current schedules and attempt to mitigate fatigue by adjusting shift timing and work patterns to ameliorate moments of high fatigue risk without reducing overall working hours. Measurement of sleep patterns, wellbeing, and relevant performance metrics could be compared between residents working on the original and mitigated schedules. Manipulating schedules for fatigue mitigation does not have to be prohibitively costly or require extensive input from subject matter experts. Software programs using different fatigue models are available with user-friendly interfaces designed for general consumer use.

FRMS represent an important part of worker safety in operational industries and can be applied to graduate medical programs. Especially during a global pandemic, fatigue remains a barrier to wellness for resident physicians and the safety of their patients. Innovative strategies are required to reduce this risk. Biomathematical modeling provides a way to evaluate how scheduling impacts sleep and makes it possible to test how scheduling changes could improve performance. While the ability of modeling to correctly predict sleep and performance has been verified, the impact on resident wellbeing or safety must also be directly verified to justify the implementation of such systems. The COVID-19 pandemic has highlighted the need for superior fatigue management strategies tailored to real-world healthcare operations. Biomathematical modeling of fatigue is a tool that allows for fine-tuned scheduling practices based on science to allow greater flexibility in resident scheduling beyond the restriction of duty-hours.

## DISCLOSURE

*Ethical Approval:* N/A *Informed Consent:* N/A *Registry and Trial Registration No.:* N/A *Animal Studies:* N/A *Conflict of Interest:* The Institutes for Behavior Resources provides sales of SAFTE-FAST, software that uses a biomathematical model of fatigue, and consulting for fatigue risk management systems. Dr Hursh is the inventor of SAFTE-FAST and benefits from royalties on sales of the system.

## AUTHOR CONTRIBUTIONS

All authors contributed to the ideas of this piece. LPS, JKD, & SRH led the writing.

## DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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