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EFFECT OF OCCUPATIONAL DEMANDS ON DRIVING SAFETY IN SURGICAL RESIDENTS

by

BENJAMIN MCMANUS

DESPINA STAVRINOS, COMMITTEE CHAIR
KAREN HEATON
JOHN PORTERFIELD
SYLVIE MRUG
MARK SCHALL

A DISSERTATION

Submitted to the graduate faculty of the University of Alabama at Birmingham,
in partial fulfillment of the requirements for the degree of
Doctor of Philosophy

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2018

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EFFECT OF OCCUPATIONAL DEMANDS ON DRIVING SAFETY IN SURGICAL RESIDENTS

BENJAMIN MCMANUS

LIFESPAN DEVELOPMENTAL PSYCHOLOGY PROGAM

ABSTRACT

The Accreditation Council for Graduate Medical Examination recently revised and implemented duty hour standards that increased maximum duty hours for first year medical residents and reduced the minimal amount of time off between duty periods for all medical residents. The new standards were introduced largely without consideration of empirical research on objectively measured occupational health and safety factors for medical residents, particularly in contexts where their safety may be at-risk such as driving. Little work has examined driving performance in medical residents at multiple periods surrounding duty, including in reference to off-duty driving performance as a baseline. Certain work-related factors such as sleep quality, fatigue, and stress are known to affect mental and physical performance, and may further exacerbate driving risks. The overall objective of this study was to examine driving performance in medical residents off duty, pre-duty and post-duty using a high-fidelity driving simulator. Both self-reported and objective estimates of sleep quality, fatigue, and stress were collected at off-duty, pre-duty, and post-duty points of time. There were three specific aims: 1) To examine differences in simulated driving performance among off days, pre-duty, and post-duty; 2) To determine the effect of sleep, fatigue, and stress on driving performance at each time point; and 3) To determine how post-duty period driving performance is affected by sleep, fatigue, and stress. Findings indicated that medical residents experienced the highest levels of stress and sleep propensity pre-duty and displayed

riskier driving behaviors post-duty. More senior medical residents were less affected by the negative effect of stress on driving performance, and increased sleep quality may buffer the negative effects of increased stress on driving outcomes. The impact of occupational demands on psychophysiological outcomes require further investigation to better understand the mechanisms of how work demands affect these psychophysiological outcomes. Understanding how to mitigate high job strain may have several implications in improving psychophysiological functions impacted by occupational demands, namely sleep quality and stress, and subsequently improving driving safety outcomes that may also be negatively affected by the duty demands.
Keywords: drowsy driving, driving safety, occupational demands, sleep, fatigue, stress

DEDICATION

This work is dedicated to the memories of my dad, grandmother, and grandfather. I also dedicate this dissertation to my sister, Beka, and nieces, MacKenzie and Rachael. My dissertation work is also dedicated to my mother, who is tougher than she looks. I also dedicate this work to Selena Gomez, just because I want to see if she notices, since she didn't seem to notice my dedication to her in my Master's thesis. Finally, I dedicate this to Dessie Stavrinos, PhD, who has always gone above and beyond as a mentor, has had the patience to endure me for several years now, has always pushed me to do my best, and has always put me in a position to succeed.

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LIST OF ABBREVIATIONS

AAA	American Automobile Association
ACGME	Accreditation Council for Graduate Medical Examination
CDC	Centers for Disease Control and Prevention
DBQ	Driving Behavior Questionnaire
ESS	Epworth Sleepiness Scale
ICC	Intraclass correlation coefficient
IIHS	Insurance Institute for Highway Safety
HRV	Heart rate variability
Kcal	kilocalorie
METs	Metabolic rate
MVC	motor vehicle collision
MVPA	moderate-to-vigorous activity
NHTSA	National Highway Traffic Safety Administration
NIOSH	National Institute of Occupational Safety and Health
SFI	Sleep Fragmentation Index
OFER	Occupational Fatigue Exhaustion Recover Scale
PSQI	Pittsburgh Sleep Quality Index
PVT	Performance Vigilance Task
USDOT	United States Department of Transportation
WASO	Wake After Sleep Onset

INTRODUCTION

Effect of Occupational Demands on Driving Safety in Surgical Residents

The Accreditation Council for Graduate Medical Examination (ACGME) revised and implemented duty hour restrictions effective July, 2017 to 1) increase the maximum duty hours for first year medical residents from 16 hours to 28 hours; 2) reduce the minimal time off between duty periods from 10 hours to 8 hours for all medical residents; and 3) remove the limit on the number of in-hospital night float shifts (ACGME, 2017). This change in duty hour policy partially resulted from research published in the New England Journal of Medicine suggesting that there was no difference in patient care outcomes or self-reported frequency at which medical resident fatigue affected patient or personal safety as a result of a policy change that waived previous duty hour restrictions (Bilimoria et al., 2016). The duty hour standard revisions were also influenced by many medical residency educators who believed that the previous duty hour restrictions and associated effort in maintaining them negatively impacted the learning environment, was sub-optimal for patient safety, increased hospital costs, and increased faculty workload (Wolf et al., 2018). The health and safety of the medical residents directly impacted by these policies, however, has largely been ignored. This is particularly noteworthy given that the demands and hours required in their occupation may affect psychophysiological functions that impact critical safety outcomes, particularly driving safety. The following will examine sleep quality, fatigue, and stress as they relate to occupational health and safety factors for medical residents, with a particular focus on motor vehicle collision risk.

Motor Vehicle Collisions

Motor vehicle collisions (MVCs) are a major public health problem. MVCs are among the top leading causes of death for those aged 4-34 (Centers for Disease Control Prevention [CDC], 2018). Over 32,000 people die annually in MVCs (Insurance Institute for Highway Safety [IIHS], 2016). An estimated 8,050 people died in MVCs within the first 3 months of 2017 – nearly a 10% increase in the fatality rate from 2015 (National Highway Traffic Safety Administration [NHTSA], 2017). In 2013, the cost associated with MVCs was $44 billion in surgical and work-related losses (Center for Disease Control and Prevention [CDC], 2015).

Drowsy Driving

Driving is a complex task requiring a combination of attention, perception, and decision making (Jeong et al., 2006; Romer, Lee, McDonald, & Winston, 2014; Spiers & Maguire, 2007). Between 2009 and 2013, an estimated 21% of fatal crashes and 13% of crashes resulting in severe injury involved a drowsy driver in the United States (Lee et al., 2016). Drowsy driving may impact driving safety because sleepiness and fatigue increase the likelihood of lapses of attention (Anderson, Wales, & Horne, 2010), increase reaction time (Lim & Dinges, 2008), decrease both lateral and longitudinal vehicle control (Akerstedt, Peters, Anund, & Kecklund, 2005; Campagne, Pebayle, & Muzet, 2004) and delay the recognition and response to hazards (Smith, Horswill, Chambers, & Wetton, 2009). Inattention in the context of driving may be defined as a failure to allocate sufficient attention to the driving task due to other tasks competing for attention (Regan, Hallett, & Gordon, 2011). Previous research has shown that stress related to work is also associated with poor driving outcomes (Rowden, Matthews, Watson, & Biggs, 2011) and is an important factor to consider in individuals working in high stress environments.

Occupational Demands

Karasek's (1979) Job Demand-Control model and subsequent expansions to include workplace social support (Johnson & Hall, 1988; Karasek & Theorell, 1990) have largely dominated research investigating work and health psychosocial outcomes, namely stress. The original Job Demand-Control model identified job demands as work load and has been characterized primarily in regards to time pressures, role conflicts, organizational or psychological demands (Ariza-Montes, Arjona-Fuentes, Han, & Law, 2018; Karasek, 1985). Job control is considered the worker's ability to control work activities and includes both skill discretion, the degree of control in utilization of abilities, and authority over decisions affecting their work (Ariza-Montes et al., 2018; Van Der Doef & Maes, 1999). The original model posits employees with high demands and low control exhibit increased stress and lower well-being, known as the strain hypothesis. The Karasek (1979) Job Demand-Control model and strain hypothesis can be conceptualized as depicted in Figure 1.

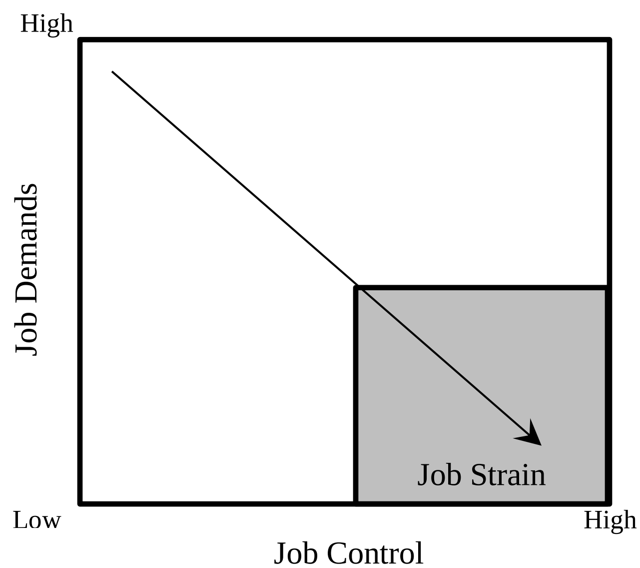

Figure 1. *Representation of Karasek's (1979) Job Demand-Control Model*

The effect of high demands on stress and well-being are mitigated when control is increased, known as the buffer hypothesis (Karasek, 1979). Models including workplace social support (Job Demand-Control-Support) contain the same hypotheses of the relationship with job demands and control, but adds that workers in isolation or that have lower workplace social support have exacerbated negative outcomes (stress) in the high demand/low control situations, known as the iso-strain hypothesis. Similar to the buffering effect of increased control in the face of high demands, increased workplace social support can mitigate the strain experienced with increased demands/low control occupational situations (Johnson & Hall, 1988).

The high job strain shown throughout medical residency (Lebares et al., 2018) may be explained by the high strain hypothesis (Karasek, 1979), which subsequently impacts psychophysiological factors that may negatively affect driving safety. High strain (high demand/low control) occupations are associated with lower psychological well-being and increased job-related stress (Van Der Doef & Maes, 1999). Specific aspects of the Job Demand-Control model have also been implicated with poorer sleep outcomes (Linton et al., 2015). Low control has been associated with more disturbed sleep (Åkerstedt, Nordin, Alfredsson, Westerholm, & Kecklund, 2012) and increased awakening problems (Hanson et al., 2011). High job strain indicated by Job Demand-Control models have been associated with poorer health outcomes in healthcare occupations (Portela, Griep, Landsbergis, & Rotenberg, 2015). Given the high demands manifested through long duty hours and shifting duty hours (Lockley et al., 2007), and the association of low autonomy with high burnout among medical residents (Llera & Durante, 2014), medical residents may often experience negative outcomes associated with high strain. Subsequently, these negative health and psychosocial outcomes also have negative impacts on critical safety outcomes, such as increased drowsy driving risk.

Medical Residents and Sleepiness, Fatigue, and Stress

The ACGME mandates that medical residents may work duty periods as long as 28 hours (ACGME, 2011), and this has recently been extended to include first year medical residents (ACGME, 2017). Despite ACGME efforts to limit duty hours in 2003 and again in 2011 to promote residency learning and patient care, sleep deprivation and fatigue continue to be reported among residents (Parshuram et al., 2015; Ripp et al., 2015; Veasey, Rosen, Barzansky, Rosen, & Owens, 2002; Zebrowski, Pulliam, Denninger, & Berkowitz, 2018). In addition to being fatigued during nearly half of their wake time, medical residents post-call have been estimated to be at fatigue levels that are comparable to having a blood alcohol concentration of 0.08, the legal limit for drunk driving in all states, where such levels of fatigue are associated with poor effectiveness and high error risk on cognitive tasks (McCormick et al., 2012). Shorter sleep durations and night shift hours common in medical professions increase the likelihood of drowsy driving instances (Lockley et al., 2007). Extended work-related stress is common in healthcare providers (de Andrade, Amaro, Farhat, & Schvartsman, 2016), and given the extended duty periods and the nature of work, medical residents may also have high levels of stress manifesting at post-duty periods that may negatively affect their driving (Rowden et al., 2011). The potential for sleep deprivation, fatigue, and stress may place medical residents at risk for drowsy driving and diminished driving performance and safety.

Post-Duty Driving

Sleep related crashes are especially common in shift workers and workers who work non-standard hours (Barger et al., 2005). Recent research has indicated that night-shift workers experience significantly more near-crashes, longer blink duration, and slower eye movements when driving following a shift (Lee et al., 2016). Barger et al. (2005) found that the risk of falling asleep while driving or while stopped in traffic was significantly higher in first year residents working at least 5 extended shifts within a single month. Considering this finding was in first year medical residents who were limited to only 16 hour duty shifts at the time of investigation (ACGME, 2011), the 28 hour duty shifts all residents may work as a result of revised ACGME duty hours (ACGME, 2017) standards may produce increased post-duty crash risk.

Previous work examining driving performance in medical residents is limited. Talusan et al. (2014) found that surgical residents' response times to a simple reaction time task were significantly slower post-duty when compared to pre-duty reaction times. Additionally, self-reported survey data obtained from first year residents have indicated that residents have increased odds for near-crashes after extended duty periods (Barger et al., 2005). Although these studies indicate medical residents may have driving performance decrements post-duty, neither utilized objective driving performance metrics.

Ware, Risser, Manser, and Karlson (2006) utilized a driving simulator to measure driving performance in twenty-two medical residents following a shift and found that driving performance as measured by lane maintenance and simulated crashes was negatively affected. However, the driving performance of participating residents in this study was only examined specifically after a period of night call, so it remains unknown how shifts of varying effort or at other times surrounding a duty period impact driving performance in medical residents. Secondly, there was no baseline referent for driving performance as residents were compared following two work days, one off-call and one on-call duty period, as opposed to a day entirely off-duty in comparison to on-duty periods. Lack of a baseline reference, namely off-duty driving, makes it difficult to assess the off-call post duty driving performance. Post duty driving performance may also be worse when following an off-call duty period and appear safer when only compared to post-duty driving performance following an on-call duty period. Ware et al. (2006), utilized actigraphy to estimate sleep the night of an off-call duty period and an on-call duty period, but only the number of estimated sleep epochs, defined as 30-second intervals when the actigraphy device detected no movement, was compared. Comparison between off-call and on-call sleep estimates using these 30 second epochs only compare the number of epochs between the periods and provides little-to-no insight on estimates of sleep quality, which is better associated with safety-relevant driving performance than sleep quantity (Lemke, Apostolopoulos, Hege, Sonmez, & Wideman, 2016). Nights of on-call duty periods had fewer sleep epochs estimated by actigraphy compared to nights of off-call duty period. Additionally, this study was conducted before the 2011 ACGME implementation of duty-hour standards (ACGME, 2011), so how the most recent duty-hour standards for medical residents impact post-shift driving performance warrants further investigation.

The most recent research on driving performance in medical residents utilizing a simulator investigated reaction time in residents following six consecutive night shifts (Huffmyer et al., 2016). Similar to the findings of Talusan et al. (2014), the residents had significantly slower reaction times and significantly more lapses of attention as measured by the Psychomotor Vigilance Task (PVT), which measures reaction time to stimuli occurring at random intervals (Dinges & Powell, 1985). In regards to driving performance, Huffmyer et al. (2016) found that after six consecutive night shifts, residents drove faster, displayed poorer lane maintenance, and had more collisions in the simulated drive compared to pre-duty simulated driving. Despite an important step forward in examining driving performance in residents following a duty shift, some limitations restrict the generalizability of these findings. The simulated driving scenario in which the participating residents drove presented a four lane oval track, an unlikely and unrealistic driving environment that residents would encounter following a duty shift.

Additionally, residents were examined either before a duty shift or following only six consecutive night shifts, and driving performance for a baseline referent, namely off duty driving performance, was not measured. Without an off-duty reference for driving performance, the assumption was that pre-duty driving is the safe “standard” for driving in medical residents, but the safety of pre-duty driving safety remains under-examined in comparison.

Anderson et al. (2017) recently examined the post-duty drive home following extended duty periods (duty periods $\geq$ 24 hours) compared to typical day shift duty periods using oculography with software for detecting drowsy driving (based on eye blink frequency and length) equipped in participants’ vehicles. Participating medical residents completed driving logs that were compared to the oculography findings. Results indicated significantly more estimated drowsy driving instances following extended duty periods when compared to typical duty periods, but a baseline reference (i.e., off day) was not used for comparison. Additionally, the small sample size (n = 16) was comprised primarily of medical residents from one non-surgical residency program, so it is unknown how medical residents from multiple programs who may have differing demands, including surgical programs, may be impacted across duty period time points. Although the examination of driving safety via naturalistic methodology employed by Anderson et al. (2017) is another important advancement in the driving safety research in this population, the work lacked sufficient experimental control necessary for characterizing driving performance to specific events and how driving may vary as a function around multiple time points relative to the duty period. Finally, it is still unknown how psychophysiology (i.e., sleep, fatigue, and stress) is affected surrounding duty periods in medical residents and ultimately, how driving performance is affected as a result.

Factors Impacting the Effect of Duty Hours on Driving Safety

Driving is a complex, purposeful, goal-directed task which relies on the ability of the driver to direct attention towards the task of driving (Craft & Preslopsky, 2013; Garrison & Williams, 2013; López-Ramón, Castro, Roca, Ledesma, & Lupiañez, 2011). Sleepiness and fatigue increase the likelihood that driver attention is drawn away from driving (Anderson et al., 2010), and this may place medical residents at risk for lapses in attention, and in turn, MVCs. In addition to examining the effect of duty hours on the driving safety of medical residents, the underlying mechanisms through which duty hours affect driving safety will be examined in the proposed study. That is, do duty hours impact driving safety depending on levels of sleepiness, fatigue, and stress of medical residents post-duty? This study focused on three physiological mechanisms that are affected by long duty periods: Sleepiness, fatigue, and stress.

Sleep Quantity Quality, and Sleepiness. Sleepiness reduces activation states and can decrease the availability of attentional resources (Recarte & Nunes, 2009). Endogenous attentional selection (deliberate selection) is especially vulnerable, because they are the most demanding selection processes, and sleepiness begins the withdrawal of the necessary recourses (Trick & Enns, 2009). Sleep loss can negatively influence visual tasks by increasing the frequency of eye closures (Wickens, Hollands, Banbury, & Parasuraman, 2013). In specific regards to driving, sleepiness significantly increases the risk of MVCs by causing attentional lapses, slowing reaction time, and affecting drivers' decision-making (Jackson, Croft, Kennedy, Owens, & Howard, 2013). A minimum of seven hours is the amount of sleep time typically associated with safe driving (Neri, Dinges, & Rosekind, 1997), and individuals in healthcare professions, such as medical residents, may not achieve this minimum amount of sleep (Lockley et al., 2007).

Research on medical residents entering the first year of residency suggests that self-reported sleep duration, sleep quality, and daytime sleep propensity significantly increase within the first year of residency, reaching levels indicative of excessive sleep propensity (Zebrowski et al., 2018). Despite intentions of ACGME hour restrictions to address potential sleep deprivation in medical residents, excessive daytime sleep propensity has remained high and unchanged since the 2011 ACGME hour restrictions (Ripp et al., 2015).

However, sleep quality and sleepiness are not the only psychophysiological processes potentially affected by the demands medical residents encounter during a work shift. Although often categorized with sleepiness, fatigue is a separate psychophysiological state that warrants consideration in medical residents and driving performance following a shift.

Fatigue. Fatigue is the transitional state between awake and sleep, and it manifests as a lack of alertness and deteriorated mental or physical performance (Gharagozlou et al., 2015). Fatigue may encompass mental fatigue and physical fatigue, inducing deterioration in cognitive or physical abilities, respectively. Fatigue impacts endogenous attentional selection processes similarly to sleepiness by withdrawing cognitive resources away from selection processes (Trick & Enns, 2009). Driver fatigue has been termed as a disinclination to continue performing the task of driving along with a progressive withdrawal of attention from the roadway and traffic demands (Brown, 1994). Although two different physiological mechanisms, both sleepiness and fatigue decrease arousal, and in turn, human performance (Wickens et al., 2013). In the present study, fatigue was defined as the perception that one is unable to maintain a predetermined level of behavioral efficiency when there are continuing demands to continue with that behavioral efficiency (Dinges & Kribbs, 1991; Kribbs & Dinges, 1994). Medical residents exhibit high levels of fatigue both during duty (McCormick et al., 2012), and throughout their tenure in residency (Ripp et al., 2015). Although some research has associated subjective physical fatigue resulting from burnout to poorer well-being in residents (Mitra et al., 2018), very little research to-date has attempted to objectively measure physical fatigue in residents. In addition to sleepiness and fatigue, stress may also impact driving performance in medical residents post-shift, but less is known on the effects of stress and driving performance.

Stress. Given the extended duty-periods and nature of work, medical residents may also have high levels of stress post-duty. Stress is an emotional and physiological state of heightened arousal that can impair performance, and potential stressors include anxiety, sleep loss, and fatigue (Wickens et al., 2013). Stress can impact performance through external influences (e.g., vibration, noise) and internal influences (e.g., anxiety, sleep loss) (Wickens et al., 2013). This study focused on internal influences of stress, namely stress encountered during a work shift. Stressors typically manifest in one of three ways in individuals: 1) producing an affective, or emotional, experience; 2) changing activity in the peripheral nervous system; and 3) affecting characteristics of information processing (Wickens et al., 2013). Stress may impact necessary processes for safe driving by narrowing selective attention (Kahneman, 1973; Wickens et al., 2013) and impairing working memory (Davies & Parasuraman, 1982). Also, stress specifically from the workplace has been shown to divert selective attention away from task-relevant processing (Alkov, Borowsky, & Gaynor, 1982; Wine, 1971). It should be noted that two psychophysiological processes that may impact driving performance in medical residents are also identified as potential stressors (sleep and fatigue), but this study focused on stress as a result of work, particularly as potentially resulting from high strain suggested by Job Demand-Control models (Karasek, 1979).

Psychosocial stress activates the salivary cortisol stress response, particularly in response to anticipation of stressful situations and contexts or within 20-40 minutes following a stressful event (Dickerson & Kemeny, 2004; Gaab, Rohleder, Nater, & Ehlert, 2005). Salivary cortisol as a biomarker of stress is also elevated during stressful life periods (Walker, O'Conner, Schaefer, Talbot, & Hendrickx, 2011). Additionally, high salivary cortisol levels may be associated with poorer sleep quality, specifically deep sleep (Buckley & Schatzberg, 2005). Similarly, decreased parasympathetic-related variation in heart rate has also been associated with anticipation of a stressful event (Wang, Lin, Huang, & Huang, 2018). Stress as indicated by variation in heart rate has also been indicated during stressful events in surgeons (Joseph et al., 2016; Weenk et al., 2017), but it is unknown how these physiological biomarkers of stress differ at multiple time points surrounding duty. The measurement of salivary cortisol and heart rate variability around duty periods in medical residents may provide insight into work-related stress.

Work-related stress may lead to the psychological and emotional exhaustion known as burnout (Maslach, Jackson, & Leiter, 1997), and burnout is particularly high in medical residents (Dyrbye et al., 2014; Thomas, 2004). The high rates of burnout may manifest from high levels of stress (Joaquim et al., 2018). The work-related stress that research suggests is common in medical residents may impact critical safety outcomes in this population, specifically driving safety.

The Current Study

This study was the first to consider not only the effect of duty hours on post-duty driving safety, but also examine the role of sleep quality, fatigue, and stress as potential covariates in this relationship, thus enabling the characterization of health aspects that may require monitoring during resident duty periods. By identifying these affected health aspects, the findings may guide policy regarding breaks or workload during duty periods. The overall goal was to test the effect of the timing of duty hours on driving safety in medical residents and to identify the underlying mechanisms through which extended duty periods affect driving performance. Thirty-two medical residents were enrolled and completed both self-reported and objective driving measures, as well as sleep, fatigue, and stress measures at three time points over multiple days, including days off-duty and on-duty.

SPECIFIC AIMS

The current study had three specific aims.

Aim 1: Examine Differences in Simulated Driving Performance Among Off Days, Pre-Shift, and Post-Shift Time Points in Medical Residents.

Drowsiness has been implicated in nearly 10% of collisions incurring injury or property damage in the United States (AAA Foundation for Traffic Safety, 2018) and as many as 21% of fatal crashes (Tefft, 2016). Compared to those who work typical daytime schedules, shift workers are more likely to drive to or from work drowsy at least a few days per month (Barger et al., 2005; Lee et al., 2016). Fatigue and sleepiness are particularly common among medical residents who often work as much as 80 hours per week (Parshuram et al., 2015; Veasey et al., 2002). Research on work schedules and drowsy driving in nurses has shown shorter sleep durations and night shift hours increases the likelihood of drowsy driving instances (Lockley et al., 2007). Although previous research has shown that residents perform worse on a simple reaction time task post-shift (Talusan et al., 2014) and display poorer driving performance on a simulated drive on a simple oval track after several consecutive night shifts when compared to pre-duty driving (Huffmyer et al., 2016), little work has examined objective measures of driving performance in a realistic and generalizable driving environment following a duty period in medical residents. Additionally, no work to-date has considered how driving performance differs not only between pre-duty and post-duty, but also in comparison to driving performance on days when residents are entirely off-duty.

Recent work published in a special issue of the New England Journal of Medicine found no difference in rate of death or serious complications in patients or self-reported frequency at which resident fatigue affected patient or personal safety between varying policies that waived rules on shift lengths and time off between shifts (Bilimoria et al., 2016). In the same issue, a perspective was published suggesting that duty hour restrictions may compromise residents' freedom to autonomously judge their patients' needs (Rosenbaum, 2016). However, objective measures of the health and safety of residents were not considered in either work, and the topic has received surprisingly little study despite its importance to resident wellbeing and public safety outcomes, namely driving safety.

Data on the driving performance of medical residents at multiple time points relative to a duty period, collected for the first time using a high-fidelity driving simulator to measure specific components of driving performance, filled critical knowledge gaps. This research yielded objective measures of driving safety in an occupation where research on safety is alarmingly lacking.

Hypothesis 1: In a driving simulator, medical residents' driving performance will decline post duty period (increased total braking reaction, speed variation, and lane position variation) compared to both off-duty and pre-duty periods.

Aim 2: Characterize the association between time-varying and time in-varying estimates of sleep, fatigue, and stress with driving performance.

Poor sleep, increased fatigue, and increased stress are factors known to impact mental and physical performance (Gharagozlou et al., 2015; Jackson et al., 2013; Wickens et al., 2013). However, it is unknown how driving safety in medical residents is impacted by sleep quality, fatigue, and stress, not only due to sleepiness, fatigue, and stress levels acutely to an instance of driving, but also due to longer-term experiences of poor sleep, fatigue, and stress. Furthermore, it is unknown how both acutely experienced sleepiness, fatigue, and stress and more chronically experienced sleepiness, fatigue, and stress impact driving performance at varying time points (off-duty, pre-duty, and post-duty).

Driving is a complex task requiring a constant processing of information fueled by attention (Castro, 2009). Sleepiness, fatigue, and stress may affect information processes necessary for safe driving. Sleepiness reduces activation states and can decrease the availability of attentional resources (Recarte & Nunes, 2009). Fatigue manifests as a lack of alertness, both mentally and physically, and results in deteriorated mental or physical performance, respectively (Gharagozlou et al., 2015). Stress may impact necessary processes for safe driving by narrowing selective attention (Kahneman, 1973; Wickens et al., 2013) and impairing working memory (Davies & Parasuraman, 1982). Workplace stress specifically has been shown to divert selective attention away from task-relevant processing (Alkov et al., 1982; Wine, 1971).

This study was among the first to obtain objectively-estimated measures of sleep quality, fatigue, and stress as covariates over the course of multiple days in residents. It was also the first to examine the impact of both time varying covariates (sleep, fatigue, and stress estimates at off-duty, pre-duty, and post-duty) and time in-varying covariates (sleep, fatigue, and stress estimates reported or averaged over multiple days) on driving performance across duty periods.

Hypothesis 1: Both time-varying and time in-varying estimates of sleep, fatigue, and stress will be associated with driving performance measured in a driving simulator, such that poorer estimated sleep quality (increased sleep propensity; decreased sleep duration and efficiency), poorer estimated fatigue (increased occupational fatigue and increased activity), and poorer estimated stress (increased cortisol, workplace stress, and life stress; decreased heart rate variability) will be significantly associated with poorer driving simulator measured driving performance (increased speed, speed variability, lane position variation, and braking reaction time).

Aim 3: Determine if post-duty period driving performance is dependent on sleepiness, fatigue, and stress.

The limited driving safety research among medical residents has largely focused on post-duty driving performance because self-reported drowsy driving occurs more frequently following duty (Barger et al., 2005). Additionally, the short sleep durations common in healthcare (Lockley et al., 2007) increase drowsy driving risk, and the post-duty period has been implicated as a time of degraded driving performance in populations with unique sleep schedules (Lee et al., 2016).

Because post-duty driving performance may be affected by sleepiness, fatigue, and stress as a result of their impacts on mental and physical performance (Gharagozlou et al., 2015; Jackson et al., 2013; Wickens et al., 2013), estimates of these psychophysiological factors for the duty period immediately preceding post-duty driving and their subsequent impact on post-duty driving performance warrant investigation.

This study was among the first to obtain both subjective and objective measures of the preceding sleep period (via actigraphy estimates), sleep propensity post-duty, fatigue (self-reported acute fatigue and actigraphy estimates of duty period activity), and stress (via heart rate variability and salivary cortisol) to determine if the effect of a work shift on post-duty driving performance was conditional upon these psychophysiological mechanisms.

Hypothesis 1: The effect of duty hours on driving performance in a driving simulator will be conditional upon sleepiness, fatigue, and stress of the residents, such that driving performance is significantly affected by duty hours at increased levels of sleepiness, fatigue, and stress.

METHOD

Participants

Thirty-two medical residents were recruited to participate in three appointments over a maximum of 2 weeks: (1) immediately before beginning a duty period, (2) after a duty period, and (3) on an off day. The order of the off-day appointment and the on-day appointments was randomized. Participants were recruited from residency programs in the Southeast United States. Eligibility criteria included: (1) Being a resident; and (2) possession of a valid driver's license. Individuals with physical limitations prohibiting participation in the experimental protocol (i.e., physical injury or disability preventing participants from being able to operate the driving simulator) were excluded. The study protocol was reviewed and approved by the University of Alabama at Birmingham Institutional Review Board for Human Use.

Measures

Table 1 describes the summary measures assessed in the study, as well as method of administration (self-report or objective) and time point of administration (initial appointment or driving appointments 1-3).

Demographics. Data on age, gender, year of residency, race and ethnicity were collected. Additionally, brief information regarding work schedules for a 2-week period were collected for scheduling purposes.

Post-Duty Assessment of Demands. A laboratory-developed questionnaire was administered to participants at their post-duty appointment. Participants rated how demanding they considered the shift to be 1) overall ("*how busy and difficult the shift was, and how much effort was required*"); 2) physically ("*frequency, duration, and intensity of any physical activity (e.g., standing, walking, and operating)*"); and 3) mentally ("*amount and type of information you had to process and difficulty of decisions you had to make*"). Participants rated all demands on a 7-point Likert scale where 1 = least demanding shift they have had, and 7 = most demanding shift they have had respective to each of the three demands. Participants additionally reported the number of surgeries or procedures they completed as well as an estimate of how many hours they were in surgery or completing procedures. The demand scales indicated good internal consistency in the sample (Cronbach's α = .83).

Sleep.

Pittsburgh Sleep Quality Index. The Pittsburgh Sleep Quality Index (Buysse, Reynolds, Monk, Berman, & Kupfer, 1989) is a 9-item measure that was administered via a take-home packet provided at the initial appointment to assess subjective sleep quality. Questions regarding sleep for the preceding month included "When have you usually gone to bed?", "When have you usually gotten up in the morning?", and "how long (in minutes) has it taken you to fall asleep each night?" that require participants to write the time or number.

A global score is calculated based on seven components:

1. Subjective sleep quality for the past month: ("During the past month, how would you rate your sleep quality overall?" [0 = "Very good," 1 = "Fairly good," 2 = "Fairly bad," 3 = "Very bad"])

2. Sleep onset: ("How long (in minutes) has it taken you to fall asleep each night" + "During the past month, how often have you had trouble sleeping because you cannot get to sleep within 30 minutes?")
3. Number of hours of actual sleep: ("How many hours of actual sleep do you get at night?")
4. Sleep efficiency: (Total hours reported sleep divided by total hours reported in bed)
5. Frequency of nine potential causes of trouble sleeping (e.g. "How often have you had trouble sleeping because you cough or snore loudly?" [0 = "Not during the past month," 1 = "Less than once a week," 2 = "once or twice a week," 3 = "three or more times a week."]);
6. Frequency of use of medication used as sleep aids: ("During the past month, how often have you taken medicine (prescribed or 'over the counter') to help you sleep?" [0 = "Not during the past month," 1 = "Less than once a week," 2 = "once or twice a week," 3 = "three or more times a week."])
7. Functioning difficulties: ("During the past month, how often have you had trouble staying awake while driving, eating meals, or engaging in social activity?" + "During the past month, how much of a problem has it been for you to keep up enthusiasm to get things done?" [0 = "Not during the past month," 1 = "Less than once a week," 2 = "once or twice a week," 3 = "three or more times a week."])

A Pittsburgh Sleep Quality Index (PSQI) global score of greater than 5 indicates poor sleep quality (Buysse et al., 1989). The PSQI has been shown to have good internal consistency with an overall Cronbach's $\alpha = 0.83$, good test-retest reliability (Pearson's $r = 0.85$), and validity as indicated with a sensitivity of 89.6% and specificity of 86.5%

(Buysse et al., 1989). The Cronbach's α for the seven PSQI subscales and global score for the current study was α = 0.67.

Epworth Sleepiness Scale. The Epworth Sleepiness Scale (Johns, 1992) is a self-reported 8-item questionnaire that was administered at each of the 3 driving appointments to provide a subjective measurement of daytime sleep propensity at each appointment. Participants reported the likelihood of dozing off or falling asleep in eight situations (e.g., sitting and reading, watching TV, in a car while stopped for a few minutes in traffic) by indicating 0 = "No chance of dozing," 1 = "slight chance of dozing," 2 = "moderate chance of dozing," and 3 = "high chance of dozing." Participants were instructed to rate the propensity for each of the situations based on the time at completion (i.e., pre-duty, post-duty, or off duty). The Epworth Sleepiness Scale (ESS) has been found to have relatively high internal consistency (Cronbach's α between 0.73 and 0.88), and good test-retest reliability (Pearson's r = 0.82) for measuring sleep propensity as a proxy for measurement of sleepiness in adults (Johns, 1992). The ESS indicated high internal consistency at each administration (Cronbach's α = 0.84 - 0.87)

Actigraphy. Participants wore an ActiGraph wGT3X-BT model (ActiGraph Corp., 2016) activity tracking watch continuously for their enrollment in the study (maximum of 2 weeks). The ActiGraph watch provided the following objective estimates of sleep:

1. *Sleep duration* – total amount of time asleep (Harvey, Stinson, Whitaker, Moskovitz, & Virk, 2008).
2. *Sleep variation* – the standard deviation of sleep duration across 24 hour periods where lower values of sleep variation indicate more similar sleep duration from night-

to-night and higher values indicate more irregularity in circadian rhythm (Merklinger-Gruchala, Ellison, Lipson, Thune, & Jasienska, 2008).

3. *Sleep efficiency* – sleep time divided by time spend in bed (Buysse et al., 1989).
4. *Wake time after sleep onset (WASO)* – an objective estimate of sleep quality measuring the amount of time in minutes awake after going to sleep (Harvey et al., 2008).
5. *Sleep Fragmentation Index (SFI)* – an objective estimate of sleep quality measuring the percentage of a sleep period that is restless or disrupted (Knutson, Van Cauter, Zee, Liu, & Lauderdale, 2011). Greater SFI indicates more disrupted sleep (Loewen, Siemens, & Hanly, 2009).

Actigraphy has been previously been used in the surgical resident population (McCormick et al., 2012), and has been shown to have strong agreement with objective standards of sleep measurement (polysomnography) as indicated by an average Pearson's r = 0.71 (Morgenthaler et al., 2007). The activity monitoring technology in the ActiGraph watch has also been shown to have high internal consistency (Intraclass correlation (ICC) = 0.80) (Welk, Schaben, & Morrow, 2004).

Fatigue.

Occupational Fatigue Exhaustion Recovery Scale. The Occupational Fatigue Exhaustion Recovery (OFER) Scale (Winwood, Winefield, Dawson, & Lushington, 2005) was administered at each of the 3 driving appointments supplying a subjective assessment of fatigue. The OFER is a 15-item scale that assesses three factors of work-related fatigue on a scale of 0 – 100, where higher scores indicate greater endorsement of that scale. The three OFER scales are below:

1. *Chronic work-related fatigue* - measured in 10 items (e.g., "I often dread waking up to another day of my work"), which has shown high internal consistency (Cronbach's α = 0.93) and test-rest reliability (Pearson's r = 0.84). The chronic work-related fatigue subscale indicated high internal consistency at each of the three administrations in the current study (Cronbach's α = 0.85 – 0.91).
2. *Acute work-related fatigue* - end-of-shift states assessed in 5 items (e.g., "I usually feel exhausted when I get home from work"), with good internal consistency (Cronbach's α = 0.82) and adequate test-retest reliability of Pearson's r = 0.64. The acute work-related fatigue subscale displayed high internal consistency across all three administrations in the study (Cronbach's α = 0.91 – 0.94).
3. *Persistent work-related fatigue* - Effective fatigue recovery between shifts measured in 3 items (e.g., "I rarely recover my strength between work shifts"), which has a Cronbach's α = 0.75 and test-retest reliability of Pearson's r = 0.62 (Winwood et al., 2005). The persistent fatigue subscales indicated high internal consistency in the study across all three administrations (Cronbach's α = 0.84 – 0.92).

Actigraphy. Actigraphy also provided the following objective estimates of fatigue where higher levels of activity were operationalized to suggest increased physical fatigue:

1. *Activity intensity* – determined by the accelerometer thresholds based on counts per minutes, where counts are the summed accelerometer values collected at 30 hertz exceeding the threshold to register movement or activity (ActiGraph Corp., 2018). Activity levels were estimated by actigraphy as the percentage of time in the following activity levels:

   a. *Sedentary activity* – registered as 0-99 counts of movement or activity per minute (Freedson, Melanson, & Sirard, 1998)
   b. *Light activity* – registered as 100-1951 counts of movement or activity per minute (Freedson et al., 1998)
   c. *Moderate-to-vigorous activity* –the combination of moderate activity (1952-5724 counts per minute) and vigorous activity (5725-9498 counts per minute) (Freedson et al., 1998).
2. *Energy expenditure* – a measure of physical activity energy expenditure using estimates of kilocalorie expenditure (daily and hourly estimates) and metabolic rate (METs) based on the three axes of the ActiGraph unit (Sasaki, John, & Freedson, 2011) to produce the following variables:
   a. *Kilocalories expended* – averaged over days and averaged per hour
   b. *METs* – averaged over days and averaged per hour

   Actigraphy estimated energy expenditure has shown good agreement with physical activity levels (Pulsford et al., 2011).
3. *Step count* – Step count was used in analyses as the total number of steps taken during a duty period. The accelerometer technology utilized in the ActiGraph unit has been shown to have a high degree of accuracy in determining steps regardless of walking or running (Le Masurier & Tudor-Locke, 2003; Sasaki et al., 2011).

Stress.

Workplace Stress Scale. The Workplace Stress Scale (Marlin Company, 2001) was administered via a take-home packet of measures provided at the initial appointment to provide subjective measurements of stress related to the workplace. The Workplace

Stress Scale (WSS) is a brief 8-item questionnaire that measured job stress levels (Marlin Company, 2001). Statements regarding feelings towards work (e.g., “I have too much work to do and/or unreasonable deadlines,” “I have adequate control or input over my work duties”) are responded to with how frequent participants believe the statements describe how they feel on a 1-5 scale where 1 = “Never”, 3 = “Sometimes,” and 5 = “Very Often.” The sum of the items produced a total score that was grouped into 5 stress categories based on data normed from WSS surveys administered from 1999-2001. Total scores <15 = “Chilled out and relatively calm”; Total scores 16-20 = “Fairly low”; Total scores 21-25 = “Moderate Stress”; Total scores 26-30 = “Severe”; Total score 31-40 = “Stress level is potentially dangerous.” The WSS was created by the American Institute of Stress along with the Marlin Company to provide a quick test of stress administered via phone survey (Marlin Company, 2001). To date, measures of reliability and validity are unknown, but the WSS had high internal consistency in this study as indicated by Cronbach’s $\alpha = 0.88$).

Social Readjustment Rating Scale. The Social Readjustment Rating Scale (SRRS) (Holmes & Rahe, 1967) is a 43-item questionnaire that measured stressful life events by asking participants to report whether or not life events have occurred in the previous year. Example items include “Death of spouse,” “Being fired at work,” “Taking on a mortgage,” and “Changes in residence.” Each of the 43 items is given a weight value, and the 43 weights are summed to produce a total score for life stress, with a maximum possible score of 4,119 if all 43 items were reported to have occurred in the previous year. Scores of 150 to 350 are suggested to be associated a 50% chance of a major health breakdown in the next 2 years, and scores over 300 are associated with an increase in the odds of a major health breakdown to 80% (Holmes & Rahe, 1967). The SRRS has shown to correlate with biomarkers of stress (Labad et al., 2015), displays stability both short term (r = 0.83) and over moderate ranges of time (r = 0.69; 6-12 months) (Gerst, Grant, Yager, & Sweetwood, 1978).

Cortisol. Participants provided a saliva sample via passive drool (Granger, Johnson, Szanton, Out, & Schumann, 2012) at each of the three driving appointments. Saliva samples were immediately stored in a freezer at -20° Celsius until assay. Salivary cortisol levels were measured in micrograms per deciliter (μg/dL) and provided an objective measure of stress. Because the aim is to measure cortisol levels in reference to stress experienced during duty, participants provided the saliva sample immediately upon arriving to the driving appointment, approximately 10-20 minutes upon completing a shift at post-duty and approximately 30 minutes before beginning a shift at pre-duty.

Heart rate variability. Participants also wore a Wahoo Fitness TICKR heart rate monitor (Wahoo Fitness, 2018) that measured heart rate and heart rate variability (HRV) for three minutes at each appointment upon arrival. HRV measures fluctuation in autonomic nervous system activity by estimating time differences between consecutive R-to-R intervals of a cardiac waveform. HRV is an indicator of the vagal branch of the autonomic nervous system control of the heart, and the vagal control of the heart is characterized by rhythmic increase and decrease (variability) of the heart rate (Porges, 1992; Task Force of the European Society of Cardiology & North American Society of Pacing Electrophysiology, 1996). When the vagal branch is not adequately responding, the organism in considered to be experiencing stress (Porges, 1992). HRV has previously been utilized to assess work-related stress and health risks in occupational health care

(Thayer, Ahs, Fredrikson, Sollers, & Wager, 2012; Togo & Takahashi, 2009). The HRV metric measuring the root mean square of successive differences (RMSSD) provides an indication of parasympathetic modulation of heart rate (Task Force of the European Society of Cardiology & North American Society of Pacing Electrophysiology, 1996) and is among the most widely reported and accepted measures of HRV in distinguishing between stress and non-stress conditions (Pereira, Almeida, Cunha, & Aguiar, 2017) and has good ICC (0.70 to 0.98) reported across multiple studies (McNames & Aboy, 2006). Lower RMSSD values indicate lower HRV, and thus, greater stress.

Driving.

Driving Experience and Behaviors. Selected domains from the Driving Habits Questionnaire (Owsley, Stalvey, Wells, & Sloane, 1999) and domains from a laboratory-generated driving behavior questionnaire (Pope, Ross, & Stavrinos, 2016; Stavrinos et al., 2013) were used to measure driving exposure and previous crashes and citations. Examples of driving exposure questions that included "During an average week, how many days of the week do your drive?", "During an average week day (Monday-Thursday), how much time do your normally spend driving per day?", and "During an average weekend day (Friday-Sunday), how much time do you normally spend driving per day?" Example questions regarding previous crashes and citations included "in the past 3 years, have you been the driver in a motor vehicle collision (regardless of fault)?" Participants indicating having been involved in a motor vehicle collisions provided additional information including month/year of the collision, whether they were deemed at-fault or not, and if they were doing anything immediately prior to the collision (e.g., using their phone or adjusting radio). Previous studies have shown test-retest reliability coefficients between 0.73 to 0.92 for driving exposure measures and 0.42 to 1.0 for crashes and citations (Owsley et al., 1999), and good internal consistency ($\alpha > 0.70$) (Welburn, Garner, Franklin, Fine, & Stavrinos, 2011).

Driving Behavior Questionnaire. The Driving Behavior Questionnaire (Parker, West, Stradling, & Manstead, 1995; Reason, Manstead, Stradling, Baxter, & Campbell, 1990) is a widely administered indicator of risky driving behavior and was administered as a measure of self-reported driving behavior aspects. The Driving Behavior Questionnaire (DBQ) assesses three subscales of driving behavior (violations, errors, and other risky behaviors) along with a total score, where higher scores indicate more violations, errors, or other risky driving behaviors. Previous research has indicated the DBQ has high internal consistency (Cronbach's $\alpha = 0.65$), high reliability ($r = 0.65$ to $r = 0.75$) (Harrison, 2009), and is significantly associated with risky driving behaviors and attitudes (Zhao, Reimer, Mehler, D'Ambrosio, & Coughlin, 2012).High internal consistency was shown for the DBQ in the current sample (Cronbach's $\alpha = .72$).

Driving Simulator. Participants drove in a driving simulator to provide an index of driving performance. This high-fidelity, fully immersive instrument was outfitted with a 2016 Honda Pilot featuring a fully functional steering wheel, throttle, brake, gear selector, turn signals, and dashboard. The simulator has a 1 degree-of-freedom motion base system allowing the vehicle to be at normal ride height for ingress and egress while providing the driver with pitch cues for acceleration and braking. The visual system consists of three large front projector screens 10 feet in front of the driver to provide proper eye relief. The scenery was displayed on three 80” LCD projection screens, providing a 180° field of view (Figure 1). A large screen behind the cab allows the driver to see the simulated environment behind the vehicle through use of the center rear mirror. LCD displays were used in the side mirror housings to account for the different calculated field of views needed for the two side mirrors. A 5.1 (six channel) sound system surrounded the vehicle for realistic vehicle and pass-by sounds.

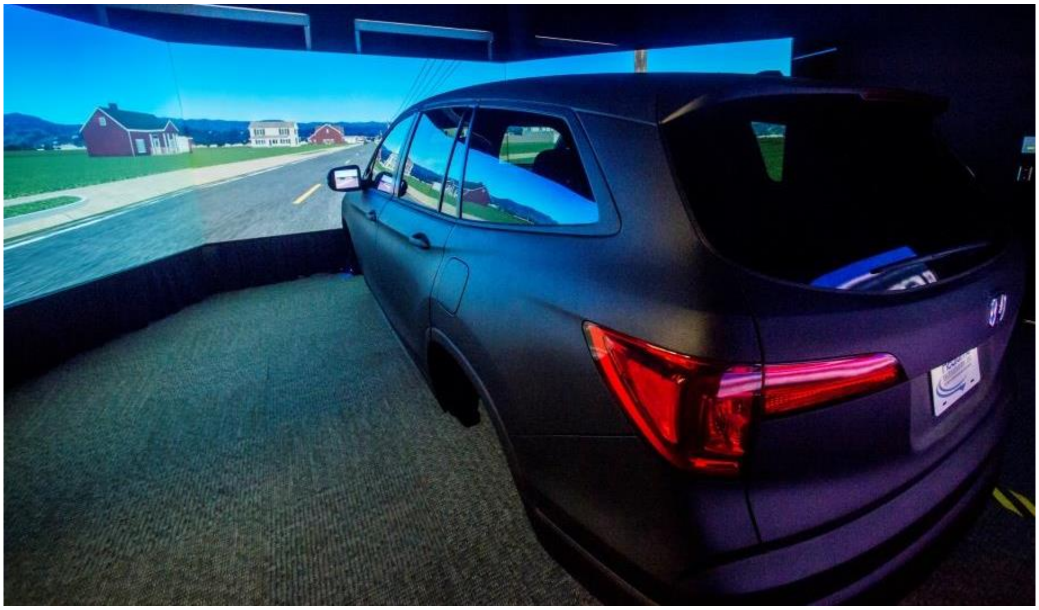

Figure 2. *Realtime Technologies, Inc Driving Simulator Utilized in Study*

Driving Outcomes. Seven performance indicators were used:

1. *Standard deviation of lane position (SD Lane Position):* measure of driving precision and steering variability (McGehee, Lee, Rizzo, Dawson, & Bateman, 2004). Lane deviations were continuously measured as the standard deviation of lane position relative to the center of a lane. Greater variation within a lane is indicative of decreased driving precision and has been shown to be sensitive to driving impairment (Helland et al., 2016; Shinar, Tractinsky, & Compton, 2005).

2. *Collisions:* total number of times participants hit a pedestrian, cyclist, another vehicle, or ran off the road and hit an object. Collisions were measured as the total count of all instances.
3. *Average speed*: measure of risky driving that substantially increases the likelihood of severe injury (Neyens & Boyle, 2008). Average speed was measured as the mean speed of the continuously measured speed from the beginning of the simulated drive to the conclusion.
4. *Speed variability*: average standard deviation of speed, where greater variability indicates more inefficient driving (Neyens, Boyle, & Schultheis, 2015; Stavrinos et al., 2013). The standard deviation of speed was continuously collected, and the average of this variable indicated speed variability.
5. *Braking reaction time:* time between presentation of a stimulus and the first force applied to brake pedal, also considered initial braking time (Egol, Sheikhazadeh, & Koval, 2008). Brake force was continuously measured, and the elapsed time between the presentation of a stimulus in the simulated environment and the first force applied to the brake provided a reaction time measure.

A summary of measures, method of administration (subjective self-report or objectively estimated), and at what time points (i.e., duty periods) measures were administered are shown in Table 1.

Table 1

Domains, Measures, Administration Method and Duty Period Time Point Administration for Study

Domain	Task	Administration		Time Point			
		Objective	Self-Report	0	1	2	3
Driving Outcomes	Driving History and Experience		X	X			
	Driving Behavior Questionnaire (DBQ)		X	X			
	High Fidelity Driving Simulator	X			X	X	X
Sleep	Epworth Sleepiness Scale (ESS)		X		X	X	X
	Pittsburgh Sleep Quality Index (PSQI)		X	X			
	Actigraphy (Sleep time & efficiency, wake after sleep onset [WASO], sleep fragmentation index [SFI])	X			X	X	X
Fatigue	Occupational Fatigue Exhaustion Recover Scale (OFER)		X		X	X	X
	Actigraphy (energy expenditure [kcals expended, METs] step count, activity levels)	X			X	X	X
Stress	Workplace Stress Scale (WSS)		X	X			
	Holmes-Rae Social Readjustment Rating Scale (SRRS)		X	X			
	Heart rate variability (RMSSD)	X			X	X	X
	Cortisol	X			X	X	X
Demographics	Age, Gender, Race/Ethnicity, Year of Residency		X	X			
	Work Schedule Information and subjective shift demand estimate		X	X			

Note. Time points: 0 = initial, and 1-3 = off-duty, pre-duty, and post-duty.

Procedure

Participants were screened for eligibility criteria by a telephone screener. Participants who met eligibility criteria for the study and that wished to participate arrived for a single session appointment that lasted approximately 15 minutes. Upon arrival to the initial appointment and provision of written informed consent, participants provided brief work schedule details regarding their work schedules over the following 2 weeks, indicating potential appointment times based on 1) off days, and 2) work days they projected to be fairly typical and at which they were willing to arrive for a driving appointment pre-shift and post-shift on the same day. The three driving appointments were scheduled over the course of a maximum of 2 weeks based on the provided work schedules. Participants were given ActiGraph watches with instructions to wear them continuously for the duration of their involvement in the study. Finally, participants were given questionnaires regarding driving (DHQ, DBQ), sleep (PSQI), and stress (Workplace Stress Scale, and Holmes-Rae Life Stress Inventory) to take home for completion and return in-person at the final scheduled appointment. Participants were also given a log which contained 1) a sleep diary based upon the National Sleep Foundation sleep diary (National Sleep Foundation, 2005); 2) actigraph watch non-wear times; and 3) caffeine use. Participants were instructed to indicate the time they went to sleep and awoke each day of involvement, note when they were not wearing the ActiGraph either due to restrictions (e.g., during surgery) or error (e.g., forgot to put back on following surgery), and the number of caffeine products consumed with approximate times the noted caffeine was consumed. This log was used to check if irregularities were noted in actigraphy data.

Approximately half of the participants (*n* = 15) had their first driving appointment scheduled to occur on an off day, and other participants (*n* = 17) had their first driving appointment scheduled to occur on an on-day (pre-duty and post-duty). The driving appointments included driving performance assessment and completion of questionnaires assessing sleep propensity and fatigue, as well saliva collection to measure cortisol for stress.

At each of the three driving appointments, participants first put on a heart rate monitor that measured and recorded HRV and provided salivary cortisol samples via passive drool. While sitting and completing questionnaires regarding sleep (ESS) and fatigue (OFER), the heart rate monitor recorded HRV over a three-minute period. During this time, participants returned the ActiGraph watch so that data could be downloaded. After three minutes and completion of the questionnaires, participants removed the heart rate monitor. Following a calibration drive (Stavrinos et al., 2013), participants completed an approximately 15-mile nighttime driving scenario with scenery similar to the local region which included roadway environments typically encountered in the local region (urban city, freeway, and residential/rural). Participants drove in one of three scenarios at each driving appointment. The scenarios were randomized across time points to minimize practice effects. To maintain consistency across driving scenarios, key factors were held constant within each road environment (e.g., traffic, light level, etc.). The driving simulation lasted approximately 15 minutes per appointment.

Because Aim 2 and Aim 3 considered how stress encountered during the duty shift impacted driving performance, participants provided the saliva sample immediately upon arrival to the driving appointment, which was approximately within the recommended 10-20 minutes of the stressor (Granger et al., 2012) – here, the conclusion of the duty period. The laboratory where the driving appointments took place was less than a mile away from the hospitals or clinics where the medical residents completed duty. As pre-duty driving appointments occurred immediately before a duty period, pre-duty saliva collection was representative of cortisol levels approximately 30 minutes before beginning duty.

Data Analysis

Preliminary Analyses. Mean and frequency distributions were used for continuous and categorical variables, respectively, to describe demographic characteristics of the participants. Analyses for outlier detection and assumptions of normality were conducted. Data that were three standard deviations away from the mean were considered outliers, and analyses were run both with the outliers in raw form and with outliers truncated to ±3 standard deviations away from the mean to determine if the outliers affected outcomes. Descriptive statistics were obtained to examine distributions and to inspect for kurtosis and skewness. Bivariate correlations were run among continuous variables. Correlations between self-reported sleep, fatigue, and stress scores and objective sleep, fatigue, and stress scores were also run to indicate agreement between the self-report and objective measures.

Driving performance outcomes were examined for overdispersion (variance ≥ mean) to determine if models that are capable of analyzing overdispersed or count outcomes (i.e., Poisson or negative binomial regressions) were necessary for utilization in primary analyses. Normality of residuals for driving outcomes analyzed in linear regressions were also examined to determine if a regression modelling a non-linear function (e.g., Poisson) was appropriate, and both models were conducted to determine if results differed between models. Bivariate relationships among variables were examined for multicollinearity ($r \geq 0.80$) (Field & Miles, 2010). All statistical analyses were conducted using SAS version 9.3 (SAS Institute Inc., 2011).

Aim 1: Examine Differences in Simulated Driving Performance Among Off Days, Pre-Shift, and Post-Shift Time Points in Medical Residents.

Fixed effects linear regressions for longitudinal analyses (Proc Mixed) or Poisson general estimating equations (GEE) where appropriate examined the single factor of duty period (off duty, pre-duty, and post-duty) on each driving performance measure. Because each participant completed three drives, participant ID (subject) was noted as a repeated factor. Pairwise comparisons among the three duty period time points were conducted with a Tukey correction for Type I error rate inflation.

Aim 2: Determine Impact of Sleep, Fatigue, and Stress on Driving Performance at Each Duty Period Time Point.

The fixed effects linear regressions and GEE for repeated measures utilized in Aim 1 were utilized for Aim 2. Analyses of sleep, fatigue, and stress covariates were conducted in two parts: 1) by time-varying covariates (collected at each duty period); and 2) by time in-varying covariates (reported or averaged over participation period).

Time-varying sleep, fatigue, and stress covariates (ESS, OFER, HRV, and Cortisol) were included as covariates in the fixed effects linear regression or GEE in addition to duty period time point. Separate models were run for each due to statistical power consideration and model parsimony. Thus, the model examining the impact of time-varying sleep propensity (ESS) for driving outcomes was as follows:

$$Driving\ Variable = Duty\ Period + ESS$$

All analyses of cortisol, including differences among duty period time points in cortisol, and the use of cortisol as a covariate included time of salivary cortisol collection to account for diurnal cortisol rhythms (Granger et al., 2012). Thus, a model examining the impact of time-varying cortisol for driving outcomes was as follows:

$$Driving\ Variable = Duty\ Period + Cortisol\ (\mu g/dL) + Time$$

Driving outcomes that were significantly associated with time-varying covariates (e.g., cortisol) were further examined to determine if other time-varying covariates interacted with one another (e.g., cortisol by OFER acute fatigue scale interaction). Driving outcomes were also analyzed by specific duty period time points (by off day, pre-duty, and post-duty) and if additional covariates (including time in-varying covariates such as averaged WASO) interacted with the time-varying covariate at specific duty period time points (e.g.,. cortisol [time-varying] by averaged WASO [time in-varying] interaction).

Time in-varying covariates included demographic variables (e.g., year in residency), and sleep, fatigue, and stress covariates included self-reported measures assessing sleep or stress over a general time period (e.g., PSQI assessed sleep quality for the past month, SRRS assed life stress based on events occurring in the past year) or no specific time period (i.e., WSS assessing workplace stress). Actigraphy estimated sleep and activity averaged over the participation period (e.g., average daily sleep duration, average variation in sleep duration, average daily step count, average kilocalories expended) were also considered time in-varying covariates.

Time in-varying covariates were included with duty period time point and an interaction between the two was included to determine if the time in-varying covariate impacted simulated driving performance dependent upon duty period time point (i.e., moderation). An example model examining the impact of a time in-varying covariate (e.g., average daily step count) for driving outcomes was as follows:

*Driving Variable = Duty Period + Daily Steps + Duty Period*Daily Steps*

Aim 3. Determine if post-duty period driving performance depends on fatigue, sleepiness, and stress levels. Actigraphy estimated sleep for the most immediate sleep period (i.e., night before) preceding the post-duty time period, actigraphy estimated during the duty shift (time between pre-duty and post-duty time periods), self-reported post-duty demands, and post-shift simulated driving performance were analyzed with bivariate correlations. Those indicating a relationship with post-duty driving performance variables were included in linear regressions or Poisson regressions where appropriate.

RESULTS

Preliminary Analyses

Missing Data

Demographics. There were no missing demographic data.

Sleep Covariates. There were no missing data for self-reported estimates of sleep propensity (Epworth Sleepiness Scale) assessed at each appointment. One participant did not complete and return the measures administered through the take-home packet, and thus there was one PSQI missing (3% of total sample).

Half of the sample was missing at least 1 night of actigraphy-estimated sleep. Eleven participants were missing one night of actigraphy estimated sleep (34% of sample), one participant was missing two nights of actigraphy estimated sleep (3% of sample), and four participants were missing three nights of actigraphy estimated sleep (13% of sample), for a total of 25 nights out of 213 nights missing actigraphy estimated sleep (12%), resulting in a final of 188 nights of actigraphy estimated sleep among all 32 participants for analyses. There was no statistical difference between participants with any missing nights of actigraphy-estimated sleep and those without any missing nights on average actigraphy-estimated sleep variables (duration, variability, efficiency, WASO, and SFI). Self-reported non-wear logs indicated forgetting to put the actigraphy device on following a shower or other activity (e.g., event) as the reason for failing to wear the actigraphy device for the missing sleep periods.

Fatigue Covariates. There were no missing data for self-reported work fatigue (OFER) assessed at each appointment. Three participants had at least one entire day of actigraphy-estimated activity missing. One participant (3% of sample) was missing four days of activity, and two participants (6%) were missing one day of activity. Actigraphy devices continued to measure estimated activity when participants were forced to remove the devices (i.e., surgery) but kept them either in a pocket or worn elsewhere (e.g., ankle). Days where under 12 hours of activity were missing were not included in analyses. This included 1) days when the actigraphy device was provided to participants, which was often near the end of a day; and 2) days when participants forgot to wear the actigraph device for several hours at a time. There were a total of 58 days' worth of activity (M = 1.81 days per participant) excluded for such reasons. The primary reason reported for non-wear during the day was surgery and taking a shower. Other reported reasons included forgetting and attending a formal event.

Stress Covariates. There were no missing salivary cortisol collections. Two participants (6%) indicated noncompliance with abstaining from food or drink 30 minutes prior to one of the appointments, as one reported chewing gum and one reported drinking water, both approximately five minutes before arrival. Removal of these participants did not alter results of differences among cortisol as a function of duty period.

There were missing data from the objective estimate of stress collected at each appointment (heart rate variability) partially for five participants (16% of sample) due to improper wear and application of the heart rate monitor. Four of these five participants (13% of total sample) were missing data for only one of the three appointments, and one of these participants (3% of total sample) was missing data for two of the three appointments. One participant was missing the WSS and SRRS (3% of total sample).

Driving Outcomes. One participant was missing data for self-reported driving history and DBQ (3% of total sample) due to failure to complete and return the take-home measurements.

Simulated driving outcomes were missing completely from one participant (3% of sample) due to simulator sickness occurring before the conclusion of the first simulated drive. The participant completed the remaining two appointments but did not attempt the simulated driving portion of these appointments. All simulated driving variable descriptive and analyses excluded this participant, resulting in a final sample size of n = 31 where simulated driving variables are presented herein. Six of the final n = 31 (19%) were missing braking reaction time from one of their 3 simulated drives, and 3 of the final n = 31 (10%) were missing braking reaction time from two of their three simulated drives. If participants did not react by pressing the brake upon presentation of the response-requiring hazard during the simulated drive, braking reaction time would register as missing. However, choosing a non-braking maneuver (e.g., swerving or only depressing accelerator) to avoid the response-requiring hazard may also register no braking reaction in the driving simulator data. Of the 12 total braking reaction times missing, eight (67%) were the result of braking too late, such that braking registered occurring outside of the hazard zone (initiation of hazard to the point hazard was out of participant’s path). The remaining four (33%) were the result of the participant making no maneuver in response to the hazard. Five (42%) of these missing braking reaction times occurred on the off day, five (42%) occurred pre-duty, and two (16%) occurred post-duty. There was no significant difference among the duty time periods on the odds of failing to react to the hazard (rendering braking reaction time as missing). The utilization of the Proc Mixed and GEE procedures in SAS employed pairwise deletion where all available data were used in regression analyses.

Descriptive Statistics and Correlations

Demographics. Participants were on average aged 28.6 years (*SD* = 2.18), male (56%), and Caucasian (94%). Participants reported an average of 2.34 years in residency (*SD* = 1.29), and the majority of participants were in a surgical residency program (78%). Participants were enrolled in the study for an average of 8.47 days (*SD* = 3.04 days). See Table 2 for descriptive statistics characterizing participants.

Table 2

Descriptive Statistics for Participant Demographics

Variable	Mean (*SD*)	*n* (%)	Range
Age	28.56 (2.18)		26.0 – 34.0
Gender (male)		18 (56%)	
Race			
Caucasian		30 (94%)	
Asian		1 (3%)	
Other		1 (3%)	
Participation (Days)	8.47 (3.04)		4.0 – 14.0
Year in Residency	2.34 (1.29)		1.0 – 5.0
Residency Program			
General Surgery		7 (22%)	
Orthopedics		8 (25%)	
Otolaryngology		4 (13%)	
Emergency Medicine		4 (13%)	
Anesthesiology		2 (6%)	
Pediatrics		6 (19%)	
Internal Medicine		1 (3%)	

Note. SD = standard deviation and n = number

Bivariate correlations indicated participant’s age and number of years in residence was positively correlated (*r* = 0.47, *p* = 0.01), and years in residency was significantly negatively correlated with SRRS measurement of life stress ($r = -0.66$, $p < 0.01$) and positively correlated with speed variability averaged across all simulated drives ($r = 0.43$, $p = 0.02$). See Table 3 for correlations among continuously measured demographic variables and sleep, fatigue, stress, and driving variables.

Table 3

Correlation Coefficients of Demographic Variables with Overall Sleep, Fatigue, Stress, and Driving Variables

	Age	Year in Residency
Year in Residency	**.47**	-
PSQI	-.10	-.27
ESS[a]	.23	.23
Average Sleep Duration (hours)	.19	.17
Sleep Variation (hours)	.22	.11
Average Sleep Efficiency	.09	.05
Average WASO	-.01	-.01
Average SFI	.04	-.03
OFER Chronic Fatigue[a]	-.06	-.23
OFER Acute Fatigue[a]	-.11	-.07
OFER Persistent Fatigue[a]	-.02	-.04
Average daily kilocalorie expenditure	.07	.16
Average hourly kilocalorie expenditure	.05	.14
Average METs	-.02	.05
Average daily percentage of sedentary activity	.07	.12
Average daily percentage of light activity	-.06	-.11
Average daily percentage of moderate-to-vigorous activity	-.07	-.08
Average daily steps	.11	.09
Average steps per minute	.07	-.14
Workplace Stress Scale	-.17	-.11
Social Readjustment Rating Scale	-.24	**-.66**
Heart Rate Variability (RMSSD)[a]	-.23	-.04
Cortisol[a]	-.22	-.01
DBQ Total	.06	.30
Average Driving Speed[a]	-.10	.28
Average Speed Variability[a]	.11	**.43**
Average SD Lane Position[a]	-.05	.24
Average Braking Reaction Time[a]	-.17	-.19
Total Collisions[a]*	-.24	-.04

Note. Bold indicates $p < .05$, [a] = averaged across all 3 appointments. * = Spearman rank correlation coefficient, PSQI = Pittsburgh Sleep Quality Index, ESS = Epworth Sleepiness Scale, OFER = Occupational Fatigue Exhaustion Recovery Scale, MET = metabolic rate, RMSSD = root mean square of successive differences, DBQ = Driving Behavior Questionnaire, and SD = Standard Deviation.

Sleep covariates.

Subjective sleep variables. Self-reported sleep quality as indicated by the PSQI Global score and sleep propensity as indicated by the ESS averaged across the three appointments met all assumptions for normality, and displayed acceptable levels of skewness (± 2) and kurtosis (± 4) (West, Finch, & Curran, 1995)with no outliers (greater than ± 3.0 SD from mean). Self-reported sleep quality as indicated by the PSQI global score was on average 8.65 (SD = 2.48) and statistically significantly higher than PSQI global score threshold for poor sleep quality of five ($t(30) = 8.17$, $p < 0.001$, Cohen's d = 1.47). The average self-reported sleep propensity across all appointments as measured by the ESS was 8.17 (SD = 4.14).

Objective sleep estimates. Actigraphy estimated sleep duration, sleep variation, WASO, and SFI were normally distributed. Sleep efficiency was not normally distributed as indicated by a Shapiro-Wilk's tests of normality (W = 0.84, p = 0.0002). Sleep duration, sleep variability WASO, SFI were within acceptable levels of skewness and kurtosis while efficiency indicated high levels of kurtosis (kurtosis = 5.66). There was one outlier detected in average sleep duration and one outlier detected in average sleep efficiency, but no analyses differed with the exclusion of either outlier.

Actigraphy estimates of sleep in participants for the duration of the study recorded an average of six nights of sleep per participant (SD = 2.88 nights). Participants averaged 7.82 hours of sleep per 24 hour period (SD = 1.77 hours) and averaged varying 2.92 hours of sleep (SD = 1.42 hours) from one 24 hour period to another as estimated by the actigraphy device. Actigraphy estimated sleep efficiency was on average 92.08% (SD =

3.76%), estimated WASO was 37.97 minutes (*SD* = 14.57 minutes), and estimated SFI was 31.87% (*SD* = 11.57%). See Table 4 for all actigraphy estimated sleep variables.

Table 4

Descriptive Statistics for Sleep Covariates Across Participation

Variable	Mean (*SD*)	Range
Self-reported		
PSQI	8.65 (2.48)	4.0 – 14.0
Average Sleep Duration (hours)*	6.60 (0.89)	4.5 – 8.0
ESS[a]	8.18 (4.14)	0.0 – 17.33
Actigraphy estimated		
Sleep periods	5.88 (2.88)	2.0 – 13.0
Duration (hours)	7.82 (1.77)	4.38 – 13.77
Sleep variation (hours)	2.92 (1.42)	0.48 – 5.56
Efficiency (%)	92.08 (3.76)	77.90 – 96.60
WASO (minutes)	37.97 (14.57)	16.43 – 75.09
SFI (%)	31.87 (11.57)	11.81 – 64.01
Lowest duration in 24 hour period (hours)	4.88 (1.80)	2.17 – 9.70

Note. PSQI = Pittsburgh Sleep Quality Index, ESS = Epworth Sleepiness Scale, WASO = Wake After Sleep Onset, and SFI = Sleep Fragmentation Index. * = single item from the PSQI and [a] = averaged across 3 appointment times.

Subjective and objective sleep variable agreement. There were no significant correlations between subjective sleep variables and objectively estimated sleep variables, including the self-reported average sleep duration item from the PSQI with actigraphy estimated sleep duration. Actigraphy estimated sleep variables were correlated with one another in general. See Table 5 for correlations coefficients among subjective and objectively estimated sleep variables.

Table 5

Correlations Among Sleep Variables Averaged Across Participation

	Self-Reported			Actigraphy Estimated				
Sleep Variable	1	2	3	4	5	6	7	8
1. PSQI	-							
2. Sleep Duration	**-.37**	-						
3. ESS[a]	.24	-.11	-					
4. Sleep Duration	-.17	.27	-.29	-				
5. Sleep Variation	.11	-.02	.05	**.65**	-			
6. Sleep Efficiency	-.13	.04	.11	**.45**	.10	-		
7. WASO	.17	.06	-.19	-.18	.03	**-.90**	-	
8. SFI	.25	-.20	-.21	-.21	.19	**-.75**	**.68**	-

Note. Bold indicates $p < .05$, [a] = averaged across 3 appointment times, PSQI = Pittsburgh Sleep Quality Index, ESS = Epworth Sleepiness Scale, WASO = Wake After Sleep Onset, and SFI = Sleep Fragmentation Index.

Sleep and fatigue correlates. Poorer subjective sleep quality as indicated by higher PSQI global scores were correlated with increased subjective OFER estimates of chronic fatigue, acute fatigue, and persistent fatigue (r's = 0.40 to 0.50, p's < 0.04), and self-reported sleep propensity was also significantly associated with acute and fatigue and persistent fatigue (r's > 0.42, p's < 0.03). Increased subjective sleep propensity was correlated with increased actigraphy estimated daily energy expenditure variables (r's > 0.35, p's < 0.05). Increased actigraphy estimated sleep duration was significantly correlated with decreased actigraphy estimated activity (r's > -0.37, p's < 0.05).

Sleep and stress correlates. Both subjective sleep quality and sleep propensity were significantly positively correlated with subjective workplace stress as measured by the WSS (r's > 0.39, p's < 0.04). There was marginal evidence to suggest a relationship between poorer subjective PSQI sleep quality and higher stress as indicated by lower RMSSD HRV measurement ($r = -0.39$, $p = 0.06$). There were no correlations of any sleep variables with cortisol.

Sleep and driving Correlates. Poorer self-reported sleep quality as measured by the PSQI was significantly correlated with increased self-reported risky driving as indicated by the DBQ (r = 0.37, p = 0.04). Correlations among sleep variables with fatigue, stress, and driving outcomes are displayed in Table 6.

Table 6

Correlation Coefficients Among Sleep Variables with Fatigue, Stress, and Driving Outcomes

Variable	PSQI	ESS[a]	Sleep Duration	Sleep Variation	Sleep Efficiency	WASO	SFI
OFER Chronic Fatigue[a]	**.50**	.17	.08	.19	-.08	.19	.10
OFER Acute Fatigue[a]	**.40**	**.42**	-.01	-.04	.10	-.01	-.03
OFER Persistent Fatigue[a]	**.42**	**.55**	-.07	.10	.10	-.08	.13
Daily kilocalorie expenditure	.01	**.36**	-.32	-.17	-.08	.01	.15
Hourly kilocalorie expenditure	-.004	.34	-.31	-.17	-.08	.002	.15
METs	-.02	**.35**	-.25	-.001	-.04	-.05	.16
Daily sedentary activity (%)	.16	-.17	.03	-.05	.12	-.17	-.21
Daily light activity (%)	-.15	.04	.06	.04	-.12	.19	.21
Daily moderate-to-vigorous activity (%)	-.09	.34	-.20	.03	-.06	.04	.11
Daily Step Count	-.14	.32	**-.49**	-.39	-.14	.02	-.01
Step Count per Minute	-.19	.28	**-.37**	-.17	-.02	-.17	-.05
Workplace Stress Scale	**.47**	**.39**	-.09	-.05	-.01	.07	.03
Social Readjustment Rating Scale	.26	.23	-.27	-.16	.14	-.17	.10
Heart Rate Variability (RMSSD)[a]	-.39	.14	-.26	-.32	.15	-.29	-.26
Cortisol[a]	-.35	-.02	.27	.19	-.01	-.00	-.09
DBQ Total	**.37**	.23	-.19	-.18	-.32	.32	.12
Average Driving Speed[a]	-.01	-.11	.05	.13	-.08	-.05	-.04
Average Speed Variability[a]	-.06	.17	.23	.30	.20	-.17	-.15
Average SD Lane Position[a]	-.05	-.03	-.01	.11	-.07	.07	-.09
Average Braking Reaction Time[a]	.16	.03	-.06	.08	-.03	.04	-.08
Total Collisions[a]*	-.13	-.06	.05	.06	.03	-.02	-.04

Note. Bold indicates $p < 0.05$, [a] = Average across three appointment times. MET = metabolic rate, RMSSD = root mean square of successive differences, PSQI = Pittsburgh Sleep Quality Index, ESS = Epworth Sleepiness Scale, WASO = Wake After Sleep Onset, SFI = Sleep Fragmentation Index, OFER = Occupational Fatigue Exhaustion Recovery scale, DBQ = Driving Behavior Questionnaire, SD = standard deviation, and * = Spearman rank correlation coefficient.

Fatigue covariates.

Subjective fatigue variables. The self-reported OFER measurement of fatigue indicated the chronic fatigue, acute fatigue, and persistent fatigue subscales were normally distributed.. All three OFER subscales were within acceptable values of skewness and kurtosis and there were no outliers. Self-reported fatigue measured across all three appointments indicated average chronic fatigue scores of 43.33 (*SD* = 17.94), acute fatigue scores of 67.67 (*SD* = 20.87), and persistent fatigue of 35.66 (*SD* = 18.76).

Objective activity estimates. Actigraphy estimated activity variables daily kilocalories and hourly kilocalories were not normally distributed as indicated by Shapiro-Wilk's tests of normality (*W*'s = .88-89, *p*'s < .05). METs, daily step count, step count per minute, percentage of time spent in sedentary activity, percentage of time spend in light activity, and percentage of time spent in moderate-to-vigorous activity were normally distributed. All actigraphy activity estimated variables were within acceptable levels of skewness and kurtosis and there were no outliers.

Actigraphy estimated an average of 50.23 kilocalories expended per hour in participants (*SD* = 22.11 kilocalories), and estimated a daily average metabolic rate (METs) of 1.40 (*SD* = 0.15), indicating averaging expending 40% more of their sedentary energy on a daily basis. Participants averaged 10,245.81 steps per 24 hour period (*SD* = 2,122.51 steps), and 8.20 steps per minute (*SD* = 1.56 steps). Actigraphy estimated participants averaged 52.54% sedentary activity (*SD* = 9.23%), 36.64% light activity (*SD* = 7.50%), and 10.82% in moderate-to-vigorous activity (*SD* = 3.70) per 24 hour period. Males were estimated to expend significantly more kilocalories both daily (*t*(24.74) =

2.09, $p = 0.047$, $d = 0.68$) and hourly ($t(22.86) = 2.17$, $p = 0.04$, $d = 0.70$). See Table 7 for all ActiGraph estimated activity variables.

Table 7

Descriptive Statistics for Fatigue Covariates Across Participation

Variable	Mean (*SD*)	Range
Self-reported		
OFER Chronic Fatigue	43.33 (17.93)	17.78 – 75.56
OFER Acute Fatigue	67.60 (20.87)	23.33 – 95.56
OFER Persistent Fatigue	35.66 (18.76)	3.33 – 77.78
Actigraphy estimated		
Daily Kilocalorie	1168.55 (532.05)	498.57 – 2696.37
Hourly Kilocalorie	50.22 (22.11)	22.81 – 112.35
METs	1.40 (0.15)	1.16 – 1.86
Steps	10245.81 (2122.51)	5398.67 – 16341.86
Steps per Minute	8.20 (1.56)	5.09 – 11.69
Sedentary Time (%)	52.54 (9.23)	33.29 – 71.96
Light Activity Time (%)	36.64 (7.50)	19.43 – 52.63
Moderate-to-Vigorous Activity Time (%)	10.82 (3.70)	4.42 – 21.60

Note. OFER = Occupational Fatigue Exhaustion Recovery Scale, METs = metabolic rate, and SD = Standard deviation.

Subjective and objective fatigue agreement. Self-reported OFER subscales of fatigue were correlated with one another (r's >0.56, p's < 0.01), and Actigraphy estimated variables of activity were largely correlated with one another (r's > 0.64). There was no significant correlation between subjective and objective estimated fatigue variables. Table 8 provides correlations among the subjective and objectively estimated fatigue variables.

Table 8

Correlation Coefficients Among Subjective and Actigraphy Estimated Fatigue Variables

	Self-Reported			Actigraphy Estimated							
Fatigue Variable	1	2	3	4	5	6	7	8	9	10	11
1. OFER Chronic Fatigue[a]	-										
2. OFER Acute Fatigue[a]	**.56**	-									
3. OFER Persistent Fatigue[a]	.29	**.60**	-								
4. Daily Kilocalorie	-.05	.13	.13	-							
5. Hourly Kilocalorie	-.07	.08	.12	**.99**	-						
6. METs	-.04	.04	.13	**.89**	**.90**	-					
7. Daily Step Count	-.04	.03	.05	**.60**	**.58**	**.61**	-				
8. Step Count per Minute	-.11	-.16	.03	.37	**.39**	**.60**	**.76**	-			
9. Sedentary Time (%)	-.02	-.23	-.24	**-.43**	**-.45**	**-.54**	-.29	-.23	-		
10. Light Activity Time (%)	.01	.25	.24	.26	.29	.28	.01	-.04	**-.92**	-	
11. Moderate-to-Vigorous Activity Time (%)	.02	.05	.12	**.53**	**.55**	**.77**	**.70**	**.64**	**-.63**	.28	-

Note. Bold indicates $p < .05$, [a] = Averaged across 3 appointment times, OFER = Occupational Fatigue Exhaustion Recovery scale, and METs = metabolic rate.

Fatigue and stress correlates. Subjective fatigue estimates measured by OFER subscales were positively correlated with self-reported workplace stress (r's > 0.47, p's < 0.01), and life stress measured by SRRS ($r = 0.44$, $p = 0.01$). Actigraphy estimated steps per minute was significantly positively correlated with higher stress measured by RMSSD HRV ($r = 0.42$, $p = 0.04$).

Fatigue and driving correlates. OFER measured chronic fatigue was significantly correlated with DBQ total score ($r = 0.40$, $p = 0.03$), and both chronic fatigue and acute fatigue were positively correlated with simulated collisions (r_s's = 0.43, p's < 0.02). Actigraphy estimated percentage of time in sedentary activity levels was positively correlated with braking reaction time ($r = 0.45$, $p = 0.04$). Correlation coefficients among fatigue variables with stress and driving variables are presented in Table 9.

Table 9

Correlation Coefficients Among Fatigue Covariates with Stress and Simulated Driving Performance Across Participation

Variable	OFER CF	OFER AF	OFER PF	Daily Kcal	Hourly Kcal	METs	Step Count	Steps per Minute	Sedentary	Light	MVPA
WSS	**.76**	**.62**	**.47**	.02	.01	-.001	-.07	-.12	.03	-.06	.05
SRRS	.12	.39	**.44**	.20	.22	.24	.15	.16	-.24	.19	.22
HRV[a]	-.28	.19	-.11	-.07	-.05	.07	.18	**.42**	.16	-.25	.10
Cortisol[a]	-.15	.47	.16	-.25	-.26	-.15	-.07	.04	-.24	.26	.06
DBQ Total	**.40**	.27	-.03	.35	.33	.21	.13	-.04	-.01	-.03	.07
Driving Speed[a]	.13	.34	-.25	.13	.13	.15	-.10	.03	.34	-.34	-.16
Speed Variability[a]	.06	.52	.08	.11	.10	.08	-.04	-.11	.19	-.18	-.09
SD Lane Position[a]	-.05	.19	-.19	-.03	-.05	.08	-.08	.001	.11	-.17	.06
BRT[a]	.33	.18	-.16	-.24	-.25	-.33	-.32	-.30	**.45**	-.36	-.36
Collisions[a]*	**.43**	**.43**	-.002	.22	.21	.17	.11	.03	-.22	.13	.10

Note. [a] = Averaged or summed across 3 appointments, WSS = Workplace Stress ScaleSRRS = Social Readjustment Rating Scale, HRV = Heart Rate Variability, DBQ = Driving Behavior Questionnaire, SD = standard deviation, BRT = braking reaction time, OFER = Occupational Fatigue Exhaustion Recovery Scale, CF = chronic fatigue, AF = acute fatigue, PF = persistent fatigue, Kcal = kilocalories, METs = metabolic rate, MVPA = moderate-to-vigorous activity and * = Spearman rank correlation coefficient.

Stress covariates.

Subjective stress variables. Both the WSS and SRRS were indicated by Shapiro-Wilk's tests of normality to not be normally distributed, but both had acceptable levels of kurtosis and skewness and no outliers. The mean WSS total score was 19.97 (*SD* = 5.85), and the average SRRS score was 222.77 (*SD* = 126.37). WSS scores were significantly higher in participants from a non-surgical residency (M_{WSS} = 24.57) compared to participants in a surgical residency program (M_{WSS} = 18.63) ($t(29) = 2.58$, $p = 0.02$, d = 2.58).

Objective stress estimates. The covariate of the stress estimate HRV as measured by RMSSD was not normally distributed as indicated by a Shapiro-Wilk's test of normality, but had acceptable levels of skewness and kurtosis and no outliers. Across all appointments, the average HRV as indicated by RMSSD was 81.90 (*SD* = 40.14). Cortisol also indicated acceptable levels of skewness and kurtosis with no outliers, but cortisol was not normally distributed as indicated by a Shapiro-Wilk's test of normality. Averaged across the three appointments, mean cortisol was 0.21 µg/dL (*SD* = 0.09). See Table 10 for descriptive statistics for both subjective and objective stress covariates.

Table 10

Descriptive Statistics for Stress Covariates Across Participation

Variable	Mean (*SD*)	Range
Self-reported		
Workplace stress scale	19.97 (5.85)	10.0 – 33.0
Holmes Rae Social Readjustment Rating Scale	222.77 (126.37)	13.0 – 475.0
Objectively estimated		
Heart rate variability (RMSSD)[a]	80.14 (40.11)	23.09 – 174.07
Cortisol (µg/dL)[a]	0.21 (0.09)	0.07 – 0.49

Note. [a] = averaged across 3 appointments, SD = standard deviation, RMSSD = root mean square of successive differences, and µg/dL = micrograms per deciliter.

Subjective and objective stress variable agreement. There was no correlation between subjective measures of stress and objectively estimated stress variables averaged across the three appointments. See Table 11 for correlations among stress variables.

Stress and driving correlates. Self-reported workplace stress was significantly positively correlated with total DBQ score (r = 0.40, p = 0.02). Self-reported life stress as measured by the SRRS was significantly negatively correlated with average driving speed and speed variability across all simulated drives (*r's* > -0.39, *p*'s < 0.04). Table 12 displays correlations between stress covariates and simulated driving performance variables averaged across the three appointments.

Table 11

Correlation Coefficients Among Subjective and Objective Stress Variables

	Self-Reported		Objectively-Estimated	
Stress Variable	1	2	3	4
1. Workplace Stress Scale	-			
2. Social Readjustment Rating Scale	.24	-		
3. HRV RMSSD[a]	-.03	.09	-	
4. Cortisol[a]	-.11	-.20	.14	-

Note. [a] = averaged across three appointments, HRV = heart rate variability and RMSSD = root mean square of successive differences.

Table 12

Correlation Coefficients Among Stress Variables and Simulated Driving Performance Outcomes Across Participation

	Self-Reported		Objectively-Estimated	
Variable	WSS	SRRS	RMSSD	Cortisol
DBQ Total	**.40**	-.23	-.21	-.34
Average Speed[a]	-.05	**-.39**	.10	-.21
Average Speed Variability[a]	-.05	**-.40**	.06	-.12
SD Lane Position[a]	-.17	-.23	-.03	-.004
Average BRT[a]	.19	.10	-.02	-.09
Total Collisions[a*]	.23	-.06	.15	.14

Note. [a] = averaged across three appointments, DBQ = Driving Behavior Questionnaire, SD = standard deviation, BRT = braking reaction time, WSS = Workplace Stress Scale, SRRS = Social Readjustment Rating Scale, RMSSD = root mean square of successive differences, and * = Spearman rank correlation coefficient.

Driving. The DBQ total score was normally distributed and had acceptable values of skewness and kurtosis. All three subscales of the DBQ (violations, errors, and other risky driving behavior) had acceptable values of skewness and kurtosis, but were not normally distributed as indicated by a Shapiro-Wilk's test of normality.

The simulated driving outcome of average speed was normally distributed as indicated by a Shapiro-Wilk's test of normality. The simulated driving outcomes of speed variability, standard deviation of lane position, braking reaction time and collisions were not normally distributed as indicated by Shapiro-Wilk's tests of normality. Additionally, as a count variable, collisions had an overdispersed distribution (i.e., the variance was larger than the mean). Average driving speed, speed variability, and braking reaction time had acceptable levels for skewness and kurtosis. Standard deviation of lane position had acceptable skewness, but slightly high kurtosis (kurtosis = 3.66). All simulated driving outcomes had no outliers. Descriptive statistics for self-reported DBQ and driving simulator collected variables are shown in Table 13.

Table 13

Descriptive Statistics for Simulated Driving Performance Across All Appointments

Variable	Mean (*SD*)	*n* (%)	Range
Self-Reported			
DBQ Total	16.97 (6.39)		6.0 – 31.0
Violations	6.16 (2.75)		2.0 – 11.0
Errors	6.71 (3.73)		1.0 – 15.0
Other Risky Driving	4.10 (2.09)		1.0 – 10.0
Objectively-Measured			
Average driving speed	52.84 (4.13)		42.22 – 59.92
Speed variability	23.11 (1.94)		18.41 – 26.96
Lane variability (SD of Lane Position)	1.21 (0.15)		0.91 – 1.73
Braking reaction time	0.56 (0.12)		0.42 – 0.90
Total Simulated Collisions			
0		23 (74%)	
1		7 (23%)	
2		1 (3%)	

Note. DBQ = Driving Behavior Questionnaire, SD = Standard deviation.

Subjective and objective driving variable agreement. There was no significant correlation between DBQ and any driving simulator variables. Average speed averaged across all simulated drives was significantly positively correlated with speed variability and SD of Lane Position (*r'*s > 0.44, *p*'s < 0.01). See Table 14 for all correlation coefficients driving outcomes averaged across all appointments.

Table 14

Correlation Coefficients of Driving Outcomes Across Participation

Driving Variable	1	2	3	4	5	6
1. DBQ Total	-					
2. Average Driving Speed	.35	-				
3. Speed Variability	.12	**.66**	-			
4. SD Lane Position	.06	**.44**	.19	-		
5. Braking Reaction Time	.20	.23	.03	.06	-	
6. Total Collisions*	-.03	.03	.11	-.05	.32	-

Note. DBQ = Driving Behavior Questionnaire, SD = Standard deviation, and * = Spearman rank correlation coefficient.

Aim 1. Examine Differences in Simulated Driving Performance Among Off Days, Pre-Shift, and Post-Shift Time Points in Medical Residents.

In analyzing differences among the three duty period time points, residuals from the three driving outcomes indicating non-normality (speed variability, SD of lane position, and braking reaction time) were assessed for normality per assumptions of linear regressions. All three indicated non-normally distributed residuals per Shapiro-Wilks's tests of normality, but the use of regressions modelling non-linear relationships (i.e., Poisson's logarithmic link) yielded the same results as linear regressions. Fixed effects linear regressions utilizing duty period as an independent variable (off day as referent) and adjusting for repeated observations within each subject indicated there was a significant difference among the duty period time points on average driving speed ($F(2, 60) = 14.02$, $p < 0.001$). Participants drove significantly faster post-shift compared to both pre-shift ($t(60) = 5.10$, Tukey adjusted $p = 0.01$) and off days ($t(60) = 3.78$, Tukey adjusted $p = 0.003$). There was no significant difference between pre-shift and off day average driving speed.

There was no significant difference among shift times on speed variability, lane variability, braking reaction time, or collision likelihood. See Table 15 for descriptive statistics for simulated driving outcomes by the three duty period time points.

Table 15

Simulated Driving Performance Variables at Off-day, Pre-shift, and Post-shift Duty Periods

	Duty Period									
	Off Day			Work Day						
				Pre			Post			
Driving Variable	Mean (*SD*)	*n*	Range	Mean (*SD*)	*n*	Range	Mean (*SD*)	*n*	Range	*F* or χ^2
Average Speed	**52.14**^{a} (5.02)		38.13 – 64.19	**51.38**^{a} (4.38)		41.61 – 58.23	**54.86**^{b} (4.64)		43.28 - 63.67	**14.02**
Speed Variability	23.25 (2.45)		18.11 – 29.25	23.21 (2.55)		18.77 – 31.03	22.76 (2.52)		16.56 – 28.19	0.81
SD Lane Position	1.19 (0.14)		0.92 – 1.49	1.21 (0.19)		0.90 – 1.87	1.22 (0.20)		0.91 – 1.83	0.44
BRT	0.49 (0.19)		0.08 – 0.98	0.59 (0.14)		0.25 – 0.90	0.57 (0.20)		0.28 – 1.15	2.29
Total Collisions	-	1	-		3	-	-	5	-	2.80

Note. Bold indicates significant difference among the time points ($p < 0.05$), letter superscripts indicate significant unique Tukey-Kramer adjusted differences between noted time point means, SD = standard deviation, and BRT = braking reaction time.

Aim 2. Determine Impact of Sleep, Fatigue, and Stress on Driving Performance at Each Duty Period Time Point.

The average time of day for pre-duty appointments was 5:38 AM (*SD* = 1.22 hours) and the average time of day for post-duty appointments was 5:03 PM (*SD* = 2.67 hours) for participants not on a night shift. For the single participant on night shift (3% of total sample), the pre-duty appointment was 5:20 PM and the post-duty appointment was 6:45 AM. Across all participants, the average time of day for off day appointments was 11:36 AM (*SD* = 3.18 hours).

Time-varying covariates. The sleep, fatigue, and stress variables collected at each duty period time point (off day, pre-duty, and post-duty) were considered as time-varying covariates. Fixed effects linear regressions adjusting for repeated observations within each subject revealed self-reported sleep propensity as measured by ESS significantly differed among all three appointments ($F(2, 62) = 11.66$, $p < 0.001$), as did the self-reported OFER subscale of acute fatigue ($F(2, 62) = 3.21$, $p = 0.047$), and the objectively-measured salivary cortisol ($F(2, 61) = 6.17$, $p = 0.003$). Controlling for time of cortisol collection, cortisol was significantly higher at pre-duty compared to both off day ($t(61) = 3.36$, Tukey-corrected $p = 0.004$) and post-duty ($t(61) = 3.16$, Tukey-corrected $p = 0.006$). See Table 16 for descriptive statics for each of the sleep, fatigue, and stress time-varying variables by duty period.

Sleep. When included as a time-varying covariate with duty period, GEE Poisson regressions adjusting for repeated observations within each subject indicated there was marginal evidence to suggest ESS predicted simulated collision risk ($\chi^2(1) = 2.96$, $p = 0.09$).

Fatigue. GEE Poisson regressions adjusting for repeated observations within each subject revealed self-reported OFER subscale acute fatigue significantly predicted the likelihood of a simulated collision when included as a time-varying covariate with duty period ($\chi^2(1) = 4.02$, $p = 0.045$) such that each point higher reported on the acute fatigue subscale was associated with a 4% increase in the likelihood of a simulated collision (RR = 1.04, 95% CI: 1.01 – 1.07).

Table 16

Sleep, Fatigue, and Stress Variables Measured at Off, Pre-Duty, and Post-Duty Duty

	Duty Period						
	Off Day		Work Day				
			Pre		Post		
Variable	Mean (*SD*)	Range	Mean (*SD*)	Range	Mean (*SD*)	Range	*F* or *t*
Time (24 hour)	**11:36**^{a} (3.18)	8:00 – 19:45	**5:32**^{b} (1.10)	3:00 – 8:00	**17:24**^{c} (1.62)	14:00 – 20:30	**1564.95**
Sleep Propensity	**5.78**^{a} (4.56)	0.00 – 15.00	**9.28**^{b} (5.43)	0.00 – 19.00	**9.47**^{b} (5.07)	0.00 – 18.00	**11.66**
Chronic Fatigue	43.54 (20.14)	16.67 – 83.33	42.50 (17.42)	16.67 – 80.00	43.96 (18.52)	16.67 – 76.67	0.41
Acute Fatigue	**69.38**^{a} (21.89)	20.00 – 100.00	**65.73**^{b} (19.79)	26.67 – 96.67	67.60 (22.45)	23.33 – 100.00	**3.21**
Persistent Fatigue	35.10 (19.12)	0.00 – 73.33	36.04 (19.17)	10.00 – 83.33	35.83 (19.87)	0.00 – 76.67	0.22
RMSSD	87.74 (60.55)	29.88 – 227.98	74.35 (31.21)	26.10 – 161.77	78.57 (55.44)	14.65 – 218.10	**1.60**
Cortisol (µg/dL)*	**0.18**^{a} (0.12)	0.03 – 0.56	**0.38**^{b} (0.23)	0.07 – 1.17	**0.08**^{a} (0.05)	0.02 – 0.22	**6.17**

Note. Bold indicates significant difference among the time points ($p < 0.05$). Letter superscripts indicate significant unique Tukey-Kramer adjusted differences between noted time point means. RMSSD = root mean square of successive differences for heart rate, and * = time of collection included as covariate.

Stress. Fixed effects linear regressions adjusting for multiple observation within each subject as well as time of salivary cortisol collection indicated cortisol predicted speed variability in the driving simulator ($F(1, 58) = 4.35$, $p = 0.04$), such that higher cortisol levels were associated with lower speed variability. The impact of cortisol at post-duty systematically differed by year in residency ($F(1, 26) = 6.40$, $p = 0.02$). Analyzing the simple slopes indicated higher post-duty cortisol levels were only significantly associated with lower speed variability at or above 1 standard deviation above the mean year in residency ($t(26) = 2.39$, $p = 0.02$). See Figure 2 for the simple slopes of year in residency plotted over post-duty cortisol for post-duty speed variability estimation.

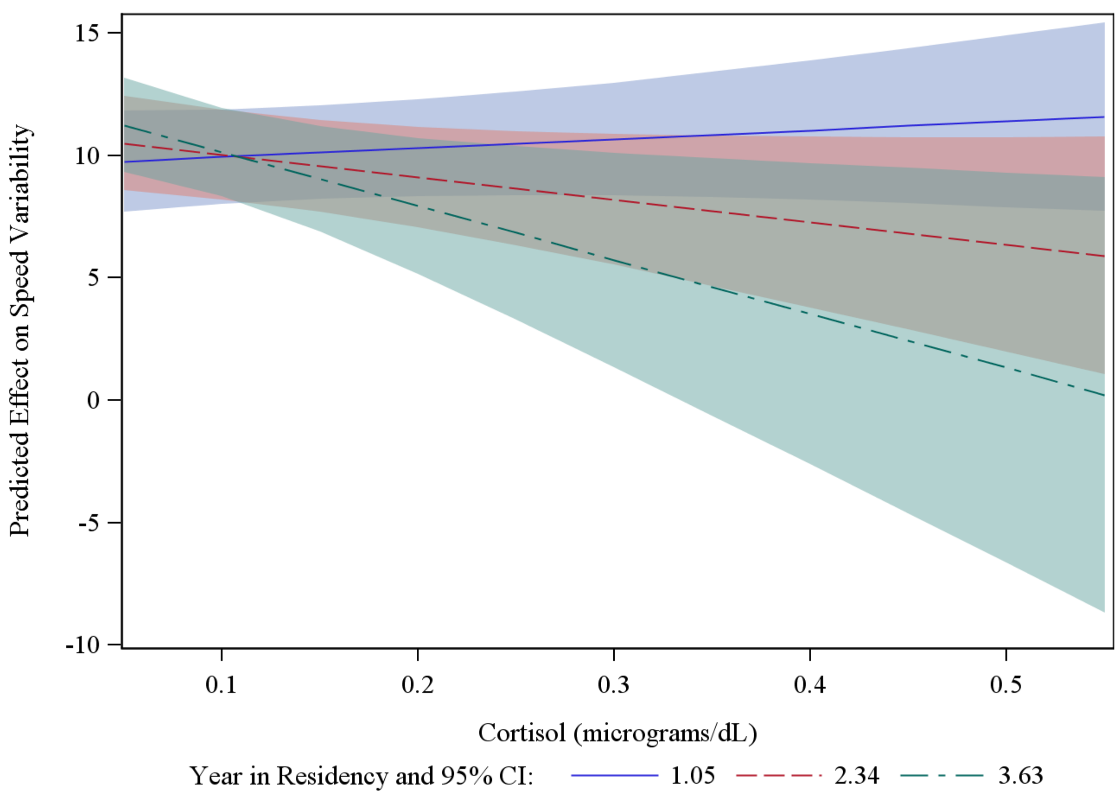

Figure 3. *Interaction of Cortisol at Post-duty with Year in Residency*

The impact of pre-duty cortisol on pre-duty braking reaction time significantly differed based on average (time in-varying) WASO ($F(1, 22) = 5.69$, $p = 0.03$). Simple slopes analysis indicated the slope of the effect of pre-duty cortisol on reaction time was significant at the mean average WASO values ($t(22) = 2.46$, $p = 0.02$) and 1 SD above mean average WASO values ($t(22) = 2.95$, $p = 0.01$), suggesting increased stress, as indicated by cortisol levels, only affected braking reaction time at increased average WASO levels, and at the lowest WASO levels, increased cortisol-estimated stress had no significant effect on braking reaction time. The interaction of pre-duty cortisol with average WASO values on pre-duty braking reaction time is visualized in Figure 3.

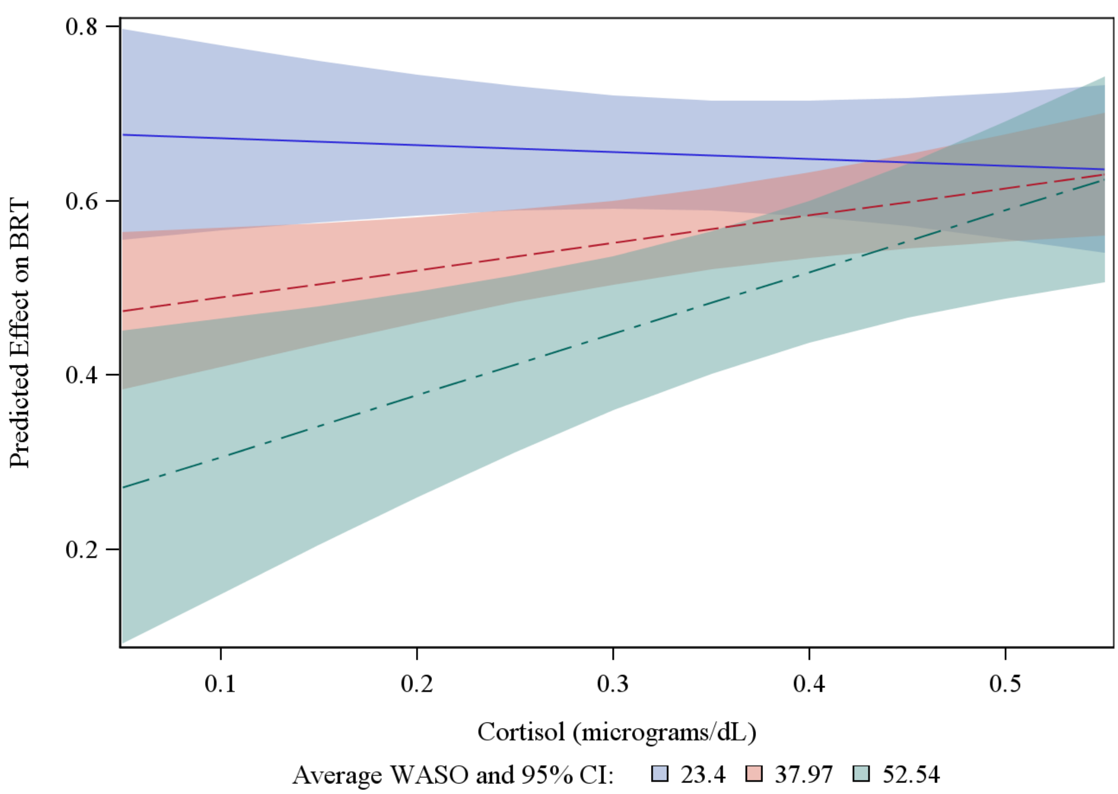

Figure 4. *Interaction of Average WASO with Pre-Duty Cortisol Levels*

Time In-varying Covariates

Demographics. Years in residency was significantly associated with speed variability in the driving simulator ($F(1, 29) = 6.97$, $p = 0.02$) such that increased years in residency was associated with greater speed variability. There was no significant interaction of years in residency with duty period time point.

Sleep. When accounting for duty period, neither the PSQI nor actigraphy estimated sleep variables were significantly associated with simulated driving performance.

Fatigue. Actigraphy estimated average percentage of time spent in sedentary activity was significantly associated with braking reaction time in the driving simulator ($F(1, 29) = 4.51$, $p = 0.04$) such that a larger percentage of time in sedentary activity was associated with increased reaction time. There was marginal evidence suggesting that actigraphy estimated average percentage of time spent in sedentary activity levels was associated with average driving speed ($F(1, 29)= 4.06$, $p = 0.05$). Average percentage of time spend in sedentary activity did not significantly interact with duty period time (off day, pre-duty, and post-duty) with either simulated driving outcome. When included as a time-in-varying covariate of simulated driving performance, there was no main effect of average daily step count, but there was marginal evidence to suggest actigraphy estimated average daily step count interacted with the effect of duty period time on braking reaction time ($F(2, 46) = 2.83$, $p = 0.07$).

Stress. Self-reported life stress as measured by the SRRS was significantly associated with speed variability ($F(1, 28) = 5.81$, $p = 0.03$) such that greater stress scores were associated with lower speed variability. SRRS score was also significantly associated with average driving speed ($F(1, 28) = 5.23$, $p = 0.03$) such that greater scores were associated with lower average driving speed. There was no interaction of SRRS with duty period time for any simulated driving performance.

Aim 3. Determine The Effect of a Duty Period on Post-Shift Simulated Driving Performance.

The time between the pre-duty and post-duty appointment times was calculated as the duty shift and estimated by the actigraphy recorded time as an average shift length of 11.47 hours (*SD* = 2.31 hours). Fifty-nine percent (*n* = 19) of the participants reported performing surgeries or procedures during the duty shift. Within those *n* = 19 participants, the average reported number of surgeries or procedures performed was 2.89 (*SD* = 2.00) and the average reported amount of time performing surgeries or procedures was 4.84 hours (*SD* = 2.92). See Table 17 for descriptive statistics for self-reported demands and actigraphy estimated activity of the duty shift.

Residents in a non-surgical residency program spent significantly more time in sedentary active levels (*M* = 59.29%) compared to those in a surgical residency program (*M* = 46.48%) as estimated by actigraphy ($t(30) = 2.11$, $p = 0.04$).

Table 17

Descriptive Statistics of Demands and Activity During a Duty Shift

Shift Variable	Mean (*SD*)	*n* (%)	Range
Self-Reported			
Overall Demands	4.06 (0.95)		2.0 – 6.0
Physical Demands	3.63 (1.21)		1.0 – 6.0
Mental Demands	4.03 (1.15)		1.0 – 6.0
Performed Surgeries/Procedures		19 (59%)	
Number	2.89 (2.00)		1.0 – 9.0
Hours	4.84 (2.92)		0.5 – 10.0
Actigraphy-Estimated			
Shift Length (Hours)	11.47 (2.31)		7.0 – 16.0
Total Kcals Expenditure	763.12 (336.97)		211.15 – 1545.83
Hourly Kcals Expenditure	66.56 (27.30)		29.87 – 118.91
METs	1.47 (0.21)		1.13 – 2.00
Step Count	640.78 (166.50)		366.40 – 1099.54
Steps per Minute	10.97 (2.88)		6.10 – 18.32
Sedentary Activity (%)	38.39 (16.21)		14.85 – 66.67
Light Activity (%)	49.28 (14.95)		25.52 – 73.54
Moderate-to-Vigorous Activity (%)	12.33 (6.21)		2.00 – 28.85

Note. Kcals = kilocalorie, METs = metabolic rate, and SD = Standard deviation.

A comparison between the actigraphy estimated sleep covariates for the sleep period preceding the post-duty period (i.e., preceding night's sleep) and the sleep period preceding an off-day is displayed in Table 18. Participants obtained significantly more sleep on the nights preceding their off-day appointments (*M* = 10.13 hours, *SD* = 3.40 hours) compared to nights preceding the work day (pre-duty and post-duty) appointments (*M* = 7.30 hours, *SD* = 2.79 hours) as estimated by actigraphy ($t(49) = 3.25$, $p = 0.02$, $d = 0.93$). A logistic regression indicated the odds of obtaining 7 or fewer hours of sleep was higher by 325% the night before the on-duty day compared to the night before the off-duty day ($\chi^2(1) = 4.73$, $p = 0.03$, Odds ratio = 4.25, 95% CI: 1.15 – 15.65). No other actigraphy estimated sleep or fatigue variables for the 24 hours preceding the duty period time points significantly differed between off day and work day.

Table 18

Actigraphy Estimated Sleep for24 Hour Period Preceding Off Day and Work Day Appointments

	24 Hours Before Off Day		24 Hours Before Work Day		
	Mean (*SD*)	Range	Mean (*SD*)	Range	*t*
Sleep					
Duration (hours)	**10.13** (3.40)	5.02 – 18.08	**7.30** (2.79)	2.57 - 13.20	**3.25**
Efficiency (%)	94.56 (4.61)	84.63 – 100.00	92.33 (3.80)	79.38 – 98.39	1.89*
WASO (minutes)	32.71 (27.34)	0.00 – 87.00	34.13 (17.66)	9.00 - 91.00	0.26
SFI (%)	20.35 (17.82)	0.00 – 68.06	20.50 (11.92)	2.73 – 52.70	0.43

Note: Bold indicates significant difference between off day and on day ($p < .05$), * indicates marginal evidence to suggest significant difference ($p < .10$), WASO = Wake after sleep onset, SFI = Sleep fragmentation index, and SD = standard deviation.

Self-reported amount of time spent in surgeries or procedures for those who reported completing any during the work shift was significantly positively correlated with the self-reported physical demands of the shift (r = 0.37, p = 0.04). Self-reported mental demands of the shift were positively correlated with heart rate variability as indicated by RMSSD (r = 0.38, p = 0.04). The self-reported physical demands of the shift were negatively correlated with cortisol (r = -0.41, p = 0.02). Time spent in surgeries or procedures was positively correlated with post-shift average driving speed (r = 0.42, p = 0.02) and speed variability (r = 0.55, p = 0.002). Time spent in surgery was negatively correlated with braking reaction time at post-shift (r = -0.42, p = 0.02).

Actigraphy estimated percentage of time spent in sedentary activity during the shift was positively correlated with post-shift average driving speed (r = 0.42, p = 0.02) and speed variability (r = 0.41, p = 0.02), and time spent in light activity during the shift was negatively correlated with post-shift average driving speed (r = -0.45, p = 0.01) and speed variability (r = -0.46, p = 0.01).

Shift length was not significantly correlated with any self-reported or objectively-estimated indicators of shift demands, and shift length was not correlated with any simulated driving performance variables. See Table 19 for correlation coefficients of selected self-reported and objectively-estimated variables of the work shift and post-shift driving performance.

Linear regressions indicated actigraphy-estimated percentage of time spent in sedentary activity during shift significantly predicted post-shift average driving speed ($t(29)$ = 2.51, p = 0.02, partial η^2 = 0.18). A model including self-reported shift demands and the actigraphy-estimated percentage of time spent in sedentary activity significantly predicted speed variability (F (2, 28) = 5.99, p = 0.01, R^2 = 0.30). Increased shift demand ratings were associated with increased speed variability (b = 0.41, SE = 0.18, t(28) = 2.27, p = 0.03, partial η^2 = 0.16), and increased percentage of time estimated in sedentary activity levels was also associated with increased speed variability (b = 0.03, SE = 0.01, t(28) = 2.42, p = 0.02, partial η^2 = 0.17). A Poisson regression indicated the actigraphy-estimated percentage of time spent in light activity significantly predicted simulated collisions (χ^2(1) = 8.30, p = 0.004), such that every percentage point higher was associated with a 12% increase in the risk of a simulated collision (RR = 1.12, 95% CI: 1.01 – 1.24).

Table 19

Correlation Coefficients Among Selected Self-Reported and Objectively-Estimated Work Shift Variables

	Self-Reported							Objectively-Estimated							
Shift Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Overall Demands	-														
2. Physical Demands	**.69**	-													
3. Mental Demands	**.74**	**.47**	-												
4. Procedures (*n*)	.30*	.30*	-.01	-											
5. Procedures (time)	.24	**.37**	.04	**.88**	-										
6. Shift hours	.16	-.04	.05	.28	.03	-									
7. Sedentary Activity	.04	.08	.01	.18	**.49**	-.16	-								
8. Light Activity	-.10	-.15	-.03	-.25	**-.55**	.09	**-.92**	-							
9. HRV RMSSD	.33*	.13	**.38**	-.04	-.13	.21	-.06	.09	-						
10. Cortisol	.25	**-.41**	-.04	-.12	-.15	-.20	-.04	.03	-.27	-					
11. Speed	.12	.11	.19	.26	**.42**	-.29	**.42**	**-.45**	-.09	-.06	-				
12. SD Speed	**.39**	.31*	.23	**.43**	**.55**	-.23	**.41**	**-.46**	.04	-.03	**.56**	-			
13. SDLP	.09	.14	.20	.02	.11	.03	.21	-.29	.08	.18	**.39**	.29	-		
14. BRT	.11	-.17	.35*	-.33*	**-.42**	.21	-.04	.08	.06	.33*	.01	-.11	.23	-	
15. Collision^{s}	.06	-.08	.21	**-.37**	**-.39**	-.21	-.34*	**.48**	.22	.15	-.16	-.03	-.27	.30	-

Note. Bold indicates significance ($p < 0.05$), * = marginal evidence suggesting significance ($p < 0.10$), n = number, ^{s} = Spearman rank correlation coefficient, HRV = heart rate variability, RMSSD = root mean square of successive differences, SD = standard deviation, SDLP = standard deviation of lane position, and BRT = braking reaction time.

DISCUSSION

This study investigated a cognitively demanding task requiring attentional resources in the context of driving performance, where time relative to a duty period was hypothesized to affect performance through differences in psychophysiological factors that have previously been implicated in depleting or reducing cognitive and attentional resources. This study was among the first to utilize both subjective accounts and objective estimates of these physiological factors, how they differ among duty period time points, and how the cognitively demanding and critical safety outcome task of driving is impacted. This work was conducted in a sample of medical residents where safety outcomes of its population is seldom researched. Investigation of safety related outcomes for medical residents is critically important and timely considering the recent duty hour restrictions (ACGME, 2017) that may lead to poorer sleep quality, increased fatigue, increased stress, and subsequently poorer driving performance as a result of the potential for increased duty hours and less time off duty between duty periods. Alarmingly, the newest duty hours were implemented as the result of a task force's recommendation that limits in first year medical residence be extended for patient care continuity and medical resident learning (ACGME, 2017), but these recommendations came without evidence to support whether the demands of these new hour standards impact health and safety of medical residents.

Impact of Time Relative to Duty on Driving Performance

Aim 1, Hypothesis 1 (Residents will perform more poorly post duty compared to both off-duty and pre-duty periods) was partially supported by findings suggesting driving performance may be riskier post-shift compared to other time points surrounding the duty period (i.e., off days and pre-shift). Although several indices of risky driving behavior were not shown to significantly differ among the three time points, residents drove significantly faster post-shift.

These findings are consistent with previous research utilizing a simple oval highway roadway that indicated residents drove significantly faster following six consecutive night shifts (Huffmyer et al., 2016), but further advance our understanding of driving by including an off-day driving performance for a more accurate referent for driving performance than pre-duty. Previous research has examined post-duty driving performance in this population only in comparison to pre-duty (Anderson et al., 2017; Huffmyer et al., 2016; Ware et al., 2006), making the assumption that pre-duty is the standard for potentially safe driving in this population. However, findings from the present study suggest that medical residents may also be at-risk for driving performance degradation pre-duty, as stress was observed to be highest pre-duty. Pre-duty perceived sleep propensity was also observed to be no different than post-duty, and residents had over 4 times the odds of not obtaining the recommended seven hours of sleep during a work day compared to an off-duty day. Examining the mean and frequency of simulated driving outcomes along with the inferential test statistics suggests that with a larger sample size, braking reaction time and collisions may have displayed statistically significant differences among the duty period time points.

Increased driving speed has been noted as a risky driving behavior that significantly increases the likelihood of injury in the event of a collision (Neyens & Boyle, 2008). Average driving speed in this sample was significantly positively correlated with increases in other driving metrics which have shown to affect driving safety, namely speed variability (Neyens et al., 2015; Stavrinos et al., 2013) and maintenance of lane position (McGehee et al., 2004).

An additional implication of significantly increased driving speed at post-duty time periods may also provide insight to decision-making post-duty. Previous research has indicated that accuracy of decisions is often expended in exchange for making decisions faster in experimentally sleep-deprived individuals (Horowitz, Cade, Wolfe, & Czeisler, 2003; McKenna, Dickinson, Orff, & Drummond, 2007). That is, individuals who are either aware of or perceive to have their functioning impaired attempt to compensate by reacting or making decisions quicker, resulting in increased errors. Although participants in the current study were not experimentally sleep-deprived and the finding of increased driving speed post-duty compared to off-day and pre-duty periods was without regard to subjective sleepiness or other considerations of arousal level, the increased driving speed may be a function of a perception of fatigue or experience actual fatigue and a resulting quicker decision-making approach in residents post-duty.

Residents may have also driven significantly faster post-duty simply because the time point occurred after an average of nearly-12 hour duty period, and as such, were ready to complete the study appointment and return home. However, this further indicates a potentially risky approach to decision-making post-duty that may also manifest in real world on-road driving contexts.

Sleep, Fatigue, and Stress in Resident Driving Performance

Aim 2, hypothesis 1 (Sleep, fatigue, and stress will be associated with driving performance and be conditional upon duty period time point) was partially supported by the findings.

Results of the current study indicate that sleep, fatigue, and stress are differentially experienced by residents dependent upon time relative to duty, with residents displaying significantly greater subjective sleep propensity and salivary cortisol levels pre-duty. The direct impact of these physiological factors was minimal on simulated driving performance when accounting for time relative to duty, but their effects were dependent upon other factors.

Although increased stress as measured by cortisol was associated with safer or more efficient driving (lower speed variability), the significant interaction of year in residency with post-duty cortisol levels on post-duty speed variability suggests that only the most senior residents display lower speed variability at increased stress levels, while less senior residents (2 years in residency and fewer) do not display any change in speed variability as a function of increased stress. As there was no effect of year in residency on cortisol levels itself, more senior residents do not appear to experience less stress than less senior medical residents. However, these more senior medical residents may have developed methods to modulate stress and avoid a subsequent effect on driving performance and potentially other safety-relevant outcomes. These findings are supported by previous studies examining stress in a single shift that have shown no statistically significant difference in stress throughout the shift based on years in residency, but suggested that the stress experienced and indicated by salivary cortisol during the day is slightly attenuated in more senior medical residents (Gonzalez-Cabrera et al., 2018). However, it is unknown how medical residents potentially develop strategies to mitigate stress and what these strategies encompass, despite stress remaining high at all years in residency (Lebares et al., 2018). More senior medical residents may experience stress from different sources due to changing responsibilities, including managing or overseeing their more junior counterparts.

Stress also affected pre-duty driving behavior, but only as a function of sleep quality, as measured by the average WASO estimated by actigraphy. Residents with the lowest actigraphy-estimated WASO values displayed no change in braking reaction time regardless of stress as measured by cortisol levels. Those with poorer sleep quality, indicated by increased WASO values, were affected by increased stress, such that estimated predicted braking time increased as stress increased. Although this finding does not necessarily suggest improved sleep quality and decreased stress result in safer driving, it may suggest a physiologic over-ride of stress during time of poor sleep quality. This finding may indicate that for those with poorer sleep quality, the impact of increasing stress may have more of a resulting impact on functioning, including in safety-relevant outcomes. Although poor subjective sleep quality has been associated with increased cortisol responses (Bassett, Lupis, Gianferante, Rohleder, & Wolf, 2015), it remains largely unknown how sleep quality and stress interact to subsequently affect safety outcomes, with particular regard to driving.

It should be noted that poor sleep and increased stress are interrelated, and one may lead to the other. Stress related specifically to one’s occupation has been associated with poorer sleep outcomes (Akerstedt, 2006). In addition to attempts to improve sleep quality in this population among others at-risk for poor sleep quality, attempts to lower work-related stress may indirectly improve sleep outcomes and associated safety outcomes. These findings also suggest that adequate sleep quality may provide a potential buffer in contexts where stress may otherwise negatively affect safety outcomes.

Contrary to the hypothesis, increased average time in sedentary activity as estimated by actigraphy was associated with poorer (increased) braking reaction time. In the present study, fatigue measured by actigraphy was operationally considered to be higher when estimated activity such as energy expenditure and movement was also higher, and lower when such activity lower. By this operationalization, more time in sedentary activity was hypothesized to indicate lower fatigue. However, it is possible that the percentage of time in sedentary activity was overestimated by the actigraph device, not due to any direct miscalculation, but because of logistical wear considerations of the residents. Residents routinely kept the actigraph device in a pocket or worn elsewhere (e.g., ankle) from the wrist as hygienic requirements for surgeries or procedures required the removal of the actigraph device from the wrist. The actigraph was typically calibrated to be worn on the non-dominant wrist at the initial visit, and the actigraph may have estimated less activity than accurate as a result.

It should also be noted that fatigue has been shown to be inversely related to fitness (Berlin, Kop, & Deuster, 2006). As such, residents displaying greater time in actigraphy-estimated sedentary behavior may actually be more fatigued. If increased estimated time in sedentary activity levels indicate increased fatigue, then results would support the hypothesis that increased fatigue would be associated with poorer simulated driving outcomes. However, fitness levels of the residents were not measured, so the impact of estimated sedentary behavior and driving outcomes is unclear.

Post Duty Driving Performance

Aim 3, hypothesis 1 (The amount of time on-duty and sleep, fatigue, and stress variables will be negatively associated with simulated driving performance) was partially supported by the current study's findings.

Similar to the findings of Aim 2, increased time in estimated sedentary activity was associated with poorer simulated driving outcomes. Again, this finding may be confounded by the selected wear location of the actigraphy device. This may indicate that those residents who spent more time in surgery, and thus potentially had sedentary behavior overestimated due to the actigraphy device being in a non-calibrated location, displayed poorer driving performance post duty. However, those residents who did perform surgery or procedures during the shift immediately preceding the post-duty appointment reported their estimated time in surgery, and the measure was observed to have no significant association with driving performance. Residents subjectively reporting more demanding shifts displayed significantly greater speed variability.

Previous research in other populations at high risk for drowsy or fatigue-related crashes has shown crash risk to increase in proportion to time-on-task (Department of Transportation, 2000), but the current study found little evidence of an association between shift length and post-duty driving performance. The majority of inferences made on post-duty driving performance among medical residents has made these inferences based on comparisons to pre-duty driving performance (Anderson et al., 2017; Huffmyer et al., 2016; Ware et al., 2006), but the activities and demands of the duty period itself have remained largely unexamined. Medical residents have been shown to experience high estimated levels of fatigue (McCormick et al., 2012), but our findings suggest that the fatigue may not be primarily a function of time-on-task. Although estimated reported time spent in surgery was not a significant predictor of simulated driving outcomes in this study, this variable was only available for analysis in those medical residents who reported completing surgery on that particular day (*n* = 19), and thus these analyses had limited power. Also, not all medical residents in the sample were in a surgical residency program (*n* = 7 were not), but they were still asked to report procedures or resuscitations completed during duty. Reported time in surgery was significantly correlated with subjective demand estimates and simulated driving outcomes for this subsample. A larger sample size is warranted to more closely examine how specific aspects of duty contribute to subjective demands of the duty period and how quantifiable duties (i.e., number of and time to complete procedures) relate to post-duty driving safety.

Impact on Occupational-Related Sleep, Fatigue, and Stress

Although actigraphy estimates of sleep indicated sleep durations of over seven hours when averaged across residents' time in the study, the estimated sleep varied from night-to-night by an average of nearly three hours. Estimated sleep duration was longer in periods surrounding off days; residents were estimated to obtain significantly more sleep (over 2.5 hours) the night before an off day. However, sleep quantity should not necessarily be equated with sleep quality, as sleep quality also encompasses restfulness and depth of sleep in addition to sleep duration (Buysse et al., 1989; Pilcher, Ginter, & Sadowsky, 1997).

Stress as indicated by objectively measured cortisol was significantly dependent upon time around duty periods. Off-duty and post-duty periods revealed cortisol levels more similar to one another than pre-duty, which was significantly higher, even after controlling for diurnal changes in cortisol by including time of collection in the analyses. These results suggest that stress is significantly increased pre-duty compared to off- and post-duty. This finding is supported by previous research investigating cortisol in medical residents across a single duty period (Gonzalez-Cabrera et al., 2018). Pre-duty cortisol elevation is likely due to anticipation of a stressful situation (Gaab et al., 2005).

Karasek's Job Demand-Control model indicates high demands and low control over those demands may result in stress, but increased control may buffer the negative impact of high demands (Karasek, 1979). For medical residents in a situation where the demands are high, yet there is little-to-no control over demands during their residency (Llera & Durante, 2014), improved sleep quality may act as a buffer necessary to reduce the negative impact of high strain, and the subsequent impact the resulting stress may have on driving performance.

This is an especially important consideration with the ACGME's revised duty hour standards that not only increased the time-demands for first year medical residents, but also removed previously recommended "strategic naps" during 24 hour continuous duty periods (ACGME, 2017). Because research leading to the implementation of the ACGME's revised duty hour standards and recommendations were based on patient outcomes and self-reported medical resident satisfaction of education and well-being (Bilimoria et al., 2016), more research into critical health and safety outcomes of medical residents is warranted. Future research should examine duty periods in medical residents by implementing detailed assessments of the Job Demand-Control(-Support) model(s) (Karasek, 1979; Karasek & Theorell, 1990) to determine 1) what aspects may be most affected in medical residents (demands, controls, and/or workplace support); and 2) which aspects are feasible to modulate to reduce job strain and the resulting potential risk for safety outcomes, including driving safety.

Impact on Driving Safety

Driving is a cognitively demanding task. Factors that negatively impact cognition, attention, and information processing may reduce driving safety. Poor sleep, increased fatigue, and increased stress have been implicated to degrade diving safety by reducing the cognitive resources necessary for safe driving (Wickens, 1980; Wickens & McCarley, 2008) and reducing the attention necessary to process relevant information (Anderson et al., 2010).

Recent naturalistic research has implicated drowsiness in nearly 10% of all crashes, and in nearly 11% of crashes where there was injury or property damage (AAA Foundation for Traffic Safety, 2018). Seven-to-nine hours of sleep is associated with safe driving outcomes (Neri et al., 1997), but 35% percent of adults obtain less than that amount of sleep (Liu et al., 2016). Every hour of sleep under this recommended minimum of seven hours has been associated with increases in crash risk as low as 30% for obtaining only 6-to-7 hours of sleep, and as high as increases of 1150% (11.5 times) for obtaining 4 hours of sleep or fewer (Tefft, 2016).

The average lowest amount of sleep estimated during participation was just under five hours, indicating each participant averaged under five hours of sleep at some point during participation - an amount of sleep that has been associated with a 330% increase in the odds of a crash (Tefft, 2016). Although actigraphy estimates of sleep quality (Sleep efficiency, WASO, and SFI) were largely not significantly associated with simulated driving outcomes, the interaction of average WASO with pre-duty cortisol indicates sleep quality may play a role in occupational factors that may lead to stress and subsequent driving performance degradation.

Although some factors (i.e., cortisol) were clearly most impacted pre-duty, it appears that post-duty driving may be a risky behavior as suggested by significantly increased speed post-duty. Despite this finding potentially being the result of simply wanting to get home post-duty, it still provides a reflection of the potential risky decision making behaviors that may be exhibited post-duty.

RECOMMENDATIONS FOR POLICY

The 2011 ACGME duty hour restrictions aimed to improve health and well-being outcomes in medical residents while maintaining the valuable education provided to the medical residents and upholding outcomes for patients under the care of the medical residents (ACGME, 2011). These policies have often been met with negative reception of medical educators and faculty, largely due to perceptions of decreased patient safety and a negative impact on the learning environment (Wolf et al., 2018). Empirical findings investigating the 2011 ACGME duty hour standards have also suggested no differences in sleep quality, fatigue, or stress in the medical residents (Ripp et al., 2015), and no difference in patient safety (Bilimoria et al., 2016). In medical residency where the medical residents are both 1) in a student capacity, in furthering their education and training; and 2) in a provider capacity, to some degree independently caring for patients where mistakes and errors may have disastrous consequences, an environment may result where job strain is high. Medical residency may be a time when it is not feasible to lower work demands, increase job autonomy or decision latitude, and/or increase workplace social support to buffer high strain as suggested by Job Demand-Control models (Karasek, 1979; Karasek & Theorell, 1990).

Sleep

The findings of this study suggest that sleep quality may act as a buffer to the negative impact of stress on critical safety outcomes, driving safety in the current study, when none of the above methods of mitigating job strain are feasible. Given that sleep quality has been suggested to steeply deteriorate upon entrance to medical residency (Zebrowski et al., 2018), obtaining a baseline for sleep quality and highlighting its importance to the entering medical residents is recommended. First year medical residents may also be highly encouraged to take mid-day naps, as research in first year medical residents has indicated improved cognitive functioning following a nap (Amin et al., 2012).

It is alarming that the 2017 ACGME removed recommendations that medical residents take strategic naps when on 24 hour continuous duty (ACGME, 2017). There is evidence that naps improve cognitive functioning, including specifically attention (Amin et al., 2012; Gillberg, Kecklund, Axelsson, & Akerstedt, 1996), working memory (Lau, Wong, Lau, Hui, & Tseng, 2015), and spatial processing (Batejat & Lagarde, 1999). Although fragmented sleep may not be restorative, natural sleep provides more recuperation relative to no sleep, particularly when individuals are sleep deprived (Levine, Roehrs, Stepanski, Zorick, & Roth, 1987).

Findings from this study suggest that emphasis should also be placed on sleep off-duty, both between shifts and on off-days. With the minimal amount of time between duty periods decreased from 10 hours to 8 hours with the recently implemented duty hour restrictions (ACGME, 2017), almost the entire time between duty periods would need to be devoted to sleep to obtain the recommended amount associated with safe driving outcomes (Neri et al., 1997; Tefft, 2016). This work also indicates that even though medical residents obtain significantly more sleep preceding their off-days, there is large variation in sleep, such that many medical residents still are not obtaining adequate sleep quality when given the opportunity.

One of the primary arguments to implementation of duty hour standards is concerns of decreased patient care as a result of increased patient turnover and handoffs resulting from the hour restrictions place on medical residents. However, patient care, particularly in crisis situations, is negatively impacted as a result of sleep deprivation in medical residents (Arzalier-Daret et al., 2017). Regardless of a potential trade-off of decreased patient turnover and handoff in exchange for potentially increased sleep deprivation risk in the medical residents, it is vital to recommend and equally emphasize adequate sleep quality to reduce medical errors risk for patients and medical resident safety, namely driving safety, alike.

Fatigue

Findings from this work suggest medical residents may experience high levels of end-of-shift fatigue, or acute fatigue. Fatigue is often used as an encompassing construct that includes sleepiness, but the findings in the present work measured subjective fatigue in terms of the amount of energy drained as a result of work and the amount of energy remaining for family, friends, or hobbies after work (Winwood et al., 2005). Regardless of perceived sleep propensity post-duty, the medical residents indicated high perceptions of end-of-shift fatigue based on lack of energy. Fatigue experienced post-duty has been strongly associated with inability to recover between shifts in healthcare settings (Fang, Kunaviktikul, Olson, Chontawan, & Kaewthummanukul, 2008). Although the newest duty hour standard state a necessity of both educators and the medical residents to monitor, recognize, and mitigate fatigue (ACGME, 2017), the reduction of minimum time off between shifts from 10 hours down to 8 hours may make the ability to recover between shifts more difficult.

Educators and medical residents should avoid conflating fatigue with sleepiness, and consider utilizing countermeasures beyond obtaining more sleep. The ACGME recommends regular exercise to improve medical resident well-being (ACGME, 2017), but there are specific types of exercise and physical activity that have been associated with improvement in fatigue. Resistance training (Dalgas et al., 2010) and yoga (Boehm, Ostermann, Milazzo, & Bussing, 2012) specifically have shown improvement in fatigue, whereas aerobic training has not (Petajan et al., 1996). Additionally, mindfulness training has been associated with reduction in fatigue (Grossman et al., 2010).

Although the eight hours of minimal time between shifts may necessitate medical residents devote a large portion of that time towards obtaining adequate sleep quality, resistance exercise, yoga, and/or mindfulness training should also be specifically recommended as part of a regular routine between shifts.

Stress

Given the interrelated relationship between sleep quality and stress, stress reduction should be emphasized along with adequate sleep quality in medical residents. Findings of this work suggest an interaction between sleep quality and stress on driving safety. As improvements in sleep quality may provide a buffer to the negative impact of higher stress on poorer driving outcomes, the converse may also be true: lower stress may mitigate the negative effects of poor sleep quality on driving safety. Additionally, as more senior medical residents may have identified methods of mitigating the negative effects of stress, it is recommended that these strategies of stress mitigation be examined and implemented in less senior medical residents.

Driving

The significantly faster driving speeds post-duty may be indicative of a decision making approach that values quicker responses over more accurate responses that is often shown in fatigued and sleep-deprived states (Horowitz et al., 2003; McKenna et al., 2007). The ACGME recommends judicial use of caffeine to mitigate drowsiness (ACGME, 2017), and although caffeine use improves reaction time and has been associated with reduction in poor driving outcomes in populations often affected by poor sleep quality (Heaton & Griffin, 2015), caffeine does not necessarily improve decision-making when fatigued or sleep-deprived (Killgore, Grugle, & Balkin, 2012). In sleep-deprived individuals, caffeine does improve reaction time, but decision-making is sub-optimal compared to well-rested states (Killgore et al., 2012). Educators and medical residents are not recommended to rely on stimulants to combat drowsiness before beginning the post-duty drive home. A nap before the drive may be more optimal to the health and safety of the medical resident than to drive drowsy reliant on caffeine to restore cognitive function.

LIMITATIONS

No study is without weaknesses, and some limitations are noted here. Although drowsy driving was thoroughly discussed, it should be noted that drowsy driving was not directly examined in this work. Sleep, fatigue, and stress were not experimentally manipulated. However, the overarching purpose of this work was to examine naturally varying levels of demands across several days to gain insight into the occupational demands of medical residents, how these demands affect psychophysiological functions that may impact driving safety and drowsy driving risk, and how the occupational demands relate to driving safety at times when drowsy driving risk may be elevated.

The small sample size of 32 medical residents (n = 31 for driving analyses) made it difficult to thoroughly analyze potential interactions among the sleep, fatigue, and stress variables and their association with simulated driving outcomes while preserving adequate statistical power. However, there were several statistically significant findings as well as findings with marginal evidence suggesting significance suggesting there was sufficient power to detect differences in regards to the aims of the study. Because multiple statistical models were run due to power considerations and model parsimony, there is a chance that a Type I error occurred. Corrections for multiple comparisons were applied (i.e., Tukey-Kramer's correction) in analyzing differences in outcomes as a function of duty period time point, and several findings were still noted as statistically significant or provided marginal evidence for significance.

Although statistical significantly differences were indicated with some driving outcomes, the differences may not infer a large practical difference. However, the variability shown in several outcomes related to sleep highlight the need for further research to understand 1) how sleep, fatigue, stress, and driving outcomes are impacted over longer periods of time; and 2) what specific occupational demands contribute to the variability and fluctuation shown in sleep, fatigue, stress, and driving in medical residents. A larger sample size would also enable the expansion into other medical residency programs, potentially from a variety of regions, to understand how the occupational demands may differ between various residency programs (e.g., surgical vs. non-surgical programs) and rotations.

Actigraphy provided estimates of sleep and fatigue as proxies of actual sleep and fatigue. That is, actual sleep and actual fatigue were not measured in the study. Despite this limitation, actigraphy estimates of sleep are strongly associated with actual measures of sleep (polysomnography), despite a tendency to overestimate sleep (Morgenthaler et al., 2007). Although 12% of total nights of estimated sleep were missing in this sample, this was much lower than other studies investigating sleep across several consecutive nights, which have shown as high as 27% of total nights missing (Ustinov & Lichstein, 2013).

Also, actigraphy devices were often not worn where calibrated (e.g., ankle vs. wrist) due to the necessity of the participants to remove the device while performing surgeries or other procedures. Future research should calibrate for a location unaffected by constraints of typical duty requirements in this population, such as the hip, which has shown to potentially be more accurate than when worn on the wrist (Esliger et al., 2011;

Rosenberger et al., 2013), although estimation is still accurate when calibrated for the wrist (Trost, Zheng, & Wong, 2014). Activity was still recorded as the participants noted placing the actigraphy device in a pocket or other location (e.g., ankle). With this considered, on-day and duty period-specific activity estimated by the actigraphy device may have been underestimated. However, sedentary activity may still be indicative of fatigue, as occupational fatigue is not only influenced by high levels of physical activity, but also very low levels of activity (Bogdanis, 2012; Taylor & Dorn, 2006).

The results of the ESS and the OFER should be interpreted with a few considerations. . Both measures were not designed for direct, acute assessments of sleep propensity or occupational fatigue. Despite this, participants were instructed to complete these measures with the consideration of how they felt “right now,” in specific relation to the duty period time point.

The ESS should also not be interpreted as a measure of sleepiness, rather than sleep propensity. Sleepiness can be defined as an inability or a difficulty in maintaining alertness during the day, where unintended lapses into drowsiness or even sleep results (Thorpy, 2012), and here, sleep propensity as measured by ESS is more indicative of likelihood of dozing off and is distinguished from feelings of tiredness (Johns, 1992). To obtain more accurate assessments of sleepiness as opposed to sleep propensity, future research may consider the use of the Karolinska Sleepiness Scale (Akerstedt & Gillberg, 1990), especially in consideration to repeated administration.

There was little agreement between subjective and objective estimates of sleep quality, fatigue, and stress indicated by correlations. Agreement between self-reported instruments on the same construct were also not often in agreement, namely in the assessments of stress. However, the measurements used were purposefully chosen to measure slightly different facets of the same construct. For instance, the WSS measured stress specific to one's occupation (Marlin Company, 2001) and the SRRS assessed life stress based on potentially stressful events that have occurred within the past year (Holmes & Rahe, 1967). However, with self-reported measures, poor estimation or misinterpretation are also possible.

The indication of no significant agreement between PSQI-measured sleep quality and actigraphy-estimated sleep quality measures (Duration, variation, efficiency, WASO, and SFI) may be explained by a few factors. In the current study, medical residents underestimated their average sleep duration by an average of over 1 hour compared to actigraphy estimates of sleep duration, but the specific reason for the discrepancy is unknown. Previous research has shown good agreement between PSQI and actigraphy in healthy adults, but poor agreement in clinical populations where depressive symptoms and altered mood states are associated with discrepancy between self-reported and objectively estimated sleep (Krishnamurthy et al., 2018). Given that burnout and depressive symptoms have been shown to often be elevated in medical residency (Joaquim et al., 2018; Lebares et al., 2018; Thomas, 2004), medical residents may also present similar sleep quality misperception. Considering the potential impact on medical errors and driving safety, misperception in sleep duration and sleep quality may have a substantial impact in medical residents. In the case of over-estimating sleep duration or quality, the medical residents may be at-risk for excessive daytime sleep propensity and drowsy driving, yet perceptually not recognize these risks. Conversely in the case of underestimating sleep duration and sleep quality, although sleep duration or quality may be adequate, an underestimation may be indicative of excessive fatigue perceived by the medical residents. However, the actigraphy measures of sleep duration and quality are estimates themselves, and polysomnography would be required to measure actual sleep and better determine accuracy of subjective sleep quality estimates.

The simulated driving scenario was relatively short (approximately 16 minutes), and longer, more monotonous scenarios may reveal more driving errors or possible incidences of drowsy driving. However, the simulated driving scenario used in the study was among the first to utilize multiple driving environments with realistic roadway types and scenery that resembled the local region as well as include a full-cab driving simulator.

STRENGTHS

The findings of this study significantly contribute to the literature on driving safety in medical residents, as well as psychophysiological factors that may be impacted as a result of occupational demands. Previous research in medical residents and driving safety is limited. Very few studies have utilized driving simulators, and those that did examine simulated driving performance did not feature realistic driving environments and situations. This study featured a state-of-the-art driving simulator and utilized a simulated driving environment made to resemble the local region and multiple environments typically encountered in a commute to or from a hospital in an urban metropolitan area (urban, freeway, and residential).

Additionally, this study is the first to the author's knowledge to include off-duty time period as a referent time period for simulated driving performance. All previous research to-date, whether utilizing simulated or naturalistic driving measures, has utilized pre-duty driving performance as the comparison to post-duty driving performance. The inclusion of off-duty allowed for more experimentally sound analyses of driving performance across duty period time points, and for more in-depth characterization of activity of medical residents across multiple duty periods, including off-days.

This study utilized both subjective and objective estimates of sleep quality, fatigue, and stress. Previous research in medical residents has typically relied on one or the other, but this work is among the first to include both and examine the agreement between the two in medical residents, providing insight into differences between the perception of sleep quality, fatigue, and stress, and objectively measured indices of them in this population. Additionally, the use of actigraphy over several days provided characterization of estimated sleep quality across multiple time periods in relation to duty (off duty, pre-duty, and post-duty) and how it may be associated with safety relevant outcomes.

FUTURE DIRECTIONS

Future research should expand on this work by continuing to utilize both subjective and objective measurements to gain a more comprehensive understanding of medical residents' daily duty requirements and the subsequent impact on psychophysiological factors of sleep, fatigue, and stress. This work utilized a maximum of a 2-week study period, but future research should consider longer-term evaluations to encompass schedule and rotation changes. Future research should also consider strategic use of daily logs over extended periods of time to measure aspects of sleep, fatigue, stress, and driving.

Longitudinal examination of medical residents is also highly warranted to utilize objective estimates of sleep quality, such as actigraphy, in entering first year medical residents and to understand 1) how marked the decrease in sleep quality may be (Zebrowski et al., 2018); and 2) what duty factors and individual differences may influence the trajectory of decreasing sleep quality. Longitudinal examination may also further advance understanding of what stress management or mitigation techniques more senior medical residents develop and through what mechanisms these potential techniques are developed. Understanding the ability to mitigate the stress experienced during medical residency may have several implications in improving other psychophysiological functions impacted in medical residency, namely sleep quality, and subsequently improving driving safety outcomes that may also be negatively affected by the duty demands.

CONCLUSIONS

By investigating the factors that affect driving performance in medical residents, this study focused on the overarching goal of identifying how occupational demands impact the cognitive resources necessary for safe driving. Findings from this work extend and contribute to the relatively small body of research that has identified a potential risk post-duty in medical residents. Medical residents experience the highest stress pre-duty and exhibit riskier driving performance post-duty. However, the impact that stress may have on driving performance may be affected by the averaged sleep quality in medical residents. Medical residents with more experience in residency may also have developed strategies to mitigate effects that stress has on driving performance. This research significantly contributes to this line of research by additionally identifying how sleep and stress may be affected by occupational demands, and how critical safety outcomes are subsequently impacted. Better understanding how occupational demands impact psychophysiological outcomes may aid in developing policies and strategies aimed at mitigating the negative effects of high strain work environments.

Results of this work may help identify how to buffer high strain when it is not feasible to 1) lower work demands, 2) increase job autonomy or decision latitude, and 3) increase workplace social support. The ability to mitigate negative impacts of high strain work environments has implications beyond medical residents, and includes other professions where the negative impact of high strain may have potentially catastrophic results (e.g., commercial truck driving, other healthcare professions, military, etc.). These findings may further develop work models and identify temporary situations as well as long term occupational contexts where critical safety outcomes are impacted as a result of occupational demands, especially in the context of driving safety.

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APPENDIX A

SLEEP, EXERCISE, ACTIGRAPH WEAR, AND CAFFEINE DAILY LOG

Complete in Morning							
Start date: ___/___/___ Day of week:	Day 1 ______	Day 2 ______	Day 3 ______	Day 4 ______	Day 5 ______	Day 6 ______	Day 7 ______
I went to bed last night at :	PM / AM	PM / AM	PM / AM	PM / AM	PM / AM	PM / AM	PM / AM
I got out of bed this morning at:	AM / PM	AM / PM	AM / PM	AM / PM	AM / PM	AM / PM	AM / PM

Complete at the End of Day							
Day of week:	Day 1 ______	Day 2 ______	Day 3 ______	Day 4 ______	Day 5 ______	Day 6 ______	Day 7 ______
I exercised from… _ _:_ _ to _ _:_ _							
	AM / PM	AM / PM	AM / PM	AM / PM	AM / PM	AM / PM	AM / PM
Throughout the day my mood was… Very pleasant, Pleasant, Unpleasant, or Very unpleasant							

Complete in Morning							
Start date: ___/___/___ **Day of week:**	**Day 8** ______	**Day 9** _______	**Day 10** _______	**Day 11** _______	**Day 12** ______	**Day 13** _______	**Day 14** ______
I went to bed last night at :	PM / AM	PM / AM	PM / AM	PM / AM	PM / AM	PM / AM	PM / AM
I got out of bed this morning at:	AM / PM	AM / PM	AM / PM	AM / PM	AM / PM	AM / PM	AM / PM

Complete at the End of Day							
Day of week:	**Day 8** ______	**Day 9** ______	**Day 10** ______	**Day 11** ______	**Day 12** ______	**Day 13** ________	**Day 14** ______
I exercised from… _ _:_ _ to _ _:_ _							
	AM / PM	AM / PM	AM / PM	AM / PM	AM / PM	AM / PM	AM / PM
Throughout the day my mood was… Very pleasant, Pleasant, Unpleasant, or Very unpleasant							

ActiGraph Diary

Please Complete at the End of the Day

Please Note Times When You Were Not Wearing the ActiGraph							
Start date: ___/___/___ **Day of week:**	**Day 1** ______	**Day 2** _______	**Day 3** _______	**Day 4** _______	**Day 5** ______	**Day 6** _______	**Day 7** ______
Not-Wearing Time 1	From: To:	From: To:	From: To:	From: To:	From: To:	From: To:	From: To:
Reason (e.g., swimming, surgery, showering, etc.)							
Not-Wearing Time 2	From: To:	From: To:	From: To:	From: To:	From: To:	From: To:	From: To:
Reason (e.g., swimming, surgery, showering, etc.)							
Not-Wearing Time 3	From: To:	From: To:	From: To:	From: To:	From: To:	From: To:	From: To:
Reason (e.g., swimming, surgery, showering, etc.)							

Please Note Times When You Were Not Wearing the ActiGraph							
Start date: ___/___/___ **Day of week:**	**Day 8** ______	**Day 9** _______	**Day 10** _______	**Day 11** _______	**Day 12** ______	**Day 13** _______	**Day 14** ______
Not-Wearing Time 1	From: To:	From: To:	From: To:	From: To:	From: To:	From: To:	From: To:
Reason (e.g., swimming, surgery, showering, etc.)							
Not-Wearing Time 2	From: To:	From: To:	From: To:	From: To:	From: To:	From: To:	From: To:
Reason (e.g., swimming, surgery, showering, etc.)							
Not-Wearing Time 3	From: To:	From: To:	From: To:	From: To:	From: To:	From: To:	From: To:
Reason (e.g., swimming, surgery, showering, etc.)							

Please Note Your Caffeine Consumption							
Start date: ___/___/___ **Day of week:**	**Day 1** ______	**Day 2** _______	**Day 3** _______	**Day 4** _______	**Day 5** ______	**Day 6** _______	**Day 7** ______
Number of Caffeine Products							
Approximate Time Each Item Consumed (please place a time for each item)							

Please Note Your Caffeine Consumption							
Start date: ___/___/___ **Day of week:**	**Day 8** ______	**Day 9** _______	**Day 10** _______	**Day 11** _______	**Day 12** ______	**Day 13** _______	**Day 14** ______
Number of Caffeine Products							
Approximate Time Each Item Consumed (please place a time for each item)							

APPENDIX B

IRB APPROVAL

THE UNIVERSITY OF ALABAMA AT BIRMINGHAM
Office of the Institutional Review Board for Human Use

470 Administration Building
701 20th Street South
Birmingham, AL 35294-0104
205.934.3789 | Fax 205.934.1301 | irb@uab.edu

APPROVAL LETTER

TO: McManus, Benjamin J.

FROM: University of Alabama at Birmingham Institutional Review Board
Federalwide Assurance # FWA00005960
IORG Registration # IRB00000196 (IRB 01)
IORG Registration # IRB00000726 (IRB 02)

DATE: 06-Sep-2017

RE: IRB-160831002
Effect of Occupational Demands on Driving Safety in Surgical Residents

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The IRB reviewed and approved the Continuing Review submitted on 05-Sep-2017 for the above referenced project. The review was conducted in accordance with UAB's Assurance of Compliance approved by the Department of Health and Human Services.

Type of Review: Expedited (Category)
Determination: Approved
Approval Date: 06-Sep-2017
Approval Period: One Year
Expiration Date: 05-Sep-2018