The American Journal of Surgery 220 (2020) 83–89

Contents lists available at ScienceDirect

The American Journal of Surgery

journal homepage: www.americanjournalofsurgery.com

Sleep and stress before and after duty across residency years under 2017 ACGME hours

Benjamin McManus [a], James W. Galbraith [b], Karen Heaton [c], Sylvie Mrug [a], Brent A. Ponce [d], John R. Porterfield Jr. [e], Mark C. Schall Jr. [f], Despina Stavrinos [a, *]

[a] University of Alabama at Birmingham, Department of Psychology, United States
[b] University of Mississippi Medical Center, Department of Emergency Medicine, United States
[c] University of Alabama at Birmingham, School of Nursing, United States
[d] University of Alabama at Birmingham, Department of Orthopaedic Surgery, United States
[e] University of Alabama at Birmingham, Department of Surgery, United States
[f] Auburn University, Industrial and Systems Engineering, United States

ARTICLE INFO

Article history:
Received 6 September 2019
Received in revised form
15 October 2019
Accepted 31 October 2019

Keywords:
Sleep
Stress
Burnout risk
Occupational
Safety
Health
Residency
ACGME

ABSTRACT

Introduction: Residents may differentially experience high stress and poor sleep across multiple post-graduate years (PGYs), negatively affecting safety. This study characterized sleep and stress among medical and surgical residents across multiple PGYs and at specific times surrounding duty.
Method: Thirty-two medical and surgical residents ($M_{age} = 28.6$ years; 56% male) across PGYs 1–5 participated in 3 appointments (immediately before duty, after duty, and on an off day) providing 96 data points. Sleep, stress, and occupational fatigue were measured by both self-report and objectively (actigraphy, salivary coritsol).
Results: Residents averaged 7 h of actigraphy-estimated sleep per night but varied ±3 h day-to-day. Residents reported clinically poor sleep quality. Life stress decreased by PGY-2. All residents averaged elevated life stress values. Poor sleep quality did not differ among PGY cohorts.
Discussion: Poor sleep quality is similar between early residency cohorts (PGY-1) and later residency cohorts (PGY-3+). Persistent fatigue is highest in later residency cohorts. Even the most experienced residents may struggle with persisting fatigue. Current hour policies may have shortcomings in addressing this risk.

Introduction

Residents, fatigue, and stress

The Accreditation Council for Graduate Medical Education's (ACGME) most recent revisions notably increased maximum duty hours for first year residents and reduced minimal time off between duty periods for all residents.[1] Objective measurements of health and safety of residents directly impacted by 2017 ACGME policies have largely yet to be examined. This lapse is noteworthy given that the demands and hours required in residency may affect psychophysiological functions impacting patient care and resident safety (i.e., drowsy driving).[2,3] Burnout risk is high in residents and negatively impacts error risk and patient safety.[4–7] Occupationally-induced stress is associated with poor sleep,[8] which contributes to greater stress reactivity, cyclically aggravating sleep problems.[9,10] The effects of poor sleep or stress may be temporally influenced and experienced differentially around duty time points (i.e., pre-duty vs. post-duty, vs. off-duty).

Current study

Research on residents' well-being has largely focused on self-reported sleep and stress assessments, resiliency factors (i.e., mindfulness, emotional intelligence), or has been conducted within a single post-graduate year (PGY) cohort.[11–15] The few comparisons across residency have been limited to comparing interns (PGY 1) to

* Corresponding author. University of Alabama at Birmingham, Department of Psychology, 916 19th Street South, Birmingham, AL, 35294, United States
E-mail addresses: bmcmanus@uab.edu (B. McManus), jgalbraith@umc.edu (J.W. Galbraith), kharnp@uab.edu (K. Heaton), smrug@uab.edu (S. Mrug), bponce@uabmc.edu (B.A. Ponce), jporterfield@uabmc.edu (J.R. Porterfield), mcs0084@auburn.edu (M.C. Schall), dstavrin@uab.edu (D. Stavrinos).

https://doi.org/10.1016/j.amjsurg.2019.10.049
0002-9610/

another cohort of residents not beyond PGY 3.[16] The current study examined sleep and stress for residents as well as how sleep and stress may be experienced at different points around duty. This study included residents from various specialties within non-surgical and surgical fields. It is among the first to 1) consider self-reported and objective measures of sleep and stress; 2) include several PGY cohorts, up to PGY 5, examining sleep and stress adaptations during residency; and 3) assess sleep and stress at three time points relative to duty, including an off-duty reference. This is among the first study to-date to examine sleep and stress in residents under 2017 ACGME standards.

Method

Participants

Thirty-two residents participated in three appointments over a maximum of two weeks resulting in 96 data points: (1) immediately before a duty period, (2) immediately after a duty period, and (3) an off-day. Residents were asked to schedule their on-day appointments representative of a "typical day." The order of the off-day and on-day appointments was randomized. Participants were recruited from residency programs in the Southeast United States. The study protocol was approved by the University of Alabama at Birmingham Institutional Review Board for Human Use.

Measures and procedure

Sleep

Self-report. The Pittsburgh Sleep Quality Index (PSQI)[17] was completed once as part of a take-home packet of questionnaires. The PSQI measures self-reported sleep quality over the preceding month through a global score calculated from 7 subscales (subjective sleep quality, sleep onset, number of hours of sleep, sleep efficiency, frequency of sleep aid medication, daytime functioning difficulties). PSQI global scores range from 0 to 21, where scores greater than 5 indicate clinical levels of poor sleep quality.[17] PSQI subscales and global score indicated good internal consistency in the current study (Cronbach's $\alpha = 0.67$). The 8-item Epworth Sleepiness Scale (ESS)[18] provided 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., in a car while stopped for a few minutes in traffic) by indicating 0 = "no chance of dozing," to 3 = "high chance …" Participants rated each situation based on the time of completion (i.e., pre-, post-, off duty). The ESS has shown good reliability for measuring sleep propensity as a proxy for instantaneous sleepiness.[18] The ESS indicated high internal consistency at each administration (Cronbach's $\alpha = 0.84–0.87$).

Objective. Residents were provided an ActiGraph wGT3X-BT model[19] activity tracking watch to wear continuously during study enrollment. Actigraphy has been used in residents[3] and has shown a strong agreement with objective standards of sleep measurement (polysomnography).[20]

Stress

Self-report. The 8-item Workplace Stress Scale (WSS)[21] provided a subjective measurement of workplace-related stress (e.g., job pressure, interference with personal life). The WSS had high internal consistency in this study (Cronbach's $\alpha = 0.88$). Participants reported whether certain life events (e.g., "Taking on a mortgage, "Changes in residence") occurred in the previous year on the Social Readjustment Rating Scale (SRRS).[22] Scoring of the 43-item SRRS involves assigning weight values to events and summing those weights to produce a total life stress score. Scores of 150–300 (maximum 1466) are associated with a 50% chance of a major health breakdown in the next two years.[22]

Objective. Participants provided a saliva sample via passive drool[23] at each appointment. Samples were immediately stored at −20° Celsius (253.15 K) until assay. Salivary cortisol levels, an objective biomarker of stress,[24] were measured in micrograms per deciliter (μg/dL). Because the aim was to measure cortisol levels in reference to stress experienced during duty, participants provided the saliva sample immediately upon arriving to the laboratory, approximately 10–20 min after completing a shift or approximately 30 min before a shift. Psychosocial stress activates the salivary cortisol stress response, particularly anticipation of stressful situations or within 20–40 min following a stressful event.[25,26]

Occupational Fatigue. Burnout is highly associated with fatigue.[12] The Occupational Fatigue Exhaustion Recovery (OFER) Scale[27] supplied a subjective assessment of work-related fatigue. The 15-item OFER assesses chronic, acute (end-of-shift states), and persistent (effective inter-shift fatigue recovery) work-related fatigue on a scale of 0–100, where higher scores indicate greater endorsement of that scale. Participants responded to items on a 7-point scale indicating the degree of agreement with the item (e.g., "I rarely recover my strength between work shifts"). All OFER scales displayed Cronbach's $\alpha \geq 0.84$ across the 3 administrations (pre-duty, post-duty, and off-duty). Residents reported acute fatigue in reference to the end of a typical duty period, although the OFER was completed at all 3 time points.

Analyses

Descriptive statistics

A 3-category variable for PGY was created: PGY 1 residents ($n = 10$), PGY 2 residents ($n = 11$), and PGY = 3+, which included PGY 3–5 residents ($n = 11$). All statistical analyses were conducted using SAS 9.4,[28] with p values $< .05$ considered statistically significant. A logistic regression estimated odds ratios (OR) and 95% Confidence Intervals (CI) for obtaining the recommended 7 h of sleep[29,30] based on whether the subsequent day was off-duty or a work day. Actigraphy-estimated sleep from the night preceding the off-duty and work day (pre-and post-duty appointments) was dichotomized into obtaining under 7 vs. 7 or more hours of sleep. This sleep outcome was regressed on a dichotomized variable indicating whether the 24-h period following the recorded actigraphy sleep period was the off-duty or work day.

Sleep, stress, and fatigue differences among PGY

Differences among time invariant variables and variables averaged across study participation for sleep (PSQI global score, averaged actigraphy-estimated sleep duration, variation, efficiency, wake after sleep onset [WASO], sleep fragmentation index [SFI]) and stress (SRRS, WSS) based on PGY were assessed with one-way ANOVAs with Tukey corrections to control for familywise error rate in multiple comparisons.

For continuously collected actigraphy-estimated sleep variables (nightly sleep duration, efficiency, WASO, SFI), intercept and time (24-h periods) were included as random effects with unstructured covariance structures in a mixed effects model with the 3-level PGY variable included as a fixed effect. All continuous variables were standardized to produce standardized coefficients in mixed effects regressions.

Sleep, stress, and fatigue differences pre-duty, post-duty, and off-duty and across PGY

Main effects (ME) of residency program type (surgical, non-surgical), time point (pre-, post-, and off-duty) and PGY on time-

varying sleep, stress, and fatigue outcomes (measured at each time point via ESS, cortisol, OFER) were analyzed using mixed effects regressions to account for repeated assessments allowing for specification of covariance structures not assuming compound symmetry among repeated assessments.[31] The intercept was a random effect with an unstructured covariance structure. Duty time point (pre-, post-, off-duty) and PGY (1, 2, and 3+) were included as 3-level fixed effects, and residency program type (surgical, non-surgical) was included as a 2-level fixed effect. Tukey corrections were used for pairwise comparisons among time points. Where cortisol was the outcome, time of collection was included as covariate to the 3-level PGY and duty time point explanatory variables.

Factors related to sleep, stress, and fatigue

An interaction of duty period by PGY was included in the ME mixed effects regression models for time varying outcomes described above to determine if sleep, stress, and fatigue surrounding duty was experienced differentially by PGYs. To examine interrelating contributing factors toward burnout risk, a linear multiple regression model with pre-duty OFER persistent fatigue (PF) subscale as the outcome was regressed on the PGY, PSQI global score, actigraphy-estimated sleep duration for the sleep period preceding the pre-duty appointment, WSS, SRRS, and pre-duty cortisol. The PF subscale was examined due to fatigue's association with burnout risk[12] and the inter-shift recovery measured by that subscale.[27] The explanatory variables were selected to examine individual contributions of PGY status and both subjective and objective measurement of sleep and stress.

Results

Descriptive statistics

Demographics

Participants were aged 28.6 years ($SD = 2.18$), male (56%), Caucasian (94%). The majority were PGY 1 or 2 (66%) and in a surgical program (78%: 25% orthopedics, 22% general surgery, 13% otolaryngology, 13% emergency surgery, and 6% anesthesiology). Participants were enrolled in the study an average of 8.47 days ($SD = 3.04$ days). See Table 1 for participant demographics and residency descriptive statistics. All residents ($n = 32$) completed each pre-, post-, and off-duty appointment providing complete data for ESS, salivary cortisol, and OFER. One resident did not complete the take-home questionnaires, therefore analyses of PSQI, WSS, SRRS represent $n = 31$.

Sleep

Residents reported poor sleep quality as measured by PSQI global score ($M = 5.87$, $SD = 2.78$),[17] but with no difference among PGYs. An average of nearly six actigraphy-estimated sleep periods (major sleep period within 24-h period) were recorded for residents over study participation. Out of 213 possible nights, 25 were missing (12%) due to failure to wear the device resulting in 188 nights of actigraphy-estimated sleep among all 32 participants for analyses. There was no statistical difference in actigraphy-estimated sleep metrics between participants with and without missing nights. The actigraphy data indicated residents averaged over 7 h of sleep per 24-h period, but averages ranged from under 4.5 h to approximately 14 h. The average lowest amount of sleep was 4.88 h ($SD = 1.80$). The average variation in sleep duration between 24-h periods was nearly 3 h ($M = 2.92$ h, $SD = 1.42$) (See Fig. 1). There were no differences among PGYs in actigraphy-estimated sleep metrics.

Stress

Residents averaged an SRRS score of 222.77, considered an elevated value, where elevated values on this measure have been associated with significant health risks.[22] SRRS-measured life stress differed among PGYs (F (2,28) = 17.75, $p < .001$, $R2 = 0.56$). Compared to PGY 3+ (MSRRS = 128.60), life stress was higher in PGY 2 (MSRRS = 190.64; $t = 5.76$, Tukey-corrected $p < .001$) and PGY 1 (MSRRS = 352.30; $t = 4.26$, Tukey-corrected $p = .001$). There was no difference between PGY 1 and 2 SRRS scores (See Table 2). There were no differences among PGYs on work-specific stress (measured by WSS).

Sleep, stress, and fatigue differences pre-duty, post-duty, and off-duty and across PGY

Sleep

The average time between the conclusion of the pre-duty assessments (immediately before beginning duty) and the beginning of the post-duty assessments (immediately upon completing duty) was 11.47 h ($SD = 2.31$) with no difference in this time between surgical and non-surgical residents. As residents There was a ME of residency program type (F (1,62) = 4.35, $p = .04$), and duty time-point on ESS (F (2, 62) = 16.04, $p < .001$). Residents reported a similar ESS-measured sleep propensity pre- and post-duty with both being higher than off-duty sleep propensity (See Table 2). There was marginal evidence for a duty time-point by PGY interaction (F (4, 58) = 2.30, $p = .07$). See Table 3. Logistic regression indicated the odds of obtaining at least 7 h of actigraphy-estimated sleep was 343% higher for the major sleep period preceding the off-duty compared to the pre-duty assessment ($\chi 2$ (1) = 4.73, $p = .03$, OR = 4.43, 95% CI: 1.16–16.92) (See Table 2).

Stress

There was a ME of duty time-point on salivary cortisol (F (2, 61) = 6.20, $p = .004$). Cortisol was higher pre-duty compared to off-duty ($t = 3.28$, Tukey-corrected $p = .005$, $\beta = 0.71$) and post-duty ($t = 3.48$, Tukey-corrected $p = .003$, $\beta = 0.98$). There was a PGY by duty time point interaction on salivary cortisol levels ($F = 2.66$, $p = .04$) indicating PGY 3 + and PGY 2 experienced higher cortisol levels pre-duty compared to post-duty (PGY 3+: $t = 3.76$, Tukey-corrected $p = .001$, $\beta = 1.23$; PGY 2: $t = 3.18$, Tukey-corrected $p = .001$, $\beta = 1.59$). PGY 3 + displayed higher cortisol level pre-duty compared to off-duty (PYG 3+: $t = 3.65$, Tukey-corrected $p = .002$, $\beta = 1.05$) and PGY 2 displayed higher cortisol off-duty compared to post-duty ($t = 2.56$, Tukey-corrected $p = .03$, $\beta = 0.52$). PGY 1 displayed no salivary cortisol level differences among duty times (See Fig. 2).

Fatigue

There was a ME of duty time point on perceptions of acute end-of-shift fatigue (F (2, 62) = 3.33, $p = .04$). Residents reported higher perceptions of acute fatigue following a typical shift at the off-duty assessment compared to the pre-duty assessment ($t = 2.56$, Tukey-corrected $p = .03$, $\beta = 0.18$). Perceptions of OFER-measured chronic or persistent fatigue did not differ across the three time points (See Table 2) or PGY, and there were no interactions between time point and PGY on any OFER-measured fatigue perceptions.

Sleep and stress factors contributing to fatigue

Linear regression provided a model explaining over 75% of the unexplained variance in the OFER PF score from the pre-duty appointment (F (9,19) = 7.03, $p < .001$, R2 = 0.77). PGY was associated with PF scores ($F = 6.73$, $p = .01$, partial $\eta 2 = 0.41$). When compared to PGY 1, PGY 2 was associated with an estimated 25.79

Table 1
Demographics, residency characteristics, and sleep and stress variables averaged across participation by PGY.

Variable	PGY 1 ($n = 10$)			PGY 2 ($n = 11$)			PGY 3 ($n = 11$)				
	Mean (*SD*)	*n* (%)	Range	Mean (SD)	*n* (%)	Range	Mean (SD)	*n* (%)	Range	*F* or χ^2	*p*
Age	28.3 (2.8)		26.0–34.0	27.6[a] (0.5)		27.0–28.0	29.8[b] (2.1)		27.0–34.0	3.6	**0.04**
Gender (male)		6 (60)			7 (64)			5 (45)		0.8	0.66
Race										4.2	0.38
Caucasian		9 (90)			10 (90)			11 (100)			
Asian		0 (0)			1 (10)			0 (0)			
Other		1 (10)			0			0 (0)			
Participation (days)	8.0 (3.3)		4.0–14.0	9.0 (3.1)		5.0–14.0	8.4 (2.9)		4.0–13.0	0.3	0.76
Residency Program										19.4	0.08
General Surgery		3 (30)			2 (18)			2 (18)			
Orthopedics					3 (27)			5 (45)			
Otolaryngology					2 (18)			2 (18)			
Emergency Med.		4 (40)									
Anesthesiology		1 (10)			1 (9)						
Pediatrics		2 (20)			3 (27)			1 (9)			
Internal Med.								1 (9)			
Self-reported											
PSQI global score	6.7 (3.3)		3.0–12.0	6.5 (2.5)		3.0–11.0	4.4 (2.1)		1.0–8.0	2.3	0.12
WSS total score	19.1 (5.7)		10.0–29.0	21.4 (3.7)		16.0–29.0	19.3 (7.9)		10.0–33.0	0.5	0.63
SRRS total score	352.3[a] (88.8)		174.0–475.0	190.6[b] (84.9)		90.0–322.0	128.6[b] (87.0)		13.0–307.0	17.8	< **0.01**
Actigraphy estimated											
Sleep periods recorded	5.1 (1.5)		3.0–7.0	6.4 (3.9)		2.0–13.0	6.1 (2.8)		3.0–11.0	0.5	0.59
Duration (hours)	7.6 (1.6)		5.0–10.4	7.4 (1.7)		4.4–9.9	8.4 (2.0)		6.0–13.8	1.0	0.39
Lowest in study	5.0 (1.6)		2.7–6.9	4.4 (1.61)		2.2–7.1	5.2 (2.2)		2.5–9.7	0.6	0.58
Sleep variation (hours)	2.9 (1.5)		1.0–5.4	2.9 (1.6)		0.5–5.6	3.1 (1.3)		0.6–5.6	0.1	0.94
Efficiency (%)	92.8 (2.4)		89.0–96.5	90.8 (5.4)		77.9–95.8	92.7 (2.5)		89.3–96.6	1.0	0.39
WASO (minutes)	35.9 (12.1)		16.4–54.2	39.7 (18.1)		16.7–75.1	38.1 (13.8)		20.8–58.1	0.2	0.85
SFI (%)	33.2 (7.4)		22.6–46.1	31.9 (16.8)		13.8–64.0	30.7 (8.9)		11.8–43.1	0.1	0.89

Note. PSQI = Pittsburgh Sleep Quality Index, WSS = Workplace Stress Scale, SRRS = Social Readjustment Rating Scale, WASO = Wake After Sleep Onset, and SFI = Sleep Fragmentation Index, Means within a row with different letter superscripts indicate significant Tukey-adjusted differences.

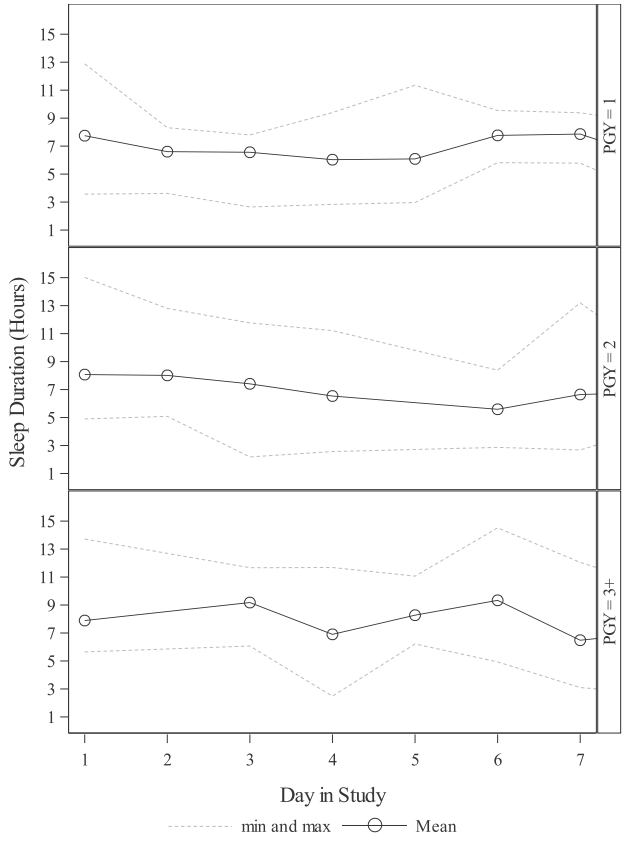

Fig. 1. Actigraphy measured sleep duration over study participation by post-graduate year.

points greater PF scores ($t = 3.55$, Tukey-corrected $p = .01$), and PGY 3 was associated with an estimated 26.71 greater PF scores ($t = 3.29$, Tukey-corrected $p = .01$). Poorer PSQI-rated sleep quality was associated with increased PF scores ($t = 3.04$, $p = .01$, partial $\eta 2 = 0.33$). Greater SRRS life stress scores and increased cortisol were associated with increased PF scores (SRRS: $t = 5.09$, $p < .001$, partial $\eta 2 = 0.58$; cortisol: $t = 2.42$, $p = .03$, partial $\eta 2 = 0.24$).

Discussion

Findings from this comparison of sleep and stress across multiple resident cohorts of non-surgical and surgical residents indicate persistent poor sleep quality and fatigue across PGY cohorts and specialties. This study was among the first to measure Actigraphy-estimated sleep over several days under 2017 ACGME standards. Although residents averaged 7 + hours of sleep, night-to-night sleep varied by nearly 3 h and appeared to persist across residency. Residents averaged a low-point sleep period under 5 h, an amount recently associated with a 325% crash risk increase in the 24 h following such a sleep period,[32] suggesting residents are driving with a substantially elevated crash risk at least weekly. Previous research indicated a steep decline in sleep quality within the first several months of residency.[11] The current study suggests sleep quality does not rebound to clinically acceptable levels as residency progresses. That is, later cohorts did not show better sleep quality compared to cohorts earlier in their residency. Self-reported sleep quality data were collected cross-sectionally and future longitudinal studies are needed to make inferences on the trajectory of sleep quality across residency years. Estimated sleep duration was longer surrounding off days; however, sleep quantity should not be equated with sleep quality.[17,33],

Life event-related stress was high but improved during residency. As there was no effect of PGY on cortisol levels, more senior residents do not appear to experience less overall stress than their

Table 2
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*	*p*
Time (24 h)	**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	**148.55**	< **0.01**
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	**16.50**	< **0.01**
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	0.44	0.65
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	**3.35**	**0.04**
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	0.37	0.70
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	**7.13**	< **0.01**

Note. Bold indicates significant difference among the time points ($p < .05$). Means within a row with different letter superscripts indicate significant Tukey-adjusted differences. Time of collection included as covariate in analyses of salivary cortisol.

more junior colleagues. Objectively measured stress was dependent upon duty period but moderated by PGY. Stress levels remained the same across duty period in PGY 1, but more experienced residents showed higher levels of cortisol pre-duty compared to post-duty and off-duty. This pre-duty cortisol elevation is likely due to anticipation of a stressful situation.25 More

Table 3
Significant regression models with standardized coefficients.

Explanatory Variable	β (SE)	*t*	*F*	*p*
ESS				
Main Effects				
Residency program type (non-surgical = referent)				
Surgical	**−0.57 (0.27)**	**−2.90**		**0.04**
Duty Time-point (off = referent)			**16.90**	< **0.01**
Post	**0.64 (0.14)**	**4.45**		< **0.01**
Pre	**0.77 (0.15)**	**5.21**		< **0.01**
PGY (1 = referent)			0.38	0.68
3+	0.30 (0.38)	0.79		0.43
2	0.12 (0.26)	0.45		0.66
PGY × Shift interaction			2.30	0.07
Salivary Cortisol				
Main Effects				
Duty Time-point (off = referent)			**6.21**	< **0.01**
Post	−0.26 (0.14)	−1.84		0.17
Pre	**0.71 (0.22)**	**3.28**		< **0.01**
PGY (1 = referent)			1.89	0.17
3+	0.23 (0.22)	1.08		0.53
2	0.48 (0.25)	1.90		0.16
Time of Collection	**−0.24 (0.10)**		**5.11**	**0.03**
PGY × Shift interaction			**2.66**	**0.04**
OFER-AF				
Main Effects				
Duty Time-point (off = referent)				**0.04**
Post	−0.09 (0.06)	−1.41		0.34
Pre	**−0.18 (0.07)**	**−2.56**		**0.03**
PGY (1 = referent)				0.15
3+	−0.03 (0.44)	−0.06		0.99
2	0.64 (0.36)	1.75		0.20
PGY × Shift interaction			0.75	0.56
Pre-Duty OFER-PF				
Model			**7.91**	< **0.01**
PGY (1 = referent)			**6.45**	**0.01**
3+	**1.47 (0.39)**	**3.29**		**0.01**
2	**1.40 (0.39)**	**3.55**		**0.01**
PSQI global score	**0.43 (0.13)**	**3.04**		**0.01**
Sleep Duration Preceding Night	0.01 (0.14)	−0.09		0.93
WSS total score	−0.10 (0.18)	−0.56		0.58
SRRS total score	**0.97 (0.19)**	**5.09**		< **0.01**
Cortisol	**0.26 (0.11)**	**2.42**		**0.03**
Time of Collection	−0.02 (0.24)	−0.07		0.94
Residency Program type (non-surgical = referent)	−0.29 (0.33)	−0.87		0.40

Note. *p* values for 3-level post graduate year (PGY) and duty time point variables reflect Tukey correction for multiple comparisons. Residency program type was included as a ME in models of Salivary Cortisol, and OFER-AF, but was not significantly associated and is omitted for space. ESS = Epworth Sleepiness Scale, OFER = Occupational Fatigue Exhaustion Recovery, AF = Acute Fatigue, PF = Persistent Fatigue, PSQI = Pittsburgh Sleep Quality Index, WSS = Workplace Stress Scale, SRRS = Social Readjustment Rating Scale.

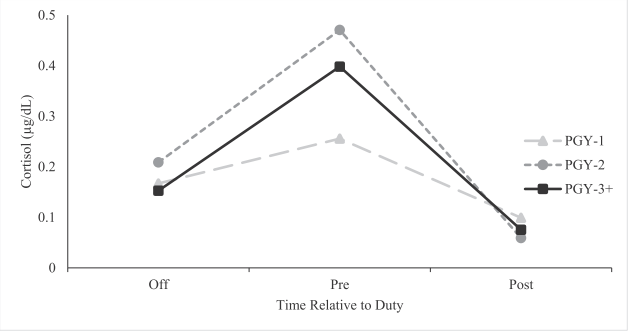

Fig. 2. Interaction of PGY by duty time point on salivary cortisol.

senior residents may have developed methods to modulate stress and avoid subsequent effects on safety-relevant outcomes. This finding is supported by previous research investigating cortisol in residents across a single duty period.[34]

Although poor subjective sleep quality has been associated with increased cortisol responses to stress [35] and poor sleep is related to increased stress[9,10,36] it remains unknown how sleep quality and stress interact to affect safety outcomes. Previous research has linked occupational stress with poorer sleep outcomes,8 and safety outcomes may subsequently be affected. Strategies to lower work-related stress may indirectly improve sleep and associated safety outcomes.

It is important to note self-reported persistent fatigue measured as the inability to recover between shifts was highest among more senior residents, those experiencing higher life stress, and those with poorer sleep. Despite lower reported life stress, more senior residents appear to perceive a reduced ability to recover between shifts. More senior residents should not be assumed to have acclimated to the demands of residency and should be monitored for persistent fatigue.

Limitations and future directions

The study sample was small with an uneven distribution of residents across PGYs. Only two PGY 5 residents participated in the study. Multi-year longitudinal data collection with larger samples is needed to better characterize how stress and sleep change over time, and how these changes affect health and functioning in residents. Most PGY 5s indicated inadequate time to take part in research, highlighting possible persisting fatigue. Similarly due to limited and changing schedules, the range of participation days is fairly wide (4–14 days), and future research may attempt to standardize the number of days of data collection among residents. Findings comparing surgical vs. non-surgical residents should be interpreted with caution as only 22% of the sample was in a non-surgical residency program in this sample. Future studies may aim for more equal representation among programs for improved ability to make important references, especially considering differences in duties and length of residency.[37] Self-report measures may introduce bias and inaccuracy, however, those used herein are well validated and often used for similar purposes. Sleep was measured by proxy via actigraphy estimation which may overestimate sleep quantity.[38] The pre- and post-duty assessments are representative of a single "typical" day, but future work should include multiple in-person work day assessments to better measure potential cumulative effects of sleep and stress. Burnout and burnout risk were not explicitly assessed, but rather persisting occupational-related fatigue which is strongly associated with burnout.[12] Future work should include direct measures of burnout risk in residents.

Conclusions

Poor sleep quality and persistent fatigue do not improve during residency, suggesting even the most experienced residents may struggle with persistent fatigue. Despite the attempts of the ACGME duty hour standards to balance resident health and well-being with patient care and resident education,[1] the newest standards may not to address the ineffective recovery between duty periods persisting through residency that is associated with burnout risk. The new standards may potentially exacerbate this persistent fatigue with the reduction of the minimum time off between shifts.

Declaration of competing interest

There are no conflicts of interest for any of the authors. The University's Institutional Review Board for Human Research approved this work. All authors have seen and approved the manuscript.

Acknowledgments

This work was supported by Grant# 2T420H008436 from National Institute for Occupational Safety and Health (NIOSH). Its contents are solely the responsibility of the authors and do not necessarily represent the official views of NIOSH. Special thanks to the UAB Translational Research for Injury Prevention Laboratory for data collection and entry, and support from the NIOSH Deep South Educational Research Center, the UAB Edward R. Roybal Center for Translational Research in Aging and Mobility (NIH/NIAgrant no. 5 P30 AG022838-09), and a grant from the National Institute on Aging (NIH/NIA grant no. 5 R01 AG005739-24).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.amjsurg.2019.10.049.

References

1. ACGME. Common program requirements Section VI with background and intent. https://www.acgme.org/Portals/0/PFAssets/ProgramRequirements/CPRs_Section%20VI_with-Background-and-Intent_2017-01.pdf2017.
2. Lockley SW, Barger LK, Ayas NT, Rothschild JM, Czeisler CA, Landrigan CP. Effects of health care provider work hours and sleep deprivation on safety and performance. *Jt Comm J Qual Patient Saf*. 2007;33(11 Suppl):7–18.
3. McCormick F, Kadzielski J, Landrigan CP, Evans B, Herndon JH, Rubash HE. Surgeon fatigue: a prospective analysis of the incidence, risk, and intervals of predicted fatigue-related impairment in residents. *Arch Surg*. 2012;147(5):430–435.
4. de Oliveira Jr GS, Chang R, Fitzgerald PC, et al. The prevalence of burnout and depression and their association with adherence to safety and practice standards: a survey of United States anesthesiology trainees. *Anesth Analg*. 2013;117(1):182–193.
5. West CP, Tan AD, Habermann TM, Sloan JA, Shanafelt TD. Association of resident fatigue and distress with perceived medical errors. *J Am Med Assoc*. 2009;302(12):1294–1300.
6. Shanafelt TD, Hasan O, Dyrbye LN, et al. Changes in burnout and satisfaction with work-life balance in physicians and the general US working population between 2011 and 2014. *Mayo Clin Proc*. 2015;90(12):1600–1613.
7. Dyrbye L, Shanafelt T. A narrative review on burnout experienced by medical students and residents. *Med Educ*. 2016;50(1):132–149.
8. Akerstedt T. *Psychosocial stress and impaired sleep*. 2006;32(6):493–501.
9. Minkel J, Moreta M, Muto J, et al. Sleep deprivation potentiates HPA axis stress reactivity in healthy adults. *Health Psychol*. 2014;33(11):1430–1434.
10. Steiger A. Sleep and the hypothalamo-pituitary-adrenocortical system. *Sleep Med Rev*. 2002;6(2):125–138.
11. Zebrowski JP, Pulliam SJ, Denninger JW, Berkowitz LR. So tired: predictive utility of baseline sleep screening in a longitudinal observational survey cohort of first-year residents. *J Gen Intern Med*. 2018;33(6):825–830.
12. Chaukos D, Chad-Friedman E, Mehta DH, et al. Risk and resilience factors associated with resident burnout. *Acad Psychiatr*. 2017;41(2):189–194.
13. Kalmbach DA, Fang Y, Arnedt JT, et al. Effects of sleep, physical activity, and shift work on daily mood: a prospective mobile monitoring study of medical

interns. *J Gen Intern Med*. 2018;33(6):914–920.
14. Olson K, Kemper KJ, Mahan JD. What factors promote resilience and protect against burnout in first-year pediatric and medicine-pediatric residents? *J. Evid. Based Complementary Altern. Med.* 2015;20(3):192–198.
15. Williford ML, Scarlet S, Meyers MO, et al. Multiple-institution comparison of resident and faculty perceptions of burnout and depression during surgical training. *JAMA Surg.* 2018;153(8):705–711.
16. Basner M, Dinges DF, Shea JA, et al. Sleep and alertness in medical interns and residents: an observational study on the role of extended shifts. *Sleep*. 2017;40(4).
17. Buysse DJ, Reynolds III CF, Monk TH, Berman SR, Kupfer DJ. The Pittsburgh Sleep Quality Index: a new instrument for psychiatric practice and research. *Psychiatry Res*. 1989;28(2):193–213.
18. Johns MW. Reliability and factor analysis of the Epworth sleepiness scale. *Sleep*. 1992;15(4):376–381.
19. ActiGraph Corp. *ActiGraph wGT3X-BT website*; 2016. http://actigraphcorp.com/actigraph-wgt3x-bt/. Accessed September 16, 2016.
20. Morgenthaler T, Alessi C, Friedman L, et al. Practice parameters for the use of actigraphy in the assessment of sleep and sleep disorders: an update for 2007. *Sleep*. 2007;30(4):519–529.
21. Marlin Company. *Attitudes in the American Workplace VII*. North Haven, CT: American Institute of Stress; 2001.
22. Holmes TH, Rahe RH. The social readjustment rating scale. *J Psychosom Res*. 1967;11(2):213–218.
23. Granger DA, Johnson SB, Szanton SL, Out D, Schumann LL. Incorporating salivary biomarkers into nursing research: an overview and review of best practices. *Biol Res Nurs*. 2012;14(4):347–356.
24. Walker S, O'Conner DB, Schaefer A, Talbot D, Hendrickx H. The cortisol awakening response: associations with train anxiety and stress reactivity. *Personal Individ Differ*. 2011;51(123-127):123–127.
25. Gaab J, Rohleder N, Nater UM, Ehlert U. Psychological determinants of the cortisol stress response: the role of anticipatory cognitive appraisal. *Psychoneuroendocrinology*. 2005;30(6):599–610.
26. Dickerson SS, Kemeny ME. Acute stressors and cortisol responses: a theoretical integration and synthesis of laboratory research. *Psychol Bull*. 2004;130(3):355–391.
27. Winwood PC, Winefield AH, Dawson D, Lushington K. Development and validation of a scale to measure work-related fatigue and recovery: the Occupational Fatigue Exhaustion/Recovery Scale (OFER). *J Occup Environ Med/American College of Occupational and Environmental Medicine*. 2005;47(6):594–606.
28. *SAS/ACCESS® 9.4 Software [computer Program]*. Cary, NC: SAS Institute Inc.; 2013.
29. Hirshkowitz M, Whiton K, Albert SM, et al. National Sleep Foundation's updated sleep duration recommendations: final report. *Sleep health*. 2015;1(4):233–243.
30. Watson NF, Badr MS, Belenky G, et al. Recommended amount of sleep for a healthy adult: a joint consensus statement of the American academy of sleep medicine and sleep research society. *Sleep*. 2015;38(6):843–844.
31. Allison PD. *Fixed Effects Methods for Linear Regression*. Cary, NC: SAS Institute, Inc.; 2005.
32. Tefft BC. *Acute Sleep Deprivation and Risk of Motor Vehicle Crash Involvement*. 2016.
33. Pilcher JJ, Ginter DR, Sadowsky B. Sleep quality versus sleep quantity: relationships between sleep and measures of health, well-being and sleepiness in college students. *J Psychosom Res*. 1997;42(6):583–596.
34. Gonzalez-Cabrera JM, Fernandez-Prada M, Iribar C, Molina-Ruano R, Salinero-Bachiller M, Peinado JM. Acute stress and anxiety in medical residents on the emergency department duty. *Int J Environ Res Public Health*. 2018;15(3).
35. Bassett SM, Lupis SB, Gianferante D, Rohleder N, Wolf JM. Sleep quality but not sleep quantity effects on cortisol responses to acute psychosocial stress. *Stressforskningsrapporter*. 2015;18(6):638–644.
36. Buckley TM, Schatzberg AF. On the interactions of the hypothalamic-pituitary-adrenal (HPA) Axis and sleep: normal HPA Axis Activity and circadian rhythm, exemplary sleep disorders. *J Clin Endocrinol Metab*. 2005;90(5):3106–3114.
37. Serenari M, Cucchetti A, Russo PM, et al. *Burnout and Psychological Distress between Surgical and Non-surgical Residents*. vol 71. 2019:323–330, 2.
38. Blackwell T, Paudel M, Redline S, Ancoli-Israel S, Stone KL. A novel approach using actigraphy to quantify the level of disruption of sleep by in-home polysomnography: the MrOS Sleep Study: sleep disruption by polysomnography. *Sleep Med Rev*. 2017;32:97–104.