Accepted: 9 January 2019
DOI: 10.1002/ajim.22956

RESEARCH ARTICLE

WILEY AMERICAN JOURNAL OF INDUSTRIAL MEDICINE

Impact of shift duration on alertness among air-medical emergency care clinician shift workers

P. Daniel Patterson PhD, NRP[1,2] | Matthew D. Weaver PhD, EMT-P[3] | Mark A. Markosyan NRP[1,2] | Charity G. Moore PhD[4] | Frank X. Guyette MD[1] | Jack M. Doman MS[5] | Denisse J. Sequeira BS[1] | Howard A. Werman MD[6] | Doug Swanson MD[7] | David Hostler PhD[8] | Joshua Lynch DO[9,10] | Megan A. Templin MPH, MS[7] | Nigel L. Rozario MS[7] | Lindsey Russo MS[8] | Linda Hines JD, RN[6] | Karen Swecker RN[6] | Michael S. Runyon MD[7] | Daniel J. Buysse MD[5]

[1] Department of Emergency Medicine, University of Pittsburgh, School of Medicine, Pittsburgh, Pennsylvania

[2] Division of Community Health Services, University of Pittsburgh, School of Health and Rehabilitation Sciences, Pittsburgh, Pennsylvania

[3] Harvard Medical School, Division of Sleep Medicine, Division of Sleep and Circadian Disorders, Departments of Medicine and Neurology, Brigham and Women's Hospital, Boston, Massachusetts

[4] Department of Physical Therapy, University of Pittsburgh, School of Health and Rehabilitation Sciences, Pittsburgh, Pennsylvania

[5] Department of Psychiatry, University of Pittsburgh, School of Medicine, Pittsburgh, Pennsylvania

[6] MedFlight of Ohio, Columbus, Ohio

[7] Carolinas HealthCare System, Charlotte, North Carolina

[8] Department of Exercise and Nutrition Sciences, , The State University of New York, University at Buffalo, Buffalo, New York

[9] MercyFlight of Western New York, Buffalo, New York

[10] Department of Emergency Medicine, Jacobs School of Medicine and Biomedical Sciences, The State University of New York, University at Buffalo, Buffalo, New York

Correspondence
Paul D. Patterson, PhD, NRP, 3600 Forbes Avenue, Iroquois Bldg., Suite 400A, University of Pittsburgh, School of Medicine, Department of Emergency Medicine, Pittsburgh, PA 15260
Email: pdp3@pitt.edu

Funding information
MedEvac Foundation (medevacfoundation.org)

Background: Greater than half of Emergency Medical Services (EMS) shift workers report fatigue at work and most work long duration shifts. We sought to compare the alertness level of EMS shift workers by shift duration.

Methods: We used a multi-site, 14-day prospective observational cohort study design of EMS clinician shift workers at four air-medical EMS organizations. The primary outcome was behavioral alertness as measured by psychomotor vigilance tests (PVT) at the start and end of shifts. We stratified shifts by duration (< 24 h and 24 h), night versus day, and examined the impact of intra-shift napping on PVT performance.

Results: One hundred and twelve individuals participated. The distribution of shifts <24 h and 24 h with complete data were 54% and 46%, respectively. We detected no differences in PVT performance measures stratified by shift duration ($P > 0.05$). Performance for selected PVT measures (lapses and false starts) was worse on night

Institution at which the work was performed: The University of Pittsburgh served as the coordinating center and one of four study sites. Other sites included: Mercy Flight based in Buffalo, NY; MedCenter Air based in Charlotte, NC; and MedFlight of Ohio based in Columbus, Ohio.

shifts compared to day shifts ($P < 0.05$). Performance also worsened with decreasing time between waking from a nap and the end of shift PVT assessment.

Conclusions: Deficits in performance in the air-medical setting may be greatest during night shifts and proximal to waking from an intra-shift nap. Future research should examine alertness and performance throughout air-medical shifts, as well as investigate the timing and duration of intra-shift naps on outcomes.

KEYWORDS

alertness, fatigue, performance, shift work, sleep

1 | INTRODUCTION

Shift work has been linked to negative health outcomes, compromised performance, and medical error.[1–4] Extended shift duration and sleep deprivation associated with shift work are linked to deficits in alertness and cognitive performance.[5] Most air-medical clinicians work extended duration shifts (eg, 12 or 24 h) and are at risk of the negative effects of fatigue and sleep deprivation.[6–8] Professional groups, including the Air Medical Safety Advisory Council and the Commission on Accreditation of Medical Transport Systems, and accreditation organizations discourage extended duration shift work, such as 24 h or longer. The 2018 Evidence Based Guidelines for Fatigue Risk Management in Emergency Medical Services (EMS) operations recommends shifts less than 24 h in duration.[9] Because the current body of evidence germane to air-medical clinicians and shift duration is limited and variable,[8,10–12] the need for research that explores and explains differences in outcomes stratified by shift duration specific to air-medical EMS operations is compelling.[13]

Reports of sleep deprivation among EMS clinicians linked to patient and clinician death are on the rise.[14–18] Recent data show that half of EMS clinicians report six or fewer hours of sleep per day.[19] More than half of EMS clinicians report mental and physical fatigue during shift work and half fail to recover between scheduled shifts.[19,20] Most EMS clinicians work shifts of 12 or 24 h in duration and in some air-medical systems greater than 80% report working multiple jobs.[7,21] The risk of occupational injury is 38% greater for EMS clinicians who work shifts greater than 12 h in duration, compared to those who work shifts less than 12 h.[22]

Deficits in alertness are well documented following acute and chronic sleep restriction, which can accrue during shift work.[23–25] Relative to baseline, individuals restricted to 4.5 mean hours of sleep per day perform worse on daily cognitive tests than individuals with 7.7 mean hours per day of sleep.[26] Shift work also conflicts with the natural circadian rhythm of wakefulness during the day and sleep at night, which further interferes with the ability to obtain the recommended 7–9 h of sleep per day.[27,28] Shift work disrupts endogenous circadian rhythms such as the rise in melatonin in the evening, decrease in cortisol secretion at night, and decrease in blood pressure and core body temperature in the early morning hours.[29–33] Less total sleep and disrupted circadian timing have been linked to disruption in glucose metabolism and hormone secretion, disturbance in neurobehavioral and immune functioning, and development of cardiovascular disease.[34–39]

Despite these data, little is known about the impact of shift duration and fatigue on safety and performance related outcomes in the air-medical EMS setting.[13] One prior study of air-medical clinicians evaluated cognitive performance and detected a decline in memory at the end of shifts compared to the beginning.[40] The impact of shift duration was not assessed. Two additional studies involving air-medical clinicians detected no differences in cognitive performance by shift duration.[8,41] We sought to improve our understanding of air-medical EMS clinician alertness in relation to shift duration by prospectively following clinicians over a 2-week period and testing objective alertness at the start and end of scheduled shifts lasting 12 or 24-h. We hypothesize that performance on a behavioral test of alertness following shifts lasting 24 h is worse than alertness following shifts lasting 12 h.

2 | METHODS

2.1 | Study design and setting

We used a prospective observational cohort study design of air-medical clinicians employed at four large air-medical services located in the Midwest, Northeastern, and Southern United States. The combined transport volume for the four study sites exceeds 20 000 patients annually (Table 1). Study sites employed 286 potentially eligible clinician participants. Recruitment remained open for 10-months from June 2015 to March 2016.

2.2 | Participants

We used email to circulate a study flyer to all potentially eligible clinicians affiliated with each of the four study sites. Study personnel gave brief presentations during scheduled continuing education sessions. An air-medical clinician was eligible if he/she (1) was 18 years

TABLE 1 Demographic characteristics of air-medical services

Demographic characteristic	Site 1	Site 2	Site 3	Site 4	Total
U.S. Census Region	Midwest	Northeast	Northeast	Southern	–
Approximated air transports in (cy2015)	7000	10 000	1130	2200	20 330
Clinicians eligible for participation	75	92	49	70	286

of age or older; (2) worked clinically at one of the four study sites; (3) worked 12 or 24-h shifts; and (4) was willing to take part in a research study that addressed sleep and fatigue. Because this was a multi-site study, we received approval from four Institutional Review Boards (IRBs). All participants gave written informed consent.

2.3 | Measures

Consented participants received a wrist actigraph device (Actigraph Corporation, Pensacola, FL), commonly used in sleep-related research,[42,43] to objectively measure sleep/wake activity and rhythms throughout a 14-day baseline study period. Participants then used a password protected website to answer a baseline cross-sectional survey. Baseline questions included 14 standard demographic questions, the 18-item Pittsburgh Sleep Quality Index (PSQI),[44] the 8-item Epworth Sleepiness Scale (ESS),[45] the 11-item Chalder Fatigue Questionnaire (CFQ),[46] and the 15-item Occupational Fatigue and Recovery scale (OFER, *with permission from developer*).[47] The PSQI, ESS, CFQ, and OFER have been shown reliable and valid in diverse populations, including EMS clinicians. The PSQI is widely used in clinical and operational settings to assess sleep quality. A PSQI score >5 on a 0-to-21 scale indicate poor sleep quality. The CFQ has been tested in healthy adult populations, in patients with sleep/fatigue disorders, and emergency care workers to assess mental and physical fatigue. The OFER is a reliable and valid instrument that measures work-related acute and chronic fatigue, as well as perceived recovery between shiftwork. Higher scores (eg, >80) on a 0–100 scoring scale indicate higher levels of fatigue (acute/chronic) and greater ability to recover between scheduled shifts.

The work of an EMS clinician involves reacting and moving quickly to perform life-saving interventions, calculate medication dosages, and to make decisions under significant time pressure. Rapid response, immediate intervention, and quick decision-making are critical to the primary mission of EMS clinicians: stabilizing the acutely ill and injured. While there is no known study linking the psychomotor vigilance test (PVT) to specific air-medical performance, we chose the brief three-min version of the (PVT-B) as our primary outcome variable of interest. The PVT test is based on the evaluation of simple reaction time and the ability of the participant to sustain attention (alertness) and respond quickly. The tool is sensitive to sleep deprivation and considered a valid assessment tool for neurocognitive performance in clinical, operational, and experimental settings, and is resistant to practice effects.[23,48–50] Individual trials consist of the participant tapping the screen of a computerized device (eg, tablet computer) when numbers appear in a small box on screen. Three, five, and ten-minute versions of the PVT have been widely used and shown to be reliable and valid indicators of cognitive performance and alertness.[49] We used the 3-min version (PVT-B), which was administered with a commercially available mobile application provided by JoggleResearch™ and installed on tablet computers. Test duration was 180 s (3 min).[49,51,52] The inter stimulus interval minimum and maximum are 2 and 5 s, respectively.[49,51,52] The threshold for lapses was set at 355 milliseconds.[49,51,52] Similar to previous research,[25] we administered PVTs at the start and end of scheduled shifts. We abstracted the following measures from each PVT test: (1) mean response time (in milliseconds); (2) number of lapses (reaction time >355 ms); (3) number of false starts; and (4) the reciprocal transform as a measure of speed (1/RT).[49] Participants completed PVTs at the start and end of a minimum of one and up to a maximum of five scheduled shifts over the 14-day study period.

We used Ecological Momentary Assessment (EMA) techniques to capture secondary outcome measures of inter-shift recovery, daily shift work, daily sleep hours, and daily subjective sleep quality.[53–55] The principles of EMA research techniques involve repeated sampling of participants regarding targeted behaviors, perceptions, and experiences in real-time and in real-world environments.[53] As prescribed by EMA principles and based on previous research,[53–55] we used single-item measures to capture secondary outcomes of interest. Participants used a web-based, secure electronic daily diary every day during the study period. Participants received daily reminders at noon (1200 h) each day via text-message and email to complete their daily diary.

2.4 | Statistical analysis

We described continuous variables with means, standard deviations (SD), and categorical variables with frequencies and percentages for primary and secondary outcomes of interest. We specified an a priori stratification by shift duration (12-h vs 24-h). Because participants were intermittingly held over due to a late dispatch or sometimes arrived to work early, we grouped shifts into two main categories (<24 h and 24 h). However, we included supplemental tables with findings isolated to only those shifts that were exactly 12 h and 24 h in duration. A participant was classified as "routinely" working a particular shift pattern during the study period if he/she worked >75% of his/her documented shifts at a particular duration (12 or 24 h).

We determined hours of sleep before, during, and after scheduled shifts with a combination of sleep diaries and actigraphy. We used the automated sleep detection function within the ActiLife6 software program (Actigraph Corporation, Pensacola, FL) to process sleep measured with actigraphy, and triangulated sleep timing with participant sleep diaries. We examined compliance with wrist actigraphy by randomly selecting actigraphy data from 50 participations. We used the ActiLife6 software automated function to determine the mean number of minutes of non-wear time.[56]

For our primary outcome of alertness measured by PVT, we anticipated that the number of PVT lapses would follow a Poisson (or negative binomial) distribution.[57] Given this distribution, we used a generalized estimating equation (GEE) to test mean lapses and false starts at start and end of shift, by shift duration (12-h vs 24-h). We used mixed effects linear models to test for differences in four PVT outcome measures by stratums of commonly reported measures of sleep and fatigue (eg, PSQI).

The sample size for this study was chosen to detect differences in alertness by shift duration, which we defined as 12 h and 24 h. With 126 total participants ($n = 63$ per category of shift duration), we estimated 80% power to detect an effect size of 0.5 standard deviations between participants with different shift duration in the start-to-end of shift PVT lapses measure. We permitted individual air-medical clinicians the ability to participate more than once, but limited the total number of participations by any one individual to two. The basis for allowing multiple participations and limiting total participations to two include: (1) our pool of potentially eligible participants was limited to four study sites and (2) minimal information would be gained with more than two participations by any one individual under the same shift duration. Our calculation was based on the following assumptions: (1) complete start and end of shift PVT data from each participant for at least one shift during the study period and (2) a 20% rate of attrition across study sites, which is of a similar level observed in previous research.[58] Findings are presented in tables stratified by the number of times a participant had participated in this study (once or twice). We also presented data from each participant's first time in the study and examined differences in PVT outcome measures stratified by day versus night shift, and by day shift start versus night shift start. We defined a night shift as any shift that started before midnight (0000 h) and extended past midnight. We defined a day shift "start" as shifts that started before 1700 h and night shift "start" as those that began at or after 1700 h. We used Generalized Linear Modeling (GLM) and two-way ANOVA to test for differences in demographic, sleep, and PVT measures stratified by the number of participant participations (once vs twice).

3 | RESULTS

3.1 | Participant characteristics

In total, 112 unique individuals participated in this study (Figure 1). Twenty-six individuals (23%) participated twice and the total number of participations was 138. One participant withdrew after completing one of the two required weeks of participation. On average, participants completed the daily diary for 13 (95%CI 13, 14) of the 14 days of the study period. Compliance with actigraph wear time was high. Mean hours of non-wear time per day was 2.4 (SD 2.6). Complete data (sleep diary, actigraph data, and at least one shift with start and end of shift PVT measurement) were obtained from 92% of all participations ($n = 127$; Figure 1). When compared to those who participated once, most individuals who participated twice were male and reported full-time employment ($P < 0.05$; Table 2).

3.2 | Main results

Nearly half of shifts were classified as <24 h in duration (46%), and 54% classified as 24 h in duration. Among these, 76% were exactly 12 h and 97% were exactly 24 h in duration. Forty-three percent of all 12-h shifts were overnight (ie, 1900 to 0700 h; 42.9%). Non-routine shift patterns worked by individuals, such as a combination of working 12-h and 24-h shifts, represented 26.8% of shifts worked. Routine 24-h shifts were more common among individuals who participated twice than individuals who participated once (50% vs 20.9%; $P = 0.0017$).

Mean hours of sleep preceding a shift and hours of sleep obtained within 24-h after shift end were similar by duration of shift ($P = 0.70$ and $P = 0.64$, respectively; Table 3). Mean hours of sleep (naps) during shifts <24 h was 2.6 (SD 3.2) and 7.3 (SD 2.6) during shifts 24 h in duration. Naps were detected for 60% of all shifts (88% of 24 h shifts and 35% of shifts <24 h). Reported hours of recovery between scheduled shifts differed by shift duration. Among total participations, mean hours of recovery for those who worked 24-h shifts was 48.7 h (SD 39.3), whereas for those who worked <24 h, mean hours of recovery was 35.4 (SD 37.7; $P < 0.0001$). A similar pattern was observed when stratifying the study sample by number of participations, and no differences were detected when comparing individuals who participated once versus those who participated twice ($P > 0.05$). Perception of recovery between shifts, as reported by the participants, was similar by shift duration (3.8; SD 1.2 on a 0-5 scale with 0 = Not at all recovered, 5 = Fully recovered mentally and physically). There were no differences in perceived recovery when comparing individuals who participated once versus twice ($P > 0.05$).

Greater than half of all PVTs (59.7%) were completed within 10-min of shift start or end, and most (76.2%) were completed within 60 min of shift start or end (Figure 2). There were no differences in PVT performance measures obtained within or after 60 min of shift start or end ($P > 0.05$). Among all participations ($n = 138$), we detected no differences in PVT outcome measures stratified by shift duration (Table 4; $P > 0.05$). Findings were similar among those participating once during the study period ($n = 86$; Supplemental Table IVb; $P > 0.05$).

Among those who participated twice ($n = 26$), lapses and response time (1/RT) differed by shift duration (Supplemental Table IVc; $P < 0.05$). Specifically, among those working shifts <24 h in duration, the mean number of lapses increased from 2.0 at the start of the shift to 2.9 measured at the end of shifts. Among those that worked 24-h shifts, the number of lapses decreased from 4.3 at the start to 3.4 measured at the end. With respect to the mean reciprocal 1/RT measure, "response speed" decreased/worsened among those working shifts <24 h from a mean of 4.4 (SD 0.2) at the start to a

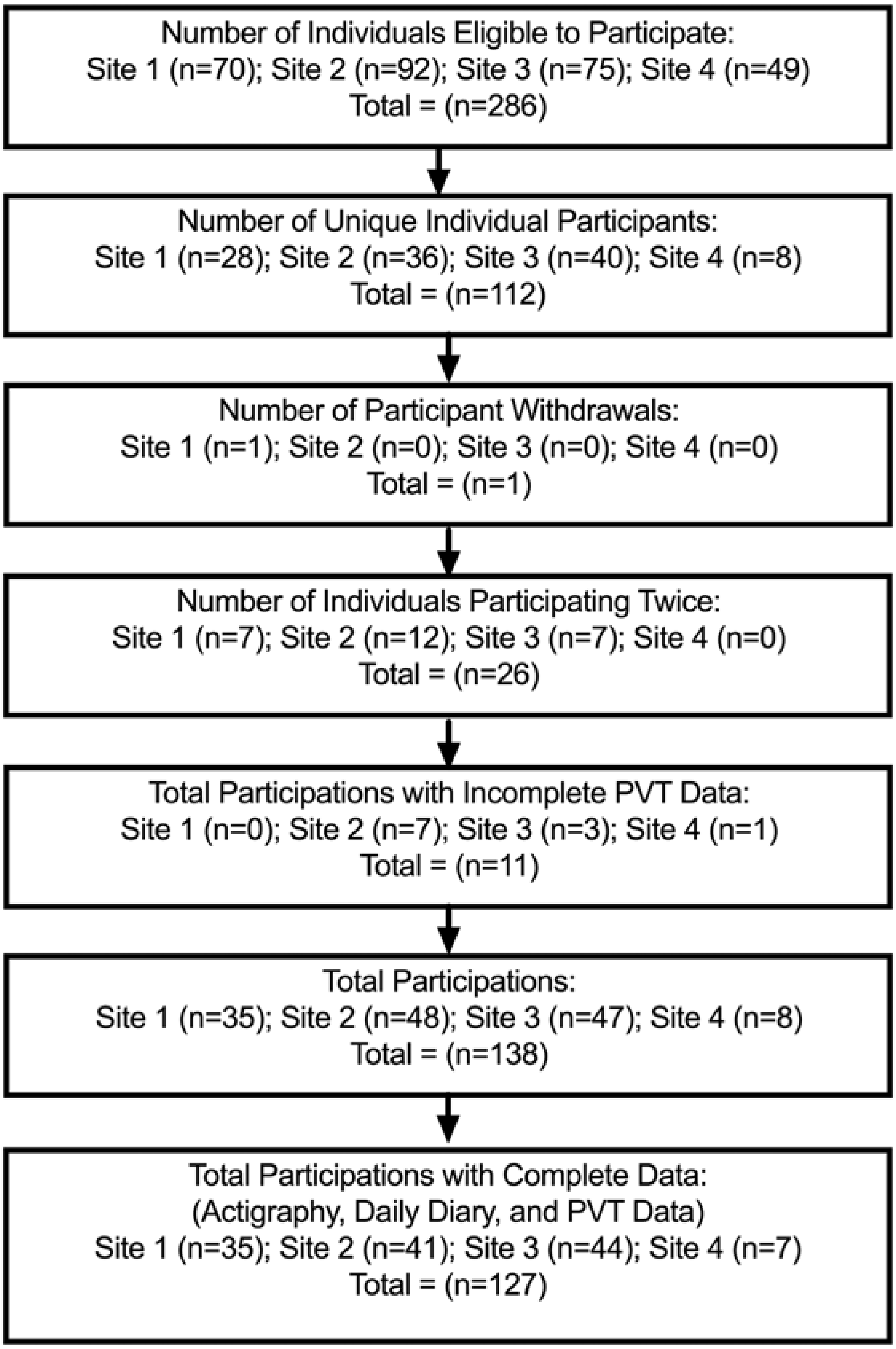

FIGURE 1 Consort diagram

mean of 4.2 (SD 0.4) measured at the end. This contrasts with those that worked 24-h shifts, where the mean 1/RT "response speed" was 4.2 (SD 0.6) at the start of the shift and increased (improved) to a mean of 4.3 (SD 0.6; Supplemental Table IVc).

Analyses with each participant's first time participating ($n = 112$) are presented in Supplemental Tables IVd, IVe, and IVf. Findings show no differences in PVT measures stratified by shift duration <24 h versus 24 h (Supplemental Table IVd). However, when stratified by day versus night shift, the mean number of lapses and false starts measured at the start and end of shifts were higher when participants worked the night shift versus when participants worked the day shift (Supplemental Table IVe). Findings presented in Supplemental Table IVf show no differences in PVT measures when shifts are stratified by shift start times as either day start (before 1700 h), or night start (start on or after 1700 h).

Supplemental Table Va is comprised of start of shift PVT measurement statistics stratified by potential sleep and fatigue confounders. Mean number of PVT false starts at the start of shifts was higher among participants that participated twice compared to participants that participated once ($P < 0.05$). The mean number of PVT

TABLE 2 Demographic and baseline characteristics of study participants

	N = 138 total participations[a]	*N* = 86 individuals participated once	*N* = 26 individuals participated twice
	Percentage (*n* = #); Mean (SD)	Percentage (*n* = #); Mean (SD)	Percentage (*n* = #); Mean (SD)
Female	34.1% (*n* = 47)	41.9% (*n* = 36)	23.1% (*n* = 6)
Mean age	43.1 (9.2)	43.4 (9.4)	42.8 (8.9)
Certification/Licensure			
Paramedic	34.8% (*n* = 48)	37.2% (*n* = 32)	30.8% (*n* = 8)
Prehospital Nurse	56.5% (*n* = 78)	55.8% (*n* = 48)	57.7% (*n* = 15)
Respiratory Therapist	8.7% (*n* = 12)	7.0% (*n* = 6)	11.5% (*n* = 3)
Employment status			
Full-time	84.8% (*n* = 117)	75.6% (*n* = 65)	100.0% (*n* = 26)
Part-time	15.2% (*n* = 21)	24.4% (*n* = 21)	0
Number of Jobs			
≥2 jobs	45.7% (*n* = 63)	52.3% (*n* = 45)	30.8% (*n* = 8)
Mean years of experience	20.0 (9.5)	20.2 (9.6)	20.3 (9.7)
Most common shift worked			
24-h	66.7% (*n* = 92)	62.8% (*n* = 54)	73.1% (*n* = 19)
<24-h	33.3% (*n* = 46)	37.2% (*n* = 32)	26.9% (*n* = 7)
General health			
Excellent	44.9% (*n* = 62)	48.8% (*n* = 42)	42.3% (*n* = 11)
Good	55.1% (*n* = 76)	51.2% (*n* = 44)	57.7% (*n* = 15)
Fair/Poor	0	0	0
BMI			
Underweight/Normal weight	26.9% (*n* = 35)	30.0% (*n* = 24)	26.9% (*n* = 7)
Overweight	56.2% (*n* = 73)	48.8% (*n* = 39)	65.4% (*n* = 17)
Obese	16.9% (*n* = 22)	21.3% (*n* = 17)	7.7% (*n* = 2)
Poor sleep quality (PSQI >5)	51.4%	54.7%	46.2%
Mean Epworth Sleepiness Scale (ESS)	6.0 (3.4)	6.1 (3.3)	5.9 (3.5)
Excessive Sleepiness (ESS ≥16)	0.7% (*n* = 1)	0% (*n* = 0)	1.9% (*n* = 1)
Situational Sleepiness (ESS 10–15)	12.3% (*n* = 17)	12.8% (*n* = 11)	11.5% (*n* = 6)
Average Sleepiness (ESS 8–9)	13.8% (*n* = 19)	17.4% (*n* = 15)	7.7% (*n* = 4)
Unlikely Abnormally Sleepy (ESS 0–7)	73.2% (*n* = 101)	69.8% (*n* = 60)	78.8% (*n* = 41)
Mean OFER			
Chronic fatigue scale	30.0 (18.1)	31.6 (19.8)	27.1 (14.4)
Acute fatigue scale	40.6 (21.7)	40.5 (22.0)	40.9 (21.5)
Inter-shift fatigue scale	54.7 (21.3)	54.2 (23.3)	55.6 (17.8)
Percent fatigued on CFQ scale	44.9%	40.7%	51.9%

[a]*n* = 112 unique individual participants. *n* = 8 participants missing height/weight. *N* = 26 individuals participated twice during the study period.

false starts at shift start was higher among participants classified with low to moderate chronic fatigue on the OFER tool compared to participants classified with moderate to high chronic fatigue ($P < 0.05$). We detected no additional differences in PVT measures taken at the start of shifts stratified by sleep and fatigue measures. Supplemental Table Vb is comprised of end of shift PVT measurement statistics stratified by potential confounders. Mean PVT reaction time at the end of shifts differed by sleep quality ($P < 0.05$). Mean PVT reaction time was higher among participants classified with poor sleep quality as measured by the PSQI compared to participants with normal sleep

TABLE 3 Sleep-wake and shiftwork activity during 2-week study period

	N = 138 total participations[a]		N = 86 individuals participated once		N = 26 individuals participated twice		N = 112 with first participation only	
	Mean (SD)		Mean (SD)		Mean (SD)		Mean (SD)	
	<24-h	24-h	<24-h	24-h	<24-h	24-h	<24-h	24-h
Number of shifts worked per study participant	4.2 (2.8)	3.2 (1.3)	4.2 (2.6)	2.8 (1.3)	4.3 (3.1)	3.7 (1.2)	4.3 (2.8)	3.1 (1.4)
Shift duration (in hours)	11.1 (2.4)	23.5 (1.9)	11.1 (2.4)	23.6 (1.8)	11.1 (2.5)	23.3 (2.0)	11.1 (2.4)	23.4 (1.9)
Hours of sleep 24 h BEFORE scheduled shifts	7.4 (1.8)	7.3 (2.0)	7.4 (1.7)	7.2 (2.3)	7.3 (1.9)	7.4 (1.6)	7.4 (1.8)	7.3 (2.0)
Hours of sleep 24 h AFTER scheduled shifts	6.7 (1.9)	6.8 (2.2)	6.7 (1.9)	6.7 (2.5)	6.7 (2.0)	6.9 (1.7)	6.7 (1.9)	6.8 (2.2)
Hours of sleep DURING scheduled shifts[b]	2.6 (3.2)	7.3 (2.6)	2.1 (1.7)	5.5 (2.5)	3.8 (3.0)	5.4 (2.6)	2.6 (2.8)	7.3 (2.8)
Hours of recovery between scheduled shifts	35.4 (37.7)	48.7 (39.3)	37.7 (40.4)	48.1 (37.7)	31.1 (32.3)	49.4 (41.0)	35.3 (37.0)	48.3 (38.6)
Subjective, self-perceived rating of inter-shift recovery within first 24-hours after shift work. (0 = Not at all recovered, 5 = Fully recovered mentally and physically)	3.8 (1.2)	3.8 (1.2)	3.8 (1.2)	3.8 (1.2)	3.7 (1.2)	3.8 (1.3)	3.8 (1.2)	3.8 (1.2)

[a]*n* = 112 unique individual participants. [b]These data are representative of 3 out of 4 study sites allowed crews to sleep/nap/rest while on duty. Comparisons of mean values stratified by number of participation showed no differences between groups ($P > 0.05$).

quality. Mean PVT reaction time at the end of shifts was higher among participants classified with low to moderate inter-shift recovery than participants with moderate to high inter-shift recovery ($P < 0.05$; Supplemental Table Vb).

Findings presented in Supplemental Table Vc show findings from each participant's first participation. The mean PVT reaction time at the start of shifts was higher among participants classified with poor sleep quality compared to participants classified with normal sleep quality ($p < 0.05$). The mean number of false starts at the start of shifts was higher among participants classified as unlikely to have abnormal daytime sleepiness compared to participants classified as excessively sleepy on the ESS tool ($p < 0.05$). Regarding end of shift PVT measures, mean PVT reaction time at the end of shifts was higher among participants classified with poor sleep quality compared to participants classified with normal sleep quality ($p < 0.05$; Supplemental Table IVd).

On average, participants were awake for 4.1 h (SD 4.6) prior to the end of shift PVT. After controlling for on-shift sleep duration, increasing time since awakening from nap was associated with improved reaction time and fewer lapses during the end of shift PVT ($P < 0.05$). This finding was isolated to 24-h shifts and not observed for shifts <24 h in duration.

4 | DISCUSSION

Our study is one of the largest prospective studies of air-medical clinician alertness in relation to shift duration.[13] We detected no differences in sleep behavior/patterns before and after shifts by shift duration. Recovery in hours between shifts was longer following a 24-h shift than after shorter duration shifts. Contrary to our hypothesis, there were no differences by shift duration in neurobehavioral performance measured at the start or end of shifts. However, lapses and false starts were more common at the end of shifts among participants that worked night shifts versus the day shift. These findings were isolated to shifts <24 h in duration. We also detected differences in PVT measures when stratified by commonly reported sleep and fatigue measures (eg, sleep quality). In addition, waking from a nap proximal to the end of a 24-h shift was associated with poorer performance on the PVT. Future hypothesis testing should explore the presence of deficits in alertness at specific time points during shift work rather than relying on performance assessed solely at the beginning or end of shifts.

Similar research on other healthcare shift worker populations (eg, resident physicians) has shown a progressive degeneration in performance and cognitive performance in relation to extended shift work.[59] Several studies have investigated the relationship between shift duration and alertness of air-medical clinicians.[8,10,13,40,41] Braude et al investigated the impact of shiftwork cognitive performance in a small air-medical system with 22 air-medical participants.[40] A decline in memory performance was detected at the end of shifts compared to the beginning for a test battery that involved memory, arithmetic performance, visual memory, and auditory monitoring.[40] However, the

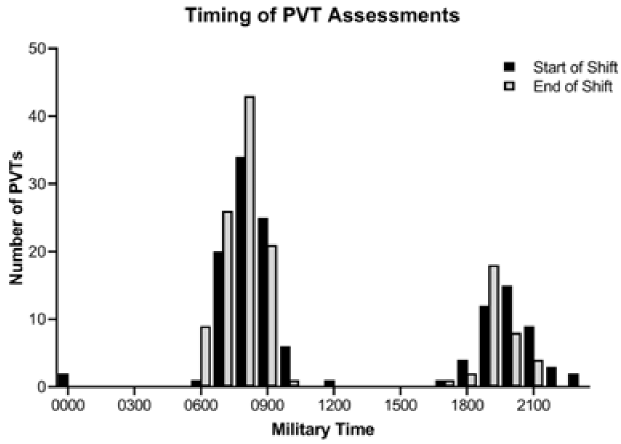

FIGURE 2 Timing of PVT assessments

investigators did not explore for possible differences in cognitive performance by shift duration. Thomas et al[41] discovered no differences in air-medical clinician cognitive performance by shift duration when comparing 12-h versus 18-h shifts. A more recent study of 34 air-medical clinicians affiliated with a large multi-base air-medical system evaluated the impact of shift duration on in cognitive performance and detected no differences in performance between clinicians who worked 12 h versus 24 h.[8] A battery of four cognitive tests were used to assess performance [the Paced Auditory Serial Addition Test (PASAT); the University of Southern California Repeatable Episodic Memory Test (USC-REMT); the Trail Making Test (TMT); and the Stroop Color-Word Test].[8] Methodological differences prevent direct comparisons between our findings and the results of prior research involving air-medical clinicians.

Participants in this study reported seven hours of sleep on average during 24-h shifts and nearly 3 h on average when working 12-h shifts. Napping during shift work has been linked to improvements in subjective ratings of alertness, lower self-reported sleepiness, and improved performance on objective tests of alertness.[60,61] Our findings reveal deficits in performance when completing a PVT the closer one gets to waking from a nap and working a 24-h extended shift. Our findings are similar to previous research,[62] and the likely explanation for this finding is sleep inertia. Sleep inertia is grogginess upon waking and has been shown to have a negative impact on performance in diverse settings and situations.[63] Preventing sleep inertia is a challenge. Scheduling naps of different durations and tailoring the timing of each nap may help reduce sleep inertia, but not eliminate it.[62] The optimal nap and duration tailored to air-medical setting is not yet known. Despite these findings, and despite the uncertainty regarding the timing and optimal duration of napping for air-medical clinicians, taking a nap during extended duration shifts may be an effective fatigue mitigation intervention for clinicians in the air-medical setting.[60,61] The evidence in favor of napping during shiftwork is increasing, and some level of sleep inertia may be unavoidable. We do not believe our data provide evidence against napping, rather highlight the need to identify the optimal duration and timing of naps. Naps as short as 20–40 min taken prior to 0400 have shown benefit.[64–66] Additional research of naps during air-medical EMS shift work is needed.

A potential explanation for the lack of differences in PVT measures by shift duration relates to circadian timing of tests on 24-h and <24-h shifts. Participants working 24-h shifts typically start and end their shifts in the morning hours between 0600 and 0900. A PVT measurement taken at this time may be impacted by circadian rhythm of alertness, associated with the circadian rise in body temperature, increase in cortisol, and decrease in melatonin, as well as exposure to environmental light (eg, the sun).[67–69] These circadian effects may mitigate differences in wake duration on 24-h and <24-h shifts. One approach to examine this phenomenon in this study population would be to capture multiple PVT measurements over the course of a shift.

Findings from baseline measures reveal a substantial number of participants with poor sleep quality, as well as severe mental and physical fatigue. Beyond acute performance deficits, shift work is a contributing factor by restricting sleep or preventing quality sleep. Shift work has been linked to cardiovascular disease, change in body weight, and increased risk of type 2 diabetes.[39,70–72] Shift work is not going away and helping air-medical clinicians cope with the challenges of shift work should be priority for medical directors and EMS administration. Adopting and testing evidence-based strategies for fatigue risk management is ideal, yet exploration of novel programs informed by the evidence is important.

Our study will have implications for future studies of air-medical clinician shift workers. Our findings provide valuable base rate information, as well as comparative data, for future research that may seek to replicate our protocol. From 1980 to 2016 only seven studies involving shift workers reported comparisons of outcomes stratified by 12 and 24-h shift durations.[13] The need for research comparing outcomes by 12-h and 24-h shifts is compelling, especially given that the majority of EMS shifts are 12 and 24 h in

TABLE 4 Psychomotor Vigilance Test (PVT) scores by shift duration with complete sample data

	<24-h		24-h		
	Shift start Mean (SD)	Shift end Mean (SD)	Shift start Mean (SD)	Shift end Mean (SD)	*P*-value
Mean response time (milliseconds)	253.3 (39.3)	258.0 (66.0)	266.3 (51.9)	258.0 (48.9)	0.20
Number of lapses	2.7 (2.8)	3.2 (5.1)	3.9 (4.4)	3.5 (4.3)	0.21
Number of false starts	1.7 (1.9)	1.5 (1.8)	2.3 (3.1)	2.1 (2.3)	0.81
Mean response time reciprocal (1/RT)	4.3 (0.4)	4.3 (0.5)	4.2 (0.5)	4.2 (0.6)	0.28

duration.[20,21,73–75] Among these studies, only three reported on measures of performance. One study showed shift duration had no impact on performance,[8] a separate study showed the shorter shift was more favorable than the longer duration shift,[10] and a third study showed favorability for the longer duration shift for one component of an index measure of performance.[76] Our study provides valuable reference data for a popular measure of performance, the PVT. None of the above mentioned studies that compared performance by 12 and 24-h shifts used the PVT tool. The PVT is a standard, widely used tool for measuring the impact of sleep deprivation on performance.[49] Future studies may use our findings to estimate a desirable level of power germane to performance on the PVT, which has implications for goal enrollment.

Our study has implications for the debate regarding shorter versus longer shift duration in high-risk operations. While the findings from this study suggest that longer duration shifts have little to no meaningful impact on a reliable measure of performance, a number of studies involving diverse shift worker groups show the opposite.[13] The air-medical industry, and scientists that investigate safety in this safety-sensitive environment, should replicate this study with a different sample to continue to add to the evidence. More studies that utilize prospective and experimental designs will clarify the relationships of interest and invoke a higher level of confidence in evidence. Finally, our study adds to the conversation and growing body of research focused on napping during shifts as a fatigue mitigation strategy. The optimal duration of napping for air-medical clinicians is not known, nor is the optimal timing. The unpredictable nature of air-medical work presents a unique challenge. Our study may spur additional research of napping that accounts for timing, duration, and the unpredictability of tasks that are safety and time-sensitive.

Future studies should incorporate more frequent assessments of PVT measures of performance. The logistical challenges associated with PVT measurement of a mobile workforce like air-medical clinicians are significant. Deficits in performance among EMS clinicians are believed to occur during the mid-point to end of shifts that last greater than 12 h—specifically between midnight and 0500.[58] Future investigations should design their protocol to include multiple measures of PVT performance, yet weigh the cost versus benefits when determining the total number of measurements per shift. Future studies may wish to consider using multiple techniques to track sleep. Actigraphy is a standard research tool, but data can be incomplete due to non-compliance of participants. Full and accurate interpretation of actigraphy data files often requires triangulation of sleep patterns with paper or electronic sleep diaries or other methods. Future studies may benefit from deployment of actigraphs, sleep diaries, and regular communications with study participants to reinforce the importance of wear time and consistent documentation of sleep timing.

5 | LIMITATIONS

Our study has several limitations. We recruited participants from four air-medical services, thus our results may not be generalizable to all air-medical systems. Forty-two percent of all eligible air-medical clinicians participated. It is possible that non-participants differed from participants in important ways; however, we have no specific evidence for bias in approaching or enrolling eligible participants. Twenty-three percent of participants opted to participate more than once. Most were male and employed as full-time ($P < 0.05$; Table 2). The mean number of days between the first and second participation was 109.1 (SD 53.4). The data contributed by these participants, in terms of the number of 12-h and 24-h shifts, did not differ from those participating once during the study period (Table 3; $P > 0.05$).

Data captured by our electronic daily diary are self-report and subject to bias. Data captured by wrist actigraphy are considered a more accurate measurement of sleep patterns relative to other objective methods such as polysomnography. However, actigraphy data can be incomplete when participants remove the device for personal reasons (eg, bathing). We addressed the limitations of both approaches by examining both self-report electronic daily diary data and wrist actigraphy data to triangulate sleep timing and quantify total sleep pre-shift, during shifts, and post-shift. Our protocol for measurement of sleep and PVT performance is analogous to the protocols of those used in prior investigations of sleep patterns of shift workers (or simulated shift work) in the operational and laboratory setting.[25,77]

One of our objectives was to capture PVT assessments for each participant at the start and end for a minimum of one scheduled shift. Although we believe the brief 3-min version of the PVT was justified on scientific and operational grounds, longer versions of the PVT (eg, 5-min or 10-min) may be more sensitive to fatigue in this occupational setting. Our research provides useful information regarding the relationship between shift duration and reaction time as measured by the PVT-B. Our study is but one of many needed to assess the impact of shift duration on cognitive as well as psychomotor performance in the time and safety sensitive air-medical environment. Future research involving air-medical EMS clinicians should consider using the 5-min and/or 10-min PVT and other tests.

Regarding the completeness of our data, we acquired complete PVT test data at the start and end of shift for 90% of the 138 total participations. Given the challenges with field research, we view this proportion as positive. The most common reasons for failing to acquire a PVT at the start or end of shift were: (1) the air-medical clinician was dispatched on a patient transport, preventing capture of the PVT proximal to shift start or end and (2) the participant forgot to complete the test. Lessons learned from this study may be useful for future protocols and improve the capture of complete data.

While air-medical clinicians traditionally work shifts of 12 or 24 h in duration, shifts may be shorter or go beyond the scheduled duration. Common reasons for alterations in shift duration include: arriving to work early, leaving work early, being held over due to a prolonged patient transport or late dispatch, a pre-shift meeting, or post-shift meeting. Few shifts documented in this study were <12 h (6%), few (1%) were ≥16 h yet <24 h, and few (1%) were documented as >24 h. Most shifts were, > = 12 h and <16 h (48%) or exactly 24 h (45%).

Because it is rare that air-medical shifts are scheduled for <12 h, shifts within a few hours of 12 h (eg, 10 h or 14-16 h) are most often the result of the crewmember needing to arrive to work early or if staying late, there was a late dispatch and transport). Similar to previous research,[58] we a priori grouped shifts into the primary shift categories common in EMS; <24 h if the shift was <12 h or >12 h and <16 h, and as 24 h if the shift was ≥16 h. We believe that our a-priori approach of shift categorization (<24 h and 24 h) will aid in the interpretation of study findings by administrators who are responsible for operational decisions and medical directors who are responsible for clinical care protocols. However, we addressed concerns about our a priori approach and performed analyses isolated to shifts documented as exactly 12 h and exactly 24 h in duration. We performed these with data from each participant's first participation. Findings are analogous to those reported in Supplemental Tables IVd to IVf with all shifts classified with the a priori approach outlined above.

We did not collect data on participant use of stimulants, such as caffeine. Use of stimulants before or during shifts may have impacted the results.[78] Future studies that measure use of caffeine and/or other stimulants may shed light on their role in the relationship between shift duration and alertness among air-medical clinicians.

6 | CONCLUSIONS

While in this study we detected no differences in alertness by shift duration, participants that worked night shifts may perform worse on select PVT outcome measures than participants that work day shifts. Our findings show deficits in PVT performance when PVTs are taken proximal to waking from an intra-shift nap. Future research should examine alertness and performance throughout air-medical shifts, as well as investigate the timing and duration of intra-shift naps on outcomes.

AUTHORS' CONTRIBUTIONS

PDP, CGM, FXG, JMD, HAW, DS, DH, JL, DJB contributed to the conception of the design of this research. Authors PDP, FXG, JMD, DJS, HAW, DS, DH, JL LR, LH, and KS contributed to the acquisition of study data. PDP, MDW, MAM, CGM, MAT, NLR, and DJB contributed to the analysis of study data. All authors contributed to the interpretation of study findings, drafting of manuscript, and providing intellectual content. All authors reviewed and approved the final version and agree to be accountable for all aspects of the reported research.

ACKNOWLEDGMENTS

Authors wish to acknowledge the grants administrators and research administrators at each institution for their assistance. Authors also wish to acknowledge the study participants for their voluntary participation and contribution to the science on fatigue and shift work in emergency care settings.

FUNDING

Work on this research study was supported by a grant from the MedEvac Foundation (www.medevacfoundation.org).

ETHICS APPROVAL AND INFORMED CONSENT

This research study received approval from four Institutional Review Boards (IRBs): (1) The University of Pittsburgh IRB; (2) Carolinas HealthCare System IRB; (3) Ohio State University IRB; and (4) University at Buffalo, The State University of New York IRB. All participants gave written informed consent.

DISCLOSURE (AUTHORS)

Authors report no conflicts of interest.

DISCLOSURE BY AJIM EDITOR OF RECORD

Paul Landsbergis declares that he has no conflict of interest in the review and publication decision regarding this article.

DISCLAIMERS

None.

ORCID

P. Daniel Patterson http://orcid.org/0000-0002-8189-0919

REFERENCES

1. Lockley SW, Barger LK, Ayas NT, et al. Effects of health care provider work hours and sleep deprivation on safety and performance. *Jt Comm J Qual Patient Saf*. 2007;33:7–18.
2. Reid K, Dawson D. Comparing performance on a simulated 12 hour shift rotation in young and older subjects. *Occup Environ Med* 2001;58:58–62.
3. Akerstedt T. Psychological and psychophysiological effects of shift work. *Scand J Work Environ Health*. 1990;16:67–73.
4. Rogers AE. 2008. *Chapter 40: The Effects of Fatigue and Sleepiness on Nurse Performance and Patient Safety*. Rockville, MD: Agency for Healthcare Research and Quality. pp. 08–0043.
5. Lim J, Dinges DF. Sleep deprivation and vigilant attention. *Ann N Y Acad Sci* 2008;1129:305–322.
6. Lathrop GM, Thomson DP. Should 24-hour shifts be allowed? *Air Med J*. 1997;3:8, 10–12.
7. Frakes MA, Kelly JG. Sleep debt and outside employment patterns in helicopter air medical staff working 24-hour shifts. *Air Med J* 2007;26: 45–49.
8. Guyette FX, Morley JL, Weaver MD, Patterson PD, Hostler D. The effect of shift length on fatigue and cognitive performance in air medical providers. *Prehosp Emerg Care*. 2013;17:23–28.
9. Patterson PD, Higgins JS, Van Dongen HPA, et al. Evidence-Based guidelines for fatigue risk management in emergency medical services. *Prehosp Emerg Care*. 2018;22:89–101.

10. Manacci C, Rogers K, Martin G, et al. Efficacy of 24-hour shifts: prepared or impaired? A prospective study. *Air Med J*. 1999;18: 20–25.
11. Allen TL, Delbridge TR, Stevens MH, Nicholas D. Intubation success rates by air ambulance personnel during 12-versus 24-hour shifts: does fatigue make a difference? *Prehosp Emerg Care*. 2001;5:340–343.
12. Thomas F, Hopkins RO, Handrahan DL, Walker J, Carpenter J. Sleep and cognitive performance of flight nurses after 12-hour evening versus 18-hour shifts. *Air Med J* 2006;25:216–225.
13. Patterson PD, Runyon MS, Higgins JS, et al. Shorter versus longer shift duration to mitigate fatigue and fatigue related risks in Emergency Medical Services: a systematic review. *Prehosp Emerg Care*. 2018;22: 28–36.
14. Blau R. Bronx woman critically injured in ambulance crash after surviving seven-hour brain surgery; family alleges she was not strapped in properly. 2015; http://www.nydailynews.com/new-york/bronx-woman-brain-dead-ambulance-crash-article-1.2143628. New York Daily News. New York, NY. Last Updated: March 10, 2015. Accessed February 15, 2016.
15. Stevens T. EMT injured after ambulance driver falls asleep on I–81. 2015; http://www.roanoke.com/news/crime/roanoke_county/emt-injured-after-ambulance-driver-falls-asleep-on-i/article_56113003-88c0-5d00-9dfb-37847bc865b6.html. The Roanoke Times. Roanoke, VA. Last Updated: Accessed February 15, 2016.
16. Staff E. Medic falls asleep at wheel, crashes ambulance: The ambulance was reportedly completely destroyed in the incident. 2013; https://www.ems1.com/ambulances-emergency-vehicles/articles/1414503-Medic-falls-asleep-at-wheel-crashes-ambulance/. EMS1. Last Updated: Accessed February 15, 2016.
17. NEMSAC. Fatigue in Emergency Medical Services. National EMS Advisory Council Quarterly Meeting 2013; http://ems., gov/pdf/nemsac/2013/NEMSAC-AdvisoryFatigueJan2013., pdf. Department of Transportation Office of EMS. Washington, DC. Last Updated: January 30, 2013.
18. Shine K. Mishawaka paramedic dies after ambulance hits car. 2018; http://www.wndu.com/content/news/Mishawaka-EMT-dies-after-ambulance-hits-car-470528113.html. WNDU News 16. Miami County, Indiana. Last Updated: January 22, 2018. Accessed January 30, 2018, 2018.
19. Patterson PD, Weaver MD, Hostler D. EMS provider wellness. In: Cone D Brice JH Delbridge T Myers B, editors. *Emergency Medical Services: Clinical Practice and Systems Oversight*. Vol 2. Chichester, West Sussex; Hoboken: John Wiley & Sons, Inc.: 2015; 211–216.
20. Patterson PD, Buysse DJ, Weaver MD, Callaway CW, Yealy DM. Recovery between work shifts among Emergency Medical Services clinicians. *Prehosp Emerg Care*. 2015;19:365–375.
21. Mears G, Armstrong B, Fernandez AR, et al. National EMS Assessment. 2011; http://www.ems.gov/pdf/2011/National_EMS_Assessment_Final_Draft_12202011.pdf. University of North Carolina at Chapel Hill; National Association of State EMS Officials; University of Utah School of Medicine; Critical Illness and Trauma Foundation. Chapel Hill, NC; Falls Church, VA; Salt Lake City, UT; Bozeman, MT. Last Updated.
22. Weaver MD, Patterson PD, Fabio A, et al. An observational study of shift length, crew familiarity, and occupational injury and illness in emergency medical services workers. *Occup Environ Med*. 2015;72: 798–804.
23. Van Dongen HP, Maislin G, Mullington JM, Dinges DF. The cumulative cost of additional wakefulness: dose-response effects on neurobehavioral functions and sleep physiology from chronic sleep restriction and total sleep deprivation. *Sleep* 2003;26:117–126.
24. Dinges DF, Pack F, Williams K, et al. Cumulative sleepiness, mood disturbance, and psychomotor vigilance performance decrements during a week of sleep restricted to 4–5 hours per night. *Sleep* 1997;20:267–277.
25. Magee M, Sletten TL, Ferguson SA, et al. Associations between number of consecutive night shifts and impairment of neurobehavioral performance during a subsequent simulated night shift. *Scand J Work Environ Health* 2016;42:217–227.
26. Zhou X, Ferguson SA, Matthews RW, et al. Mismatch between subjective alertness and objective performance under sleep restriction is greatest during the biological night. *J Sleep Res*. 2012;21: 40–49.
27. Boivin DB, Boudreau P. Impacts of shift work on sleep and cricadian rhythms. *Pathol Biol (Paris)* 2014;62:292–301.
28. Rajaratnam SM, Arendt J. Health in a 24-h society. *Lancet*. 2001;358: 999–1005.
29. Kim HS, Yoon KH, Cho JH. Diurnal heart rate variability fluctuations in normal volunteers. *J Diabetes Sci Technol*. 2014;8:431–433.
30. Kitamura T, Onishi K, Dohi K, et al. Circadian rhythm of blood pressure is transformed from a dipper to a non-dipper pattern in shift workers with hypertension. *J Hum Hypertens*. 2002;16: 193–197.
31. Van Someren EJ. More than a marker: interaction between the circadian regulation of temperature and sleep, age-related changes, and treatment possibilities. *Chronobiol Int* 2000;17: 313–354.
32. Jung CM, Khalsa SB, Scheer FA, et al. Acute effects of bright light exposure on cortisol levels. *J Biol Rhythms*. 2010;25:208–216.
33. James FO, Cermakian N, Boivin DB. Circadian rhythms of melatonin, cortisol, and clock gene expression during simulated night shift work. *Sleep* 2007;30:1427–1436.
34. Schultes B, Schmid S, Peters A, Born J, Fehm HL. Sleep loss and the development of diabetes: a review of current evidence. *Exp Clin Endocrinol Diabetes*. 2005;113:563–567.
35. Spiegel K, Leproult R, Van Cauter E. Impact of sleep debt on metabolic and endocrine function. *Lancet* 1999;354:1435–1439.
36. Copinschi G. Metabolic and endocrine effects of sleep deprivation. *Essent Psychopharmacol*. 2005;6:341–347.
37. Van Cauter E, Spiegel K, Tasali E, Leproult R. Metabolic consequences of sleep and sleep loss. *Sleep Med* 2008:S23–S28.
38. Meier-Ewert HK, Ridker PM, Rifai N, et al. Effect of sleep loss on C-reactive protein, an inflammatory marker of cardiovascular risk. *J Am Coll Cardiol*. 2004;43:678–683.
39. van Leeuwen WM, Lehto M, Karisola P, et al. Sleep restriction increases the risk of developing cardiovascular diseases by augmenting proinflammatory responses through IL-17 and CRP. *PLoS ONE* 2009;4:e4589.
40. Braude D, Goldsmith T, Weiss SJ. Assessing air medical crew real-time readiness to perform critical tasks. *Prehosp Emerg Care*. 2011;15: 254–260.
41. Thomas F, Hopkins RO, Handrahan DL, Walker J, Caprenter J. Sleep and cognitive performance of flight nurses after 12-hour evening versus 18-hour shifts. *Air Med J* 2006;25:216–225.
42. Dorrian J, Baulk SD, Dawson D. Work hours, workload, sleep and fatigue in Australian Rail Industry employees. *Appl Ergon*. 2011;42: 202–209.
43. Ancoli-Israel S, Cole R, Alessi C, et al. The role of actigraphy in the study of the sleep and circadian rhythms. *Sleep*. 2003;26:342–392.
44. Buysse DJ, Reynolds CFr, Monk TH, Berman SR, Kupfer DJ. The Pittsburgh Sleep Quality Index: a new instrument for psychiatric practice and research. *Psychiatry Res*. 1989;28:193–213.
45. Johns MW. A new method for measuring daytime sleepiness: the Epworth sleepiness scale. *Sleep*. 1991;14:540–545.
46. Chalder T, Berelowitz G, Pawlikowska T, et al. Development of a fatigue scale. *J Psychosom Res*. 1993;37:147–153.
47. 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*. 2005;47:594–606.

48. Balkin TJ, Bliese PD, Belenky G, et al. Comparative utility of instruments for monitoring sleepiness-related performance decrements in the operational environment. *J Sleep Res*. 2004;13:219–227.
49. Basner M, Mollicone D, Dinges DF. Validity and sensitivity of a brief psychomotor vigilance test (PVT-B) to total and partial sleep deprivation. *Acta Astronaut*. 2011;69:949–959.
50. Basner M, Hermosillo E, Nasrini J, et al. Repeated administration effects on psychomotor vigilance test performance. *Sleep*. 2018;41: zsx187.
51. Roach GD, Dawson D, Lamond N. Can a shorter psychomotor vigilance task be used as a reasonable substitute for the ten-minute psychomotor vigilance task? *Chronobiol Int*. 2006;23:1379–1387.
52. Basner M, Dinges DF. Maximizing sensitivity of the psychomotor vigilance test (PVT) to sleep loss. *Sleep*. 2011;34:581–591.
53. Shiffman S, Stone AA, Hufford MR. Ecological momentary assessment. *Annu Rev Clin Psychol*. 2008;4:1–32.
54. Stone AA, Shiffman S, Atienza AA, Nebeling L. Historical roots and rationale of ecological momentary assessment (EMA). In: Stone AA Shiffman S Atienza AA Nebeling L, eds. *The Science of REAL-TIME Data Capture: Self-Reports in Health Research*. Oxford, NY: Oxford University Press, Inc.; 2007: 3–10.
55. Buysse DJ, Thompson W, Scott J, et al. Daytime symptoms in primary insomnia: a prospective analysis using ecological momentary assessment. *Sleep Med*. 2007;8:198–208.
56. Choi L, Liu Z, Matthews CE, Buchowski MS. Validation of accelerometer wear and nonwear time classification algorithm. *Med Sci Sports Exerc*. 2011;43:357–364.
57. Geiger-Brown J, Rogers VE, Trinkoff AM, et al. Sleep, sleepiness, fatigue, and performance of 12-hour-shift nurses. *Chronobiol Int* 2012;29:211–219.
58. Patterson PD, Buysse DJ, Weaver MD, et al. Real-Time fatigue reduction in emergency care clinicians: the SleepTrackTXT randomized trial. *Am J Ind Med*. 2015;58:1098–1113.
59. Anderson C, Sullivan JP, Flynn-Evans EE, et al. Deterioration of neurobehavioral performance in resident physicians during repeated exposure to extended duration work shifts. *Sleep*. 2012;35: 1137–1146.
60. Ruggiero JS, Redeker NS. Effects of napping on sleepiness and sleep-related performance deficits in night-shift workers: a systematic review. *Biol Res Nurs*. 2014;16:134–142.
61. Martin-Gill C, Barger LK, Moore CG, et al. Effects of napping during work on sleepiness and performance in Emergency Medical Services personnel and similar shift workers: a systematic review and meta-analysis. *Prehosp Emerg Care*. 2018;22:47–57.
62. Oriyama S, Miyakoshi Y. The effects of nighttime napping on sleep, sleep inertia, and performance during simulated 16h night work: a pilot study. *J Occup Health*. 2018;60:172–181.
63. Scheer FA, Shea TJ, Hilton MF, Shea SA. An endogenous circadian rhythm in sleep inertia results in greatest cognitive impairment upon awakening during the biological night. *J Biol Rhythms*. 2008;23: 353–361.
64. Purnell MT, Feyer AM, Herbison GP. The impact of a nap opportunity during the night shift on the performance and alertness of 12-h shift workers. *J Sleep Res*. 2002;11:219–227.
65. Smith SS, Kilby S, Jorgensen G, Douglas JA. Napping and nightshift work: effects of a short nap on psychomotor vigilance and subjective sleepiness in health workers. *Sleep & Biological Rhythms*. 2007;5:117–125.
66. Lovato N, Lack L, Ferguson SJ, Tremaine R. The effects of a 30-min nap during night shift following a prophylactic sleep in the afternoon. *Sleep & Biological Rhythms*. 2009;7:34–42.
67. Vosko AM, Colwell CS, Avidan AY. Jet lag syndrome: circadian organization, pathophysiology, and management strategies. *Nat Sci Sleep*. 2010;2:187–198.
68. Goal N, Van Dongen HPA, Dinges DF. Circadian rhythms in sleepiness, alertness, and performance. In: Kryger MH Roth T Dement WC, eds. *Principles and Practice of Sleep Medicine*. Fifth Edition ed. St. Louis, Missouri: Elsevier; 2011: 445–455.
69. Bliwise DL. Normal aging. In: Kryger MH Roth T Dement WC, eds. *Principles and Practice of Sleep Medicine*. St. Louis, Missouri: Elsevier; 2011: 27–41.
70. Vyas MV, Garg AX, Iansavichus AV, et al. Shift work and vascular events: systematic review and meta-analysis. *BMJ*. 2012;345:e4800.
71. van Drongelen A, Boot CR, Merkus SL, Smid T, van der Beek AJ. The effects of shift work on body weight change—a systematic review of longitudinal studies. *Scand J Work Environ Health* 2011;37:263–275.
72. Pan A, Schernhammer ES, Sun Q, Hu FB. Rotating night shift work and risk of type 2 diabetes: two prospective cohort studies in women. *PLoS Med*. 2011;12:e1001141.
73. Patterson PD, Suffoletto BP, Kupas DF, Weaver MD, Hostler D. Sleep quality and fatigue among prehospital providers. *Prehosp Emerg Care*. 2010;14:187–193.
74. Patterson PD, Weaver MD, Frank RC, et al. Association between poor sleep, fatigue, and safety outcomes in emergency medical services providers. *Prehosp Emerg Care*. 2012;16:86–97.
75. Patterson PD, Buysse DJ, Weaver MD, et al. Emergency healthcare worker Sleep, Fatigue, and Alertness Behavior survey (SFAB): Development and content validation of a survey tool. *Accid Anal Prev*. 2014;73C:399–411.
76. Yi WS, Hafiz S, Sava JA. Effects of night-float and 24-h call on resident psychomotor performance. *J Surg Res*. 2013;184:49–53.
77. Gander P, Millar M, Webster C, Merry A. Sleep loss and performance of anaesthesia trainees and specialists. *Chronobiol Int*. 2008;25: 1077–1091.
78. Temple JL, Hostler D, Martin-Gill C, et al. Systematic review and meta-analysis of the effects of caffeine in fatigued shift workers: implications for emergency medical services personnel. *Prehosp Emerg Care* 2018;22:37–46.

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

How to cite this article: Patterson PD, Weaver MD, Markosyan MA, et al. Impact of shift duration on alertness among air-medical emergency care clinician shift workers. *Am J Ind Med*. 2019;62:325–336. https://doi.org/10.1002/ajim.22956