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Benchmarking Fatigue in United States Helicopter Air Ambulance Pilots

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12. Abstract Helicopter air ambulance (HAA) pilots are exposed to fatigue risk due to on-call and shiftwork operations required for 24-hour emergency service. The current field study aimed to provide a benchmark for fatigue in US HAA operations to inform future fatigue management strategies. US HAA pilots working 7-days-on, 7-days-off schedules were invited to participate in a field study. Data collection included 3 days Pre-hitch, a 7-day Duty Period (hitch), and 3 days Post-hitch (recovery) and involved reaction time tests, subjective sleepiness and fatigue ratings, workload ratings, and actigraphy to estimate sleep metrics. Pilots (N = 120, from 21 US HAA companies) working either daytime, nighttime, or mixed (e.g., 3 days followed by 4 nights) schedules completed an initial survey followed by 13 days of data collection during normal operations. The current study found that: (i) half of the HAA pilots surveyed have poor quality sleep; (ii) cumulative fatigue builds across a 7-day hitch, affecting performance on all schedule types; (iii) pilot subjective fatigue and sleepiness ratings remained consistent, even when objective measures of performance worsened; (iv) pilots obtain less sleep during a hitch than on days off on all schedule types, despite taking extra naps during night duties; (v) fatigue accumulates faster across a duty period for night and mixed schedules compared to day schedules; (vi) fatigue accumulated across a hitch persists into recovery days; (vii) circadian disruptions associated with flight requests and subsequent trips operated during periods of low circadian alertness negatively impact performance; and (viii) pilots experience sleep inertia effects (reduced alertness) when woken up by a flight request. Altogether, these results offer the most comprehensive assessment of US HAA pilot fatigue since the introduction of updated HAA regulations in 2014 and offer a number of potential fatigue mitigation opportunities for the industry.			
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List of Abbreviations

AMOA	Air Medical Operators Association
EMS	Emergency Medical Services
ESS	Epworth Sleepiness Scale
FAA	Federal Aviation Administration
HAA	Helicopter air ambulance
KSS	Karolinska Sleepiness Scale
MEQ	Morningness-Eveningness Questionnaire
NASA	National Aeronautics and Space Administration
NASA-TLX	NASA Task Load Index
NEMSPA	National EMS Pilots Association
OCC	Operational control center
PSQI	Pittsburgh Sleep Quality Index
PVT	Psychomotor Vigilance Task
SD	Standard deviation
SE	Standard error
SP	Samn-Perelli Fatigue Scale
US	United States
WOCL	Window of circadian low

Executive Summary

Helicopter air ambulance (HAA) pilots are exposed to fatigue risk due to on-call and shiftwork operations required for 24-hour emergency service. Previous research on fatigue in HAA operations has largely focused on European operators, many of whom operate through state-run emergency service providers. Most HAA services in the United States (US) instead operate as private companies, with a variety of company policies and environments that could differentially affect pilot fatigue. The current field study aimed to provide a benchmark for fatigue in US HAA operations to inform future fatigue management strategies.

US HAA pilots working 7-days-on, 7-days-off schedules were invited to participate in a field study. Data collection included 3 days Pre-hitch, a 7-day Duty Period (hitch), and 3 days Post-hitch (recovery) and involved reaction time tests, subjective sleepiness and fatigue ratings, workload ratings, and actigraphy to estimate sleep metrics. Pilots (N = 120, from 21 US HAA companies) working either daytime, nighttime, or mixed (e.g., 3 days followed by 4 nights) schedules completed an initial survey followed by 13 days of data collection during normal operations.

The current study found that:

- (i) half of the HAA pilots surveyed have poor quality sleep;
- (ii) cumulative fatigue builds across a 7-day hitch, affecting performance on all schedule types;
- (iii) pilot subjective fatigue and sleepiness ratings remained consistent across the hitch, even when objective measures of performance worsened;
- (iv) pilots obtain less sleep during a hitch than on days off on all schedule types, despite taking extra naps during night duties;
- (v) fatigue accumulates faster across a duty period for night and mixed schedules compared to day schedules;
- (vi) fatigue accumulated across a hitch persists into recovery days;
- (vii) circadian disruptions associated with flight requests and subsequent trips operated during periods of low circadian alertness negatively impact performance; and
- (viii) pilots experience sleep inertia effects (reduced alertness) when woken up by a flight request.

Altogether, these results offer the most comprehensive assessment of US HAA pilot fatigue since the introduction of updated HAA regulations in 2014 and offer a number of potential fatigue mitigation opportunities for the industry.

Our results are limited to 7-day on/7-day off 12-hour duty schedules but suggest that extending the duty period beyond 7 days or reducing the recovery period to less than 7 days may result in significant further increases to fatigue and would require additional fatigue mitigation strategies.

Specific recommendations to operators that stem from this work include considering the following factors as part of pre-flight risk assessments:

- Whether flights occur during the window of circadian low (WOCL, 0200 – 0600), and reschedule non-time sensitive requests;
- Whether the pilot just woke up (i.e., may be suffering from sleep inertia), and provide extra time before the pilot engages in safety-critical tasks;
- How many days a pilot has been on duty, as performance significantly worsens by day 4 of a duty period; and
- How many previous flight requests have been accepted during a night duty, given that >3 trips were noted as potentially fatiguing (although objective data are needed to confirm these reports).

1. Introduction

Pilot fatigue risks in helicopter air ambulance (HAA) operations are an important safety consideration due to the on-call nature and shiftwork required for 24-hour emergency medical service (EMS) (Baumgartner et al., 2023). The International Civil Aviation Organization (ICAO) defines fatigue as:

> *"A physiological state of reduced mental or physical performance capability resulting from sleep loss, extended wakefulness, circadian phase, and/or workload (mental and/or physical activity) that can impair a person's alertness and ability to perform safety related operations"* (ICAO, 2020, pg. xi).

Previous research on fatigue in HAA operations has been focused on European operators, many of whom operate through state-run emergency service providers (Flaa et al., 2019; 2021; 2022). HAA services in the United States (US) instead operate as private companies, with a variety of company policies and environments that could differentially affect pilot fatigue. Indeed, a recent study indicated that fatigue may be an issue for on-duty US HAA pilots (Haber Kamine et al., 2022). Further, Baumgartner et al. (2023) identified various human factors issues in HAA operations, including fatigue, stress, human error, and perceived pressure to take a flight request. Based on an assessment of HAA schedules provided by four different operators, we have identified three leading factors of fatigue to investigate within US HAA operations as a fatigue risk benchmark: cumulative fatigue (sleep debt), circadian disruptions, and sleep inertia.

1.1 Cumulative Fatigue

Cumulative fatigue refers to fatigue from accumulated sleep debt, or sleep loss that occurs over multiple days of insufficient sleep. The body has a homeostatic need for sleep that accumulates across continuous hours of wakefulness. If adequate sleep is not acquired, or repeated sleep loss is experienced across multiple days, behavioral alertness and performance will degrade (Åkerstedt et al., 2021; Flynn-evans et al., 2018; Van Dongen, et al., 2003). Within HAA operations, pilots who work long duty hours and consecutive duty blocks, such as those in 7-day on/7-day off 12-hour shifts, may face fatigue risk that increases throughout the workweek. Even dayshift workers may experience an accumulation of fatigue due to limited opportunity for sleep between consecutive duties, given other factors such as commute time cutting into time off. Pilots working the night shift may be at even greater risk of cumulative fatigue because their rest opportunities between duties occur at times that are adverse to quality sleep, leading to a more rapid accumulation of sleep debt.

1.2 Circadian Disruption

Human sleep patterns are largely influenced by a physiological circadian rhythm that promotes sleep and wakefulness at different points throughout a 24-hour period. Shiftwork, particularly when changing a shift schedule from daytime to nighttime, or *vice versa*, may a) shift opportunities for sleep to and b) create demands for wakefulness at times that are not in line with these innate circadian rhythms, leading to a misalignment or circadian disruption. Operations involving night shift or on-call work, by their nature, often induce circadian disruptions and, thus, put workers at a higher risk of fatigue than standard daytime shifts.

Therefore, in HAA operations, pilots who work the night shift may have limited opportunity for sleep during their normal sleeping periods and may be required to operate at times of low alertness relative to day-shift pilots. Operations may be particularly challenging when they occur during the window of circadian low (WOCL), which spans approximately 0200-0600 for most individuals, when alertness is least promoted physiologically (FAA AC 117-3; Dinges et al., 1996).

1.3 Sleep Inertia

While sleep alleviates the cognitive and physical detriments caused by sleep loss, the time immediately following awakening often coincides with a temporary period of grogginess called sleep inertia (see Hilditch & McHill, 2019, for a review). This short yet salient period coincides with reduced alertness and associated cognitive performance impairment (Burke et al., 2015). Further, while sleep inertia can occur following any sleep period (Wertz et al., 2006; Hilditch et al., 2016), it is often worsened by other co-occurring fatigue risks, such as cumulative sleep loss (McHill et al., 2019), or waking during the physiological night (Scheer et al., 2008). Note that these exacerbating fatigue factors are also the two identified as potential issues in HAA (sections 1.1 and 1.2), suggesting that the sleep inertia symptoms experienced by HAA pilots may be at a higher risk of greater severity and/or longer duration. Sleep inertia symptoms typically resolve within 20 minutes but may last up to an hour (Jewett et al., 1999). Safety-critical work performed soon after waking is, therefore, at risk of impaired performance due to sleep inertia and may contribute to accidents and errors (Hilditch & McHill, 2019). The experience of sleep inertia may vary across individuals (Hilditch et al., 2023a; Lundholm et al., 2021), and self-recognition of performance impairment during this period is not always accurate (Hilditch et al., 2016).

Decision-making has been shown to be negatively affected by sleep inertia in tasks replicating real-world challenges, such as fire management (Bruck & Pisani, 1999) and tactical planning (Horne & Moseley, 2011). For HAA pilots, the risk of sleep inertia is particularly relevant due to the on-call nature of work. Pilots working the night shift will likely use sleep opportunities available to them, only to be awakened by a call that they must respond to rapidly (Fletcher et al., 2022; Zakariassen et al., 2019; Gupta et al., 2022). For example, the decision to accept or reject a flight request can be impacted by sleep inertia, and the likelihood of committing a mathematical error may become inflated during the sleep inertia period (Wertz et al., 2006). Moreover, HAA crews have goals to launch as quickly as possible after receiving a flight request; sometimes pilots may be in the aircraft less than 10 minutes after receiving the flight request. Sleep inertia is a risk factor that may impact the pilot's pre-flight and in-flight performance in these cases.

1.4 Purpose

The objective of this research is to characterize the current state of fatigue in US HAA operations and benchmark risk for previously identified fatigue factors: cumulative fatigue, circadian disruptions, and sleep inertia. While separate analyses will probe the relative independent influence of these factors, we are also interested in the interaction of these factors (e.g., how circadian disruption interacts with cumulative fatigue). A field study was conducted in which HAA pilots performed their normally scheduled duties and flights in response to EMS requests. Specifically, the focus of this analysis includes factors that may contribute to pilot cognitive performance, fatigue ratings, sleepiness ratings, workload ratings, and sleep metrics in separate statistical models. This research aims to provide empirical data to inform Flight Standards personnel who update FAA regulatory and guidance material to improve the strategic use of rest facilities and fitness for duty requirements in HAA operations.

1.5 Research Questions

Q1. Cumulative fatigue: How do consecutive duty days affect outcome measures?

Q1A) Do sleep, sleepiness, fatigue, and performance indicators change across consecutive days on-duty, and does this differ between daytime, nighttime, and mixed schedule types due to circadian disruptions?

Q2. Circadian Disruption: How do night duties affect outcome measures?

Q2A) Do sleep, sleepiness, fatigue, and performance indicators change between baseline (Pre-hitch), Duty Period days, and recovery (Post-hitch), and does this differ between daytime, nighttime, and mixed schedule types?

Q2B) Do sleep, sleepiness, fatigue, workload, and performance indicators differ between WOCL and non-WOCL trips that occur during night duties?

Q3. Sleep inertia: How does being awoken for a flight request affect outcome measures?

Q3A) Do subjective sleepiness and fatigue ratings differ between being awoken by a flight request versus already being awake for trips that occur during night duties?

2. Materials and Methods

2.1 Participants

A total of 205 (*n* = 10 female) actively certified US HAA pilots, maintaining a 7-day-on / 7-day-off schedule, applied to participate in this study. A 7-day period of work is known as a “hitch”. Data collection occurred during regularly scheduled 12-hour duty days that occurred during daytime (typically ~0700 – 1900), nighttime (typically ~1900 – 0700), or mixed schedule types. Mixed schedule types included pilots who worked a combination of 3-daytime followed by 4-nighttime duty days, or pilots who worked 4-nighttime followed by 3-daytime duty days. Pilots working daytime or nighttime schedule types alternate on these schedules every other hitch, while mixed schedule types work permanently on mixed hitches. Participating pilots came from 21 separate HAA operators for adequate representation of the industry. Pilots were recruited through advertisements on social media, through operators in the Air Medical Operators Association (AMOA), through the National Emergency Medical Services Pilots Association (NEMSPA), and through talks at industry events. Pilots were eligible if they were actively employed by a US HAA operator with one of the required hitch schedules. All procedures were approved in advance by the FAA Civil Aerospace Medical Institute Institutional Review Board (Study #202414).

2.2 Procedures & Materials

After an initial screening for a qualifying schedule, pilots were shipped a package that contained an informed consent document, a wrist actigraphy device (MotionWatch 8, CamNtech Ltd.), and an Apple iPad mini (6^{th} generation, iOS version 17.3.1) and charger.

Before data collection, pilots provided informed consent and underwent virtual training on study procedures (Day 0; Figure 1). During this session, pilots completed an initial demographic questionnaire that included baseline questions about their HAA operator, perceptions about fatigue, and work history. Additionally, pilots completed the Morningness-Eveningness Questionnaire (MEQ; Horne & Östberg, 1976), Epworth Sleepiness Scale (ESS; Johns, 1991), Pittsburgh Sleep Quality Index (PSQI; Bussye et al., 1989), and the NASA Task Load Index (pairwise comparisons) (TLX; Hart & Staveland, 1988).

Pilots wore an actigraphy device, completed questionnaires, and performed a validated 5-minute Psychomotor Vigilance Task (PVT; Arsintescu et al., 2019a; Arsintescu et al., 2017) at designated times of the day for a total of 13 days across three phases of the study. This included 3 days of data collection before their scheduled hitch (i.e., 7-day Hitch) for baseline data (Pre-Hitch, Days 1-3), 7 days of data collection during their scheduled hitch (Hitch, Days 4-10), and 3 days of data collection for recovery data (Post-Hitch, Days 11-13). At the end of Day 13, pilots also completed a post-study questionnaire.

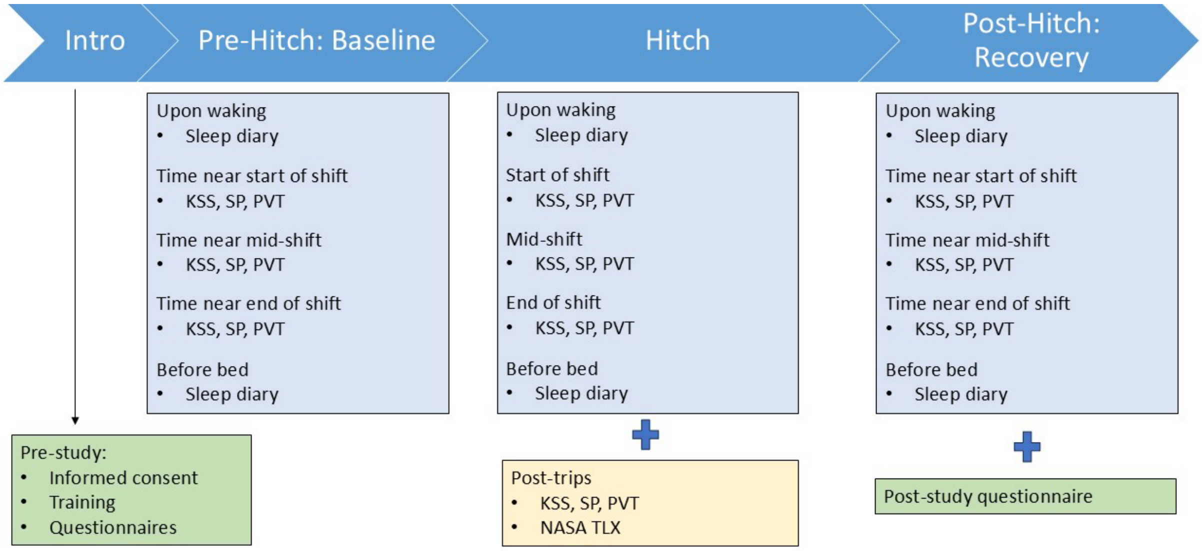

Figure 1. Phases of study timeline

Note. KSS = Karolinska Sleepiness Scale; SP = Samn-Perelli fatigue scale; PVT = Psychomotor Vigilance Task.

On every day of data collection (Days 1-13), pilots completed sleep diaries, Karolinska Sleepiness Scales (KSS), and Samn-Perelli (SP) fatigue ratings through Qualtrics survey software (Provo, UT), and PVTs through the NASA PVT+ application at designated times throughout the day. These included a sleep diary upon waking and before bed, and KSS, SP, and PVTs at the start time of their scheduled duty (e.g., 0700 or 1900), near the mid-point of their scheduled duty (e.g., 1300 or 0100), and at the end of their scheduled duty (e.g., 1900 or 0700), even during off-duty days. Pilots who were scheduled for nighttime duties were asked to complete the mid-duty surveys as close to mid-point as possible without waking unnecessarily, especially during off-duty days. While on duty, pilots were additionally asked to complete a PVT, KSS, SP, and NASA-TLX immediately after returning from a trip. A trip was defined as the collection of flights performed in response to an initial flight request. During this post-trip questionnaire, pilots were asked to retrospectively complete a KSS and SP based on their pre-trip status (i.e., how did they feel when they received the flight request), as well as rating their current post-trip status (i.e., how do they feel after returning from the trip).

2.3 Psychomotor Vigilance Task (PVT)

Throughout data collection, pilots completed the Simple PVT in the NASA PVT+ application (version 1.4.6-B2499; Arsintescu et al., 2019b). PVT data were exported from the NASA PVT+ application following data collection. Per our laboratory's standards, PVTs that did not meet 35 valid trials were marked as not finishing. Also, PVTs that had 4+ distractions, had >3x the standard deviation of false starts, and/or had a maximum stimulus reaction time greater than 10 seconds were excluded from PVT analyses. A latency correction of 59.375 ms was applied after consulting the NASA PVT+ user guide (Arsintescu, Mulligan, & Flynn-Evans, 2017). While no latency validations have been completed for the current device (6th generation iPad mini running iOS version 17.3.1), the average latency between the two closest devices (iPhone 11 iOS version 16.1.1 and iPad 13 iOS version 18) was used (NASA, 2025). Metrics from PVT analysis included response speed (1000/reaction time) and number of lapses (responses with reaction time >500 ms; Arsintescu et al., 2019a).

2.4 Karolinska Sleepiness Scale (KSS)

The Karolinska Sleepiness Scale (KSS) is a subjective measure of sleepiness commonly used in aviation studies that has been validated against objective measures of sleepiness such as electroencephalography and slow rolling eye movements (Åkerstedt & Gillberg, 1990; Arsintescu et al., 2019a; Kaida et al., 2006). The scale includes: 1 = Extremely alert; 2 = Very alert; 3 = Alert; 4 = Rather alert; 5 = Neither alert nor sleepy; 6 = Some signs of sleepiness; 7 = Sleepy, but no effort to keep awake; 8 = Sleepy, some effort to keep awake; and 9 = Very sleepy, great effort to keep awake, fighting sleep.

2.5 Samn-Perelli Fatigue Scale (SP)

The SP fatigue scale is a well-validated subjective fatigue measure commonly found in shiftwork research (Arsintescu et al., 2019a; Dorrian et al., 2011; Gander et al., 2014; Samn & Perelli, 1982). The scale includes: 1 = Fully alert. Wide awake. Extremely peppy; 2 = Very lively. Responsive, but not at peak; 3 = Okay. Somewhat fresh; 4 = A little tired. Less than fresh; 5 = Moderately tired. Let down; 6 = Extremely tired. Very difficult to concentrate; and 7 = Completely exhausted. Unable to function effectively.

2.6 NASA Task-Load Index (TLX)

The NASA TLX (Hart & Staveland, 1988) is a subjective assessment of workload that evaluates different subcomponents of perceived workload. The initial TLX performed pre-study (Day 0) obtained individual pairwise comparisons for subscales that were used to determine overall weighted workload contributions for each pilot. Pilots then completed a TLX following every trip during their hitch. Workload subscales include Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, and Frustration.

2.7 Wrist Actigraphy

A MotionWatch 8 (CamNtech Ltd., Fenstanton, England) worn on the non-dominant wrist was used as an objective estimate of sleep duration and timing. Pilots were asked to press the device marker button every time they went to bed and awoke. Marker presses, along with sleep diary information, were used to score rest intervals using our standard laboratory protocol, from which the MotionWare software (CamNtech Ltd., Fenstanton, England) estimated sleep metrics.

The total sleep time estimated per 24-hour study day (beginning at the start time of each scheduled duty day) was used for sleep analysis (e.g., main sleep period and naps were added together). Specifically, total sleep time was used in the analysis, defined as the total sleep duration between the estimated start and end of a sleep period, minus the estimated time awake after sleep onset.

2.8 Data analysis

All analyses were performed in R-Studio. Differences in participant demographic data were first analyzed by schedule type (i.e., daytime, nighttime, mixed schedules) using Kruskal-Wallis rank sum tests for numeric data (e.g., age) and Pearson's Chi-squared test for categorical data (e.g., sex; Table B-1). Backward stepwise regression was used to evaluate the contribution of potential covariates to primary dependent variables. Potential covariates assessed included age, sex, HAA experience in years, total flight hours, whether the pilot had another job, the size of the HAA operator (using whether they have an operational control center [OCC] as a proxy), MEQ score, PSQI score, and ESS score. Covariates that were found to be significant were included in the models described below (see Table B-2). Subsequently, a series of mixed-effects models with a random intercept of participant was performed for primary analyses. For SP and KSS analyses, covariates for PSQI scores were retained because they were significant in the backward stepwise regression. For analyses related to speed inertia in Research Question 3, a binary covariate for night/day was also included to account for potential effects from concurrent circadian disruption.

Linear models were used to analyze PVT speed, total sleep time, and workload scores, while a negative binomial model was used for PVT lapses as they were zero-inflated count data. Because KSS and SP are Likert-type scales collecting ordinal data, which were skewed, ordinal regression models were used to analyze these data. Marginal and conditional R^2 values were computed for all models to assess the variance attributed to fixed effects (R^2_M) and the total variance attributed to both fixed and random effects (R^2_C). When appropriate, post-hoc pairwise comparisons were made using Bonferroni corrections for linear models and effect coefficients (*b*) and standard error (SE) are reported. For PVT lapses, KSS, and SP, post-hoc comparisons were performed using estimated marginal means, and *p*-values were based on Wald *z*-tests. For analyses on (i) cumulative fatigue, (ii) outcomes within a Duty Day, and (iii) outcomes across Duty Phases, only Duty Day data (i.e., duty start, mid-duty, and duty end responses) were included. For WOCL analyses, only night duty trips (defined as beginning or ending between 1900 – 0700, for nighttime or mixed schedule pilots) were included. For all analyses, a significant α level was set at <0.05.

3. Results

3.1 Participant demographics

A total of 120 pilots (*n* = 10 female) completed data collection and were included in the analysis for the study. Five pilots completed an initial data collection in a pilot study and were excluded from the main analysis. One pilot was excluded from analysis due to not completing data collection. The analyzed sample included 42 pilots working daytime duties, 40 pilots working nighttime duties, and 38 pilots working mixed duties (3-day/4-night, *n* = 20; 4-day/3-night, *n* = 18). There were no statistically significant differences between schedule types for all demographic variables (Table 1). Pilots were aged between 26 and 69 years and had HAA flying experience ranging from 78 to 4000 hours over 0.3 to 30 years. Most pilots reported “always” or “mostly” flying single-pilot operations (99.2%) and that their organization had its own Operational Control Center (OCC; 86.7%), indicating that their organization has at least 10 aircraft. A few pilots (n = 20, 16.7%) reported having an additional job where they worked a range of 3 to 150 extra hours per month.

Table 1. Demographic data of included pilots

Variable	Daytime	Nighttime	Mixed shift	Overall
n	42 *Mean (SD)*	40 *Mean (SD)*	38 *Mean (SD)*	120 *Mean (SD)*
Age (yrs)	44.2 (9.1)	44.3 (9.8)	43.8 (9.6)	44.1 (9.4)
HAA experience (yrs)	6.1 (5.1)	6.6 (4.7)	9.1 (8.7)	7.2 (6.4)
HAA flight hours[1]	956.7 (962.5)	987.0 (1009.6)	954.2 (699.5)	966.1 (897.0)
MEQ Score	61.3 (9.0)	59.4 (11.1)	59.6 (8.5)	60.1 (9.6)
ESS Score	6.5 (2.8)	5.9 (2.9)	7.1 (3.4)	6.5 (3.0)
PSQI Score	6.0 (2.5)	5.5 (2.2)	5.7 (2.3)	5.7 (2.3)
	n (%)	*n (%)*	*n (%)*	*n (%)*
Sex - Male	38 (90.5%)	37 (92.5%)	35 (92.1%)	110 (91.6%)
Additional job	9 (21.4%)	9 (22.5%)	2 (5.3%)	20 (16.7%)
Single pilot[2]	41 (97.6%)	40 (100%)	38 (100%)	119 (99.2%)
Has an OCC	39 (92.9%)	36 (90.0%)	29 (76.3%)	104 (86.7%)

Note. SD = standard deviation; HAA = helicopter air ambulance; MEQ = Morningness-Eveningness Questionnaire; ESS = Epworth Sleepiness Scale; PSQI = Pittsburgh Sleep Quality Index; OCC = Operational Control Center. MEQ scores 59 – 69 indicate a moderate morning types, with a moderate preference for morning over evening. ESS scores 0 – 5 indicate lower normal daytime sleepiness, scores 6 – 10 indicate higher normal daytime sleepiness, scores >10 indicate excessive daytime sleepiness. PSQI scores >5 indicate significant sleep difficulties. [1]Denotes flight hours in most frequently flown helicopter model. [2]Includes pilots who answered that they ‘always’ or ‘mostly’ fly single-pilot operations.

Pilots completed three validated sleep-related questionnaires to gather information about baseline sleep characteristics in the HAA pilot population. Most pilots reported Morningness-Eveningness Questionnaire (MEQ) scores in the “Moderate morning” type (*n* = 54, 45%) or “Intermediate” range (*n* = 44, 37%; Figure 2A). Fewer pilots reported scores in the “Definite morning” type (*n* = 19, 16%) or “Moderate evening” type (*n* = 3, 2%), while no pilots reported scores in the “Definite evening” type. Most pilots reported an ESS score between 6-10 (50%), indicating that the population demonstrates higher normal daytime sleepiness, while 39% of pilots reported a score of 0-5, indicating lower normal daytime sleepiness (Figure 2B). Only 13 pilots (10.8%) reported ESS scores above 10, indicating mild to moderate excessive daytime sleepiness. Finally, 53% (*n* = 64) of pilots reported a PSQI score above 5, indicating significant sleep difficulties in half the sample population (Figure 2C).

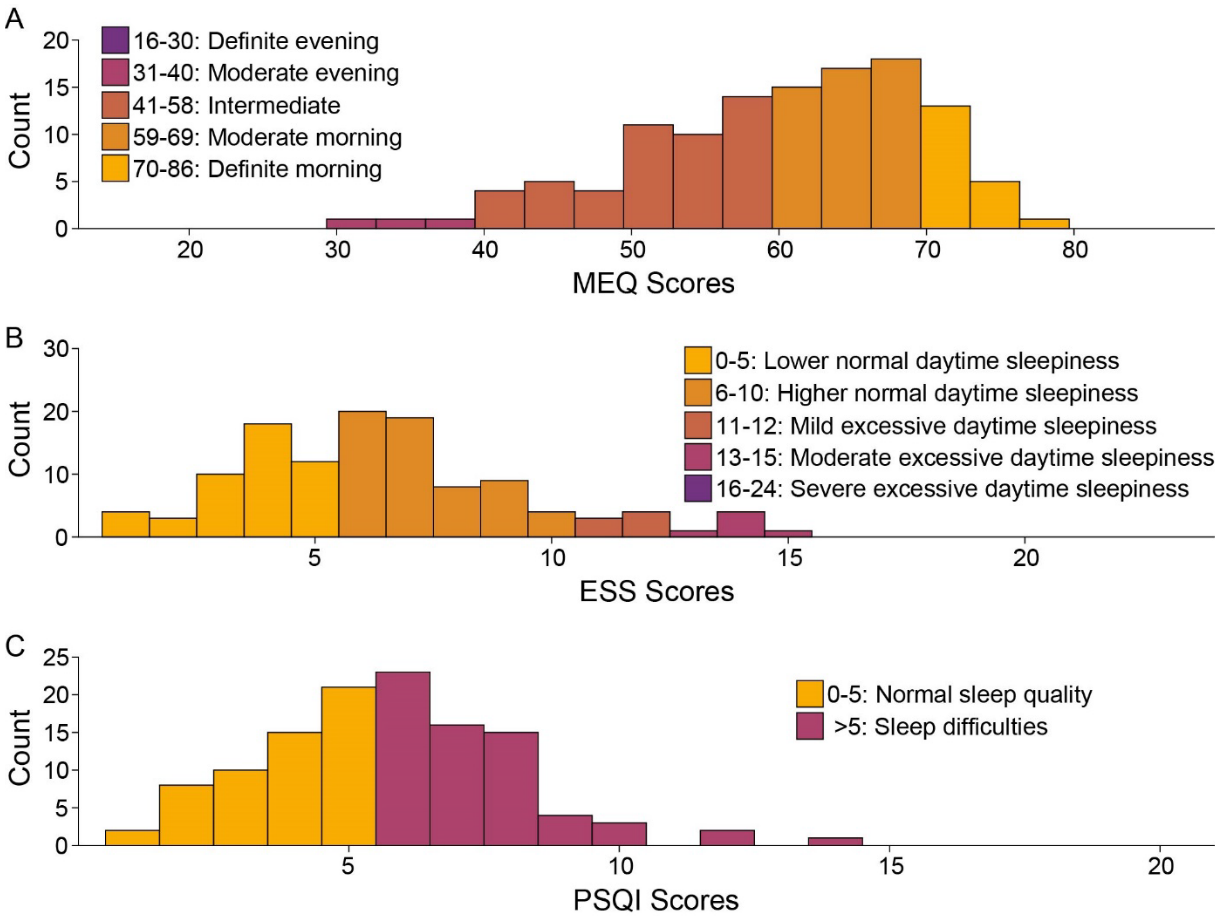

Figure 2. Distribution of validated sleep questionnaire results
Note. MEQ = Morningness-Eveningness Questionnaire; ESS = Epworth Sleepiness Scale; PSQI = Pittsburgh Sleep Quality Index.

3.2 Fatigue perceptions

During the pre-study questionnaire, pilots were asked a number of questions related to their perceptions and experiences with fatigue. A series of tables and figures displays the results from these questions below.

Table 2. Fatigue perceptions related to HAA experience

Question	Response Options (*n*)					
	Yes	*No*	*Prefer not to say*			
Have you ever turned down an HAA flight request because of fatigue?	46	74	0			
In retrospect, are there HAA flights that you should have turned down because of fatigue?	49	64	7			
	Pre-flight	*Pickup leg*	*Drop-off leg*	*Reposition leg*	*Return to base leg*	*Post-flight*
Which phase of trip are you most likely to experience fatigue?	9	9	3	2	85	6
	All the time	*Often*	*Sometimes*	*Rarely*	*Never*	
How often do you catch yourself "nodding off" during a flight?	0	0	6	34	80	
In your role as an HAA pilot, how often does sleep inertia affect your performance?	3	5	58	47	7	

An open-ended comment box was included following the question on how often sleep inertia affects performance, which elicited a number of responses from pilots, including:

- *"By far my most dangerous time on night shift is immediately after getting up to answer a call.*
- *"Inter-facility transports should not be scheduled between 1 am and 4 am. Hospitals should keep/retain patients if able during this period of time. Pilots on night shift should only be awake for SCENE CALLS between 1am and 4am."*
- *"Build in a specified wake-up period of 5 minutes with a flight request while on night shift to allow for sleep inertia to subside before flying. A legal specified period would reduce complaints from customers regarding lift times."*

Pilots responded to questions regarding the maximum number of flight requests they would accept before fatigue becomes a risk on nighttime duty (Figure 3A) and the longest duty duration they would feel comfortable working (Figure 3B).

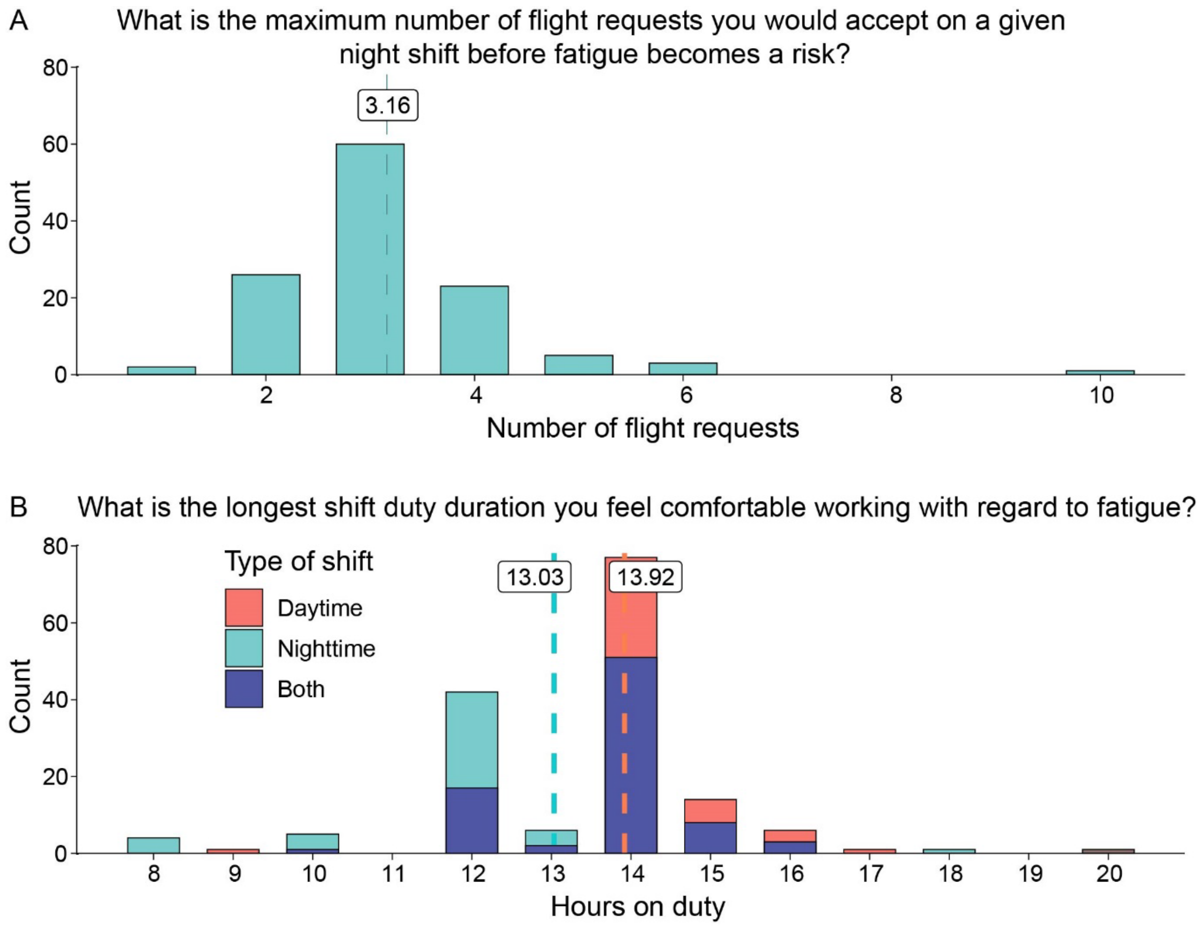

Figure 3. Fatigue perceptions on schedule and workload limits
Note. Means are displayed along dashed lines and described in white boxes.

3.3 Research Q1 Results: Cumulative fatigue

Across the 7 Duty Days during each Duty Period, pilot PVT speed decreased ($F_{6,2206}$ = 15.790, p < 0.001; see Appendix Table B-3 and Table B-4 for detailed statistical outputs) and the number of lapses increased (χ^2 (6, 2342) = 45.16, p < 0.001; Figure 4A and 4B). PVT speed scores were significantly slower than Duty Day 1 by Duty Day 4 of the hitch (b = -0.12, CI = -

0.20, -0.03 $p = 0.009$), and the number of PVT lapses was significantly higher in comparison to Duty Day 1 by Duty Day 6 (incidence rate ratios [IRR] = 1.44, *CI* = 1.06, 1.97, $p = 0.021$; Figure 4). There was no main effect of schedule type (speed: $F_{2,2206} = 0.524$, $p = 0.593$; lapses: χ^2 (2, 2342) = 1.842, $p = 0.398$; Figure 5) or significant interaction of Duty Days by schedule type for PVT speed ($F_{12,2206} = 0.449$, $p = 0.934$) or PVT lapses (χ^2 (12, N = 2342) = 11.04, $p = 0.526$; Figure 5).

Across the 7 Duty Days, SP fatigue ratings (Figure 4C) and KSS ratings (Figure 4D) showed no significant main effects of Duty Day (SP: χ^2(6, 2409) = 8.297, $p = 0.217$; KSS: χ^2(6, 2496) = 2.951, $p = 0.815$; Figure 4) or schedule type (SP: χ^2(2, 2409) = 4.734, $p = 0.094$; KSS: χ^2(2, 2496) = 4.674, $p = 0.097$). There was a significant interaction between Duty Day and schedule type for both SP fatigue ratings (χ^2(12, 2409) = 29.713, $p = 0.003$) and KSS ratings (χ^2(12, 2496) = 28.997, $p = 0.004$; Figure 5), with mixed schedule pilots showing increased SP and KSS ratings during the last three Duty Days (Duty Days 5-7) when they would all be working during the nighttime.

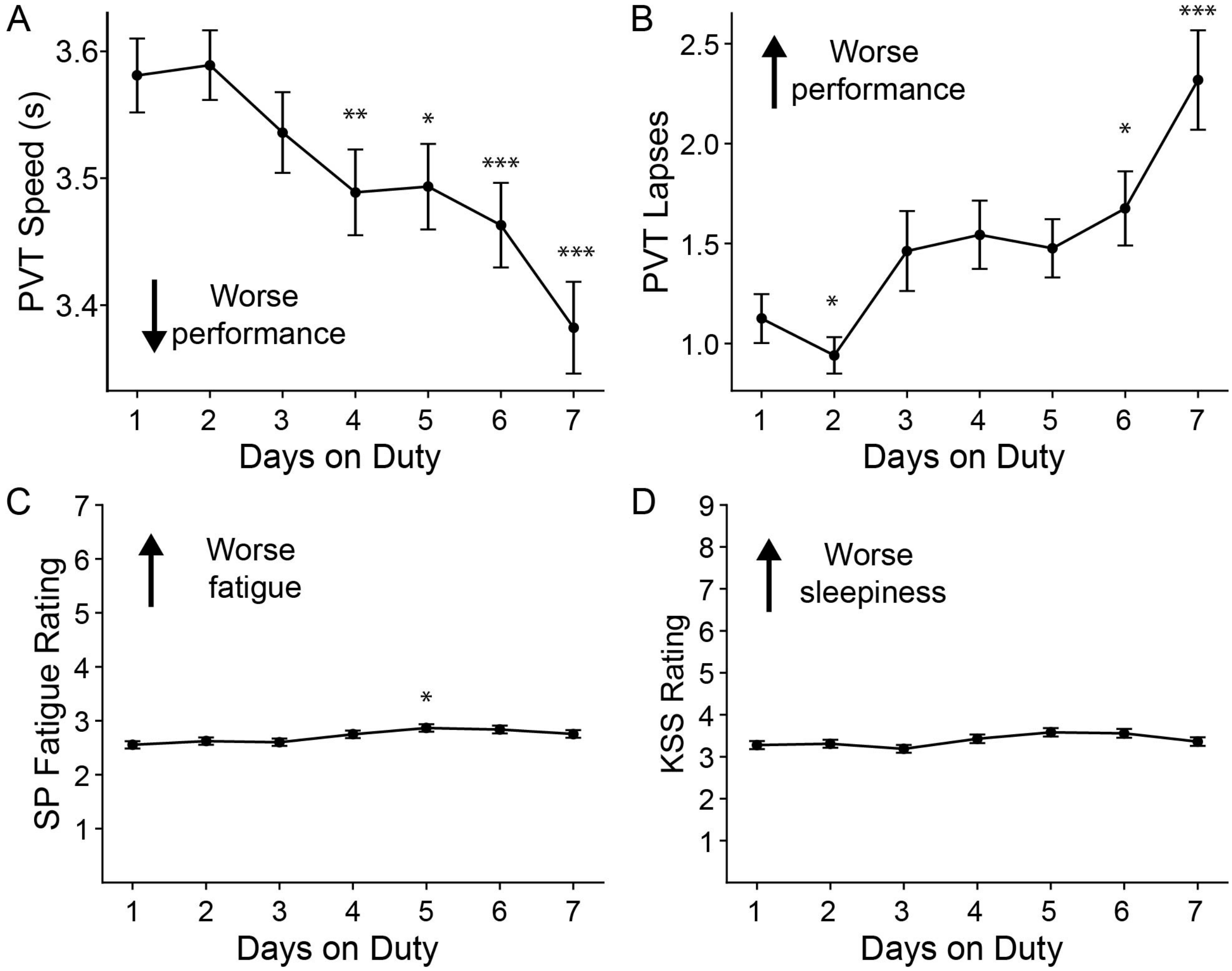

Figure 4. Outcome variables across Duty Days.

*Across 7 days on duty, pilots (n = 120) showed a decrease in PVT speed (A) and an increase in the number of PVT lapses (B). SP fatigue (C) and KSS (D) ratings did not show differences across Duty Days. KSS = Karolinska Sleepiness Scale; PVT = Psychomotor Vigilance Task; SP = Samn-Perelli scale. Means and SE shown. Asterisks signify a significant difference in comparison to Duty Day 1. *p<0.05, **p<0.01, ***p<0.001.*

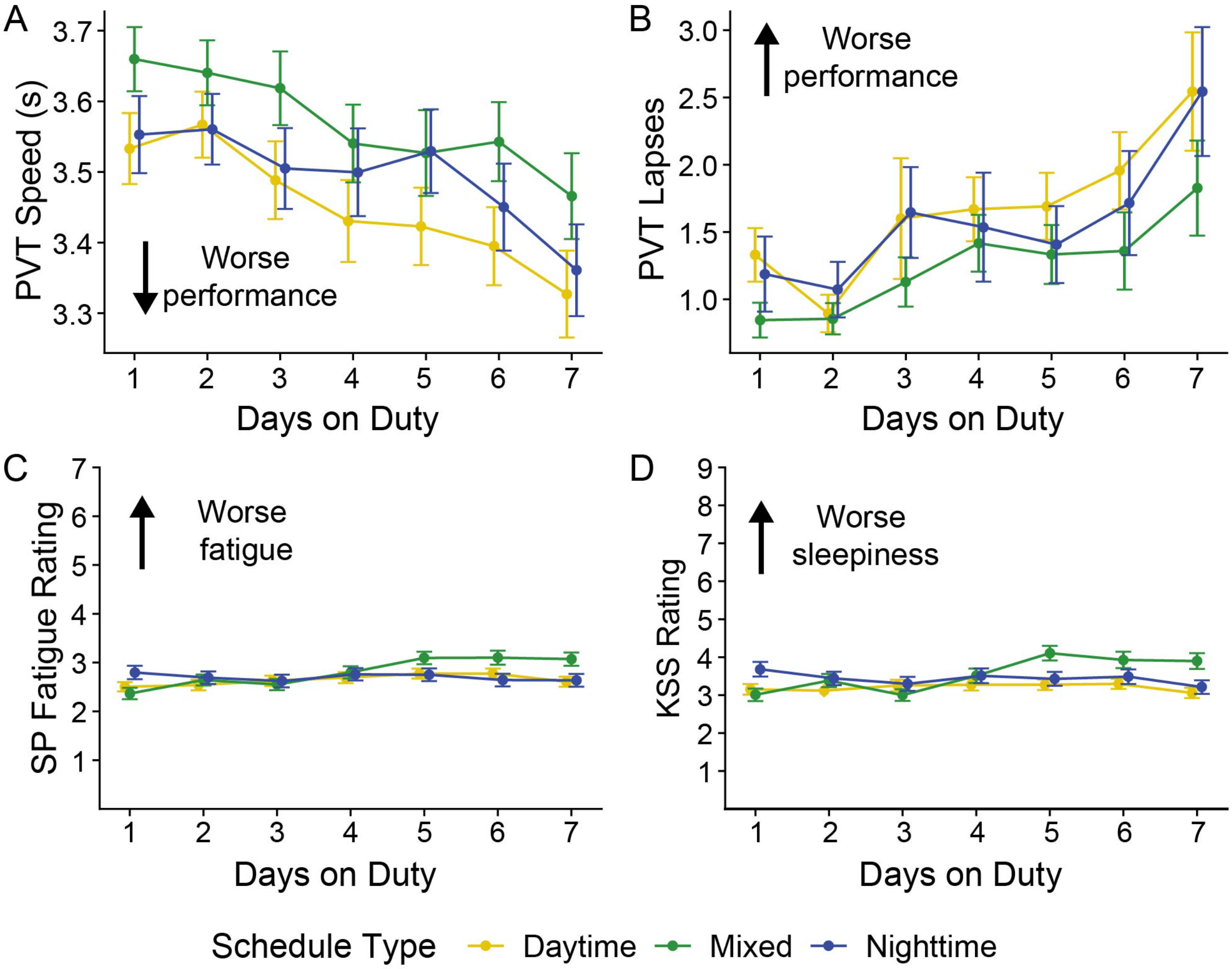

Figure 5. Outcome variables across Duty Days by schedule type.

There was no effect of schedule type or duty day by schedule type interaction for PVT speed (A) nor PVT lapses (B), with performance deteriorating across duty days. There were interactions between days on duty and schedule type for SP fatigue ratings (C) and KSS ratings (D), with mixed schedule pilots reporting an increase in fatigue and sleepiness in the second half of the 7-day Duty Period when they changed to nighttime Duty Days. KSS = Karolinska Sleepiness Scale; PVT = Psychomotor Vigilance Task; SP = Samn-Perelli fatigue scale. Means ± SE shown.

Sleep Data

Across the 7 Duty Days, pilots showed no changes in total sleep time across Duty Days ($F_{6,569}$ = 0.922, p = 0.478; Figure 6; see Appendix Table B-3 and Table B-4 for detailed statistical outputs) or differences by schedule type ($F_{2,95}$ = 0.763, p = 0.469). There was also no interaction between Duty Days and schedule type for total sleep time ($F_{12,569}$ = 1.15, p = 0.319). When considering the number of sleep periods per day, there was a significant difference between schedule types ($F_{2,95}$ = 16.977, p < 0.001; Figure 6) with nighttime schedule pilots (1.7 sleep periods per day ± 0.7) and mixed schedule pilots (1.8 ± 0.7) averaging a higher number of sleep periods per day than daytime scheduled pilots (1.3 ± 0.5). There was no significant effect of Duty Day on the number of sleep periods (F6,568 = 1.425, p = 0.203); however, there was a significant interaction between schedule type and Duty Day ($F_{12,568}$ = 3.007, p < 0.001). Mixed schedule pilots were the only group that showed an increase in the number of sleep periods per day during the hitch. Mixed schedule pilots had significantly more sleep periods on Duty Day 4 (when all mixed schedule pilots were on night duties) compared to Duty Day 1 (on day duty). (b = -0.514, SE = 0.133, p = 0.026). Daytime pilots (b = 0.286, SE = 0.133, p = 0.1.000) and nighttime pilots (b = 0.114, SE = 0.150, p = 1.000) showed no changes in the number of sleep periods across the hitch. The differences in the number of sleep periods across schedule types are highlighted by example representative data shown in Figure 7.

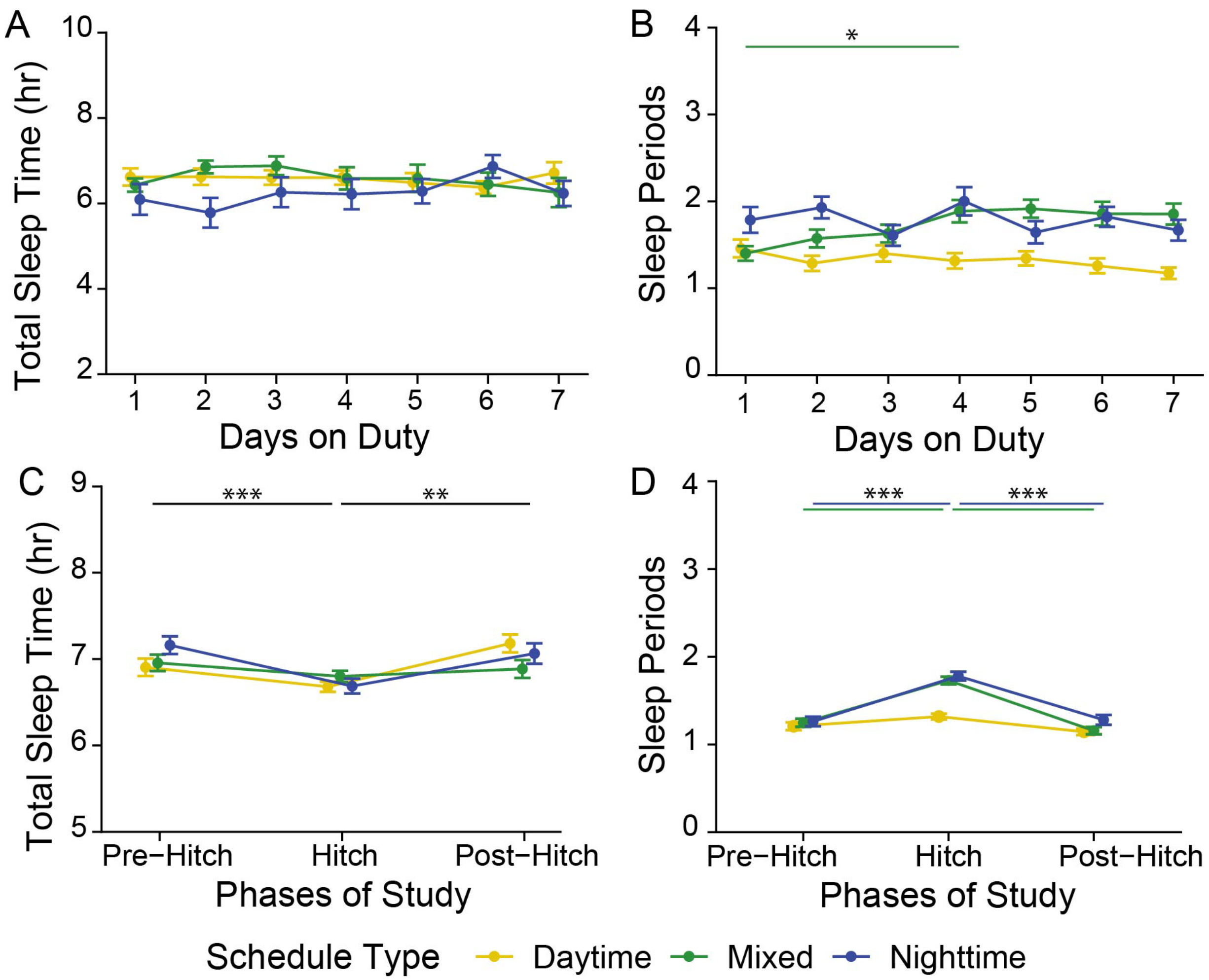

Figure 6. Total sleep time and number of sleep periods per day across the study.

There was no effect of schedule type or change across Duty Days for total sleep time during the 7-days on duty (A). There was a significant effect of schedule type and an interaction between schedule type and Days on Duty for the number of sleep periods per day (B), with day schedule pilots having fewer sleep periods per day, and mixed schedule pilots increasing the number of sleep periods across the 7-days on duty. There was a significant difference across phases of study (C) with less sleep occurring during the 7-days on duty (Hitch) in comparison to Pre-Hitch and Post-Hitch. There was a significant interaction for the number of sleep periods per day between phases of study and schedule type (D), where nighttime and mixed schedule pilots had more sleep periods during the 7-days on duty (Hitch) in comparison to Pre-Hitch and Post-Hitch. Means ± Standard Error shown. *$p<0.05$, **$p<0.01$, ***$p<0.001$.

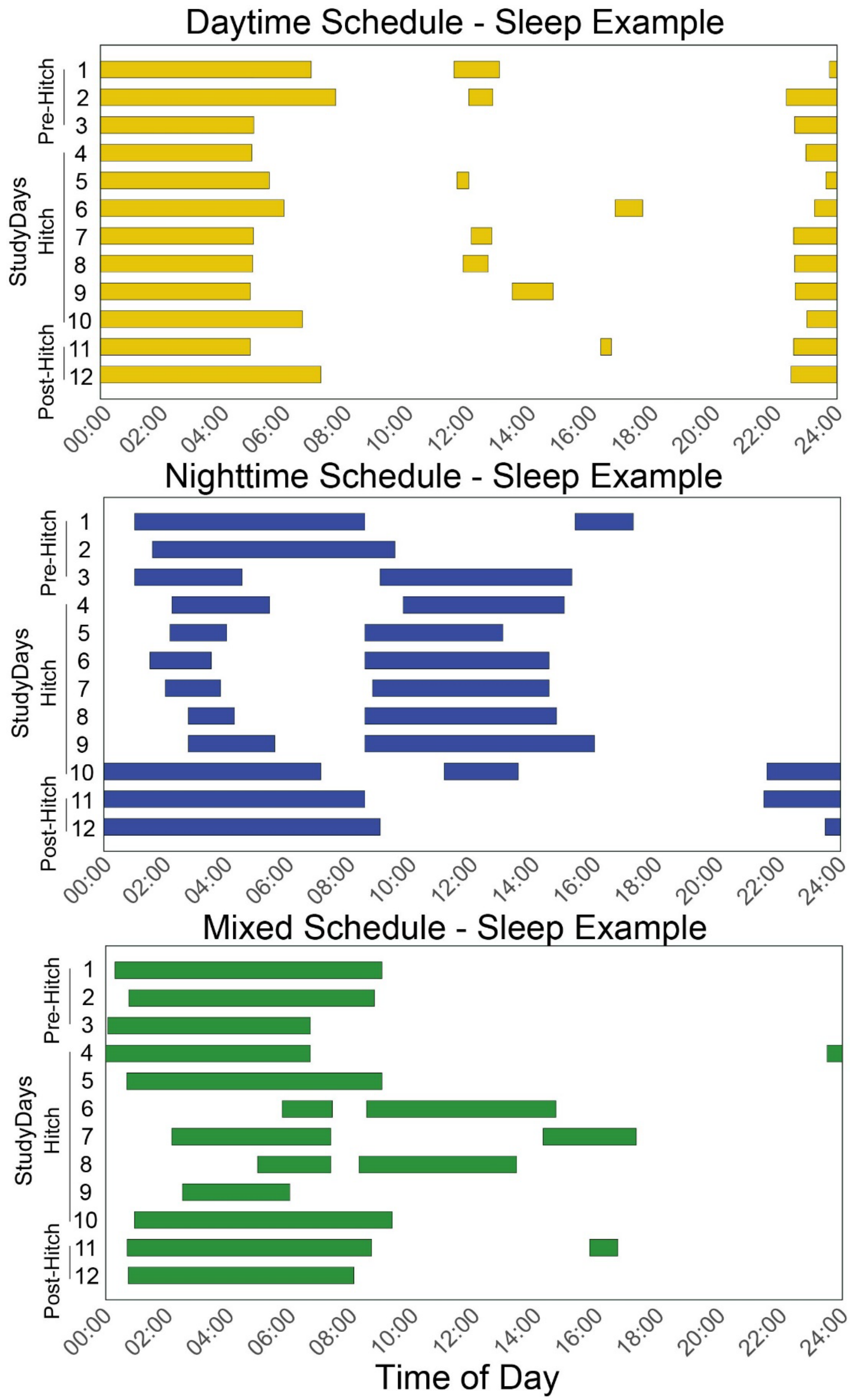

Figure 7. Example sleep patterns across study days.

Representative examples of individual pilot sleep plots are shown across the 12 days of study that collected sleep data for a daytime (top), nighttime (middle), and mixed schedule pilot (bottom). The daytime pilot slept mostly during the typical sleep time with occasional daytime naps. The nighttime schedule pilot transitioned to sleeping mostly during the day with longer ~2-hour naps at night during the 7 days on duty, and the mixed shift pilot shifted to sleeping during the day during their last 3 days on nighttime duty. Colored blocks indicate actigraphically estimated sleep periods.

There was a significant main effect of study phase (Pre-hitch, Duty Period, Post-hitch) for total sleep time ($F_{2,1166} = 11.013$, $p < 0.001$; Figure 6; see Table B-7 and Table B-8 in the appendix) and no significant main effect of schedule type ($F_{2,104} = 0.042$, $p = 0.959$). There was no significant interaction between study phase and schedule type ($F_{4,1165} = 1.855$, $p = 0.116$). Total sleep time significantly decreased from Pre-hitch (7.0 ± 1.3 hrs) to Duty Period (6.6 ± 1.6 hrs; $b = 0.410$, SE = 0.095, $p < 0.001$) and increased again from Duty Period to Post-hitch (6.9 ± 1.5 hrs; $b = -0.297$, SE = 0.096, $p = 0.006$). There was no significant difference between Pre-hitch and Post-hitch periods ($b = 0.113$, SE – 0.114, $p = 0.960$).

There were significant differences between schedule types ($F_{2,107} = 6.597$, $p = 0.002$; Figure 6), phases of study ($F_{2,1166} = 87.865$, $p < 0.001$), and an interaction between schedule type and phases of study ($F_{4,1166} = 9.610$, $p < 0.001$) for the average number of sleep periods per Duty Day. Pilots working nighttime and mixed schedules had significantly more sleep periods per day during the Duty Period compared to Pre-hitch (nighttime: $b = -0.518$, SE = 0.069, $p < 0.001$; mixed: $b = -0.482$, SE = 0.061, $p < 0.001$) and Post-hitch (nighttime: $b = 0.506$, SE = 0.069, $p < 0.001$; mixed: $b = 0.573$, SE = 0.062, $p < 0.001$). Daytime pilots showed no significant difference in the number of sleep periods per day across phases of study.

3.4 Research Q2A Results: Circadian disruption

Outcomes Within Duty Day

Within a given Duty Day, there was a significant main effect of timing within duty (duty start, mid-duty, duty end) on PVT speed ($F_{2,4169} = 37.481$, $p < 0.001$; Figure 8; see Table B-5 and Table B-6 in the appendix) and no significant main effect of schedule type ($F_{2,115} = 0.407$, $p = 0.667$). There was a significant interaction between timing within the duty and schedule types for PVT speed ($F_{4,4169} = 12.815$, $p < 0.001$). Specifically, all pilots showed a slower PVT speed at duty end in comparison to duty start (daytime: $b = 0.090$, SE = 0.024, $p = 0.006$; nighttime: $b = -$

0.136, SE = 0.024, $p < 0.001$; mixed: $b = 0.110$, SE = 0.024, $p < 0.001$). Pilots working nightime and mixed schedule pilots showed a greater decrease in speed between duty start and mid-duty (nighttime: $b = 0.136$, SE = 0.024, $p < 0.001$; mixed: $b = 0.131$, SE – 0.025, $p <0.001$) while pilots working daytime schedules showed a significant increase between mid-duty and duty end ($b = 0.121$, SE = 0.024, $p < 0.001$).

PVT lapses showed a similar pattern, with a significant main effect of timing within duty ($\chi^2(2, 4293) = 30.344$, $p < 0.001$; Figure 8) and no significant main effect of schedule type ($\chi^2(2, 4293) = 0.976$, $p = 0.614$). There was a significant interaction between timing within duty and schedule types ($\chi^2(4, 4293) = 23.863$, $p < 0.001$). Post-hoc analysis showed that the only significant differences in PVT lapses were increases from duty start to mid-duty for mixed shift pilots ($b = -0.339$, SE = 0.096, $p = 0.012$) and from mid-duty to duty end for daytime pilots ($b = -0.338$, SE = 0.107, $p = 0.043$).

There was a significant main effect of timing within duty for SP and KSS scores (SP: $\chi^2(2, 4395) = 342.472$, $p < 0.001$; KSS: $\chi^2(2, 4600) = 240.084$, $p < 0.001$; Figure 8) and no main effect of schedule type (SP: $\chi^2(2, 4395) = 0.929$, $p = 0.629$; KSS: $\chi^2(2, 4600) = 0.885$, $p = 0.642$). SP fatigue ratings and KSS ratings also showed an interaction between timing within duty and schedule type (SP: $\chi^2(4, 4395) = 185.736$, $p < 0.001$; KSS: $\chi^2(4, 4600) = 117.149$, $p < 0.001$; Figure 6). Post-hoc comparisons across all pilots showed an increase in scores between duty start and duty-end for SP (daytime: $b = -0.980$, SE = 0.111, $p < 0.001$; nighttime: $b = -1.839$, SE = 0.125, $p < 0.001$; mixed: $b = -1.08$, SE = 0.121, $p < 0.001$), and KSS (daytime: $b = -0.686$, SE = 0.103, $p < 0.001$; nighttime: $b = -1.454$, SE = 0.112, $p < 0.001$; mixed: $b = -0.828$, SE = 0.115, $p < 0.001$). However, only pilots working nighttime schedules and mixed schedule pilots reported significantly higher SP ratings (nighttime: $b = -2.287$, SE = 0.127 $p < 0.001$; mixed: $b = -1.009$, SE = 0.127, $p < 0.001$) and KSS ratings (nighttime: $b = -1.637$, SE = 0.113, $p < 0.001$; mixed: $b = -0.557$, SE = 1.121, $p < 0.001$) at the mid-duty time point in comparison to duty start.

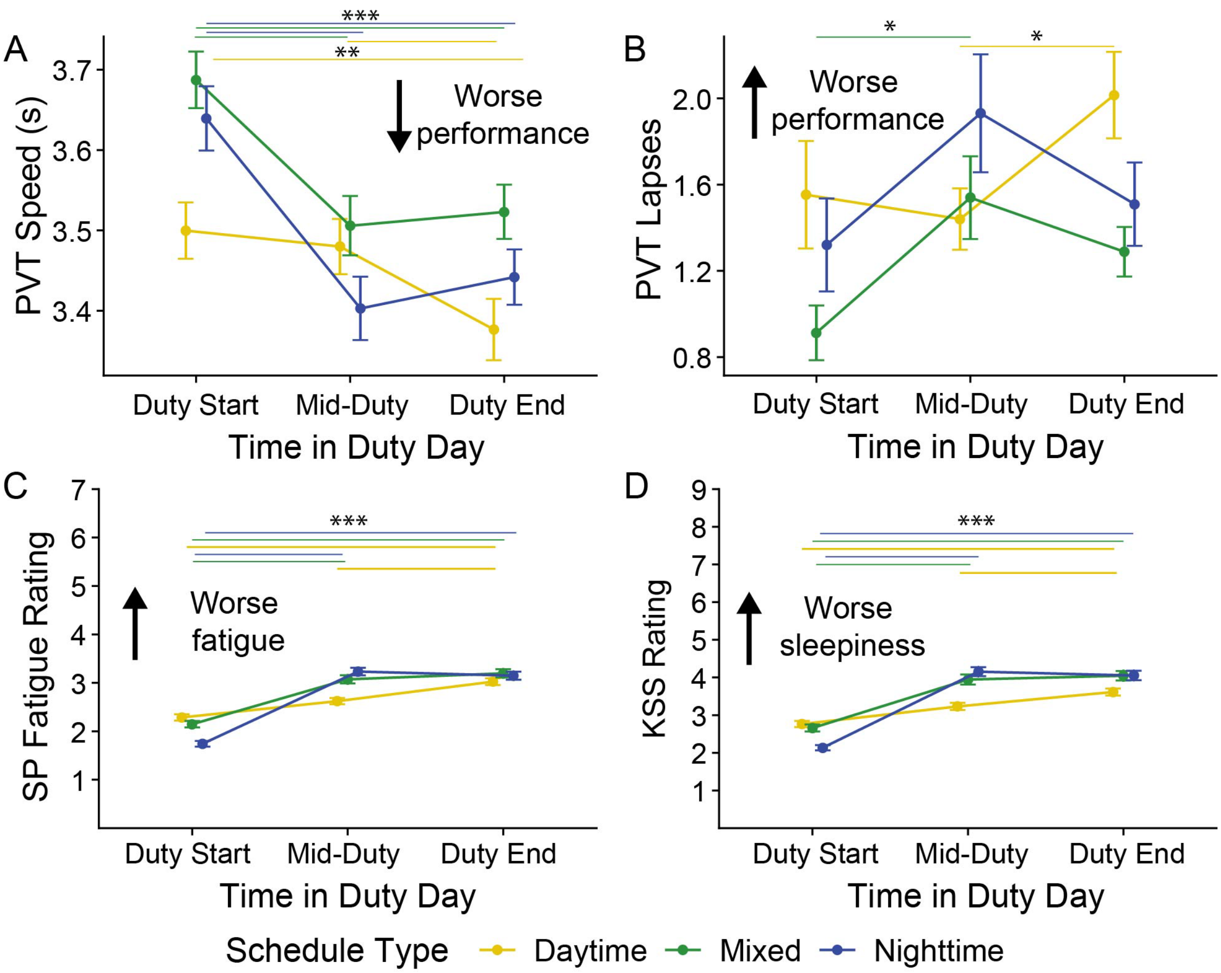

Figure 8. Outcome variables across timing within duty by schedule type.

*Within an individual Duty Day, PVT speed (A) decreased from duty start for all schedule types, with the slowest speeds occurring at mid-duty for both nighttime and mixed schedules, and at duty end for the daytime schedule. PVT lapses (B) similarly increased within the Duty Day. SP fatigue ratings (C) and KSS ratings (D) also slightly increased within the Duty Day. PVT = Psychomotor Vigilance Task; SP = Samn-Perelli fatigue scale; KSS = Karolinska Sleepiness Scale. Means ± SE shown. Colored lines signify significant post-hoc comparisons. *p<0.05, **p<0.01, ***p<0.001.*

Outcomes Across Study Phase

There was a significant main effect of study phase (Pre-hitch, Hitch, Post-hitch) for PVT speed ($F_{2,4170}$ = 195.737, p < 0.001; Figure 9; see Table B-7 and Table B-8 in the appendix) and no significant main effect of schedule type ($F_{2,115}$ = 0.321, p = 0.726). There was a significant study phase by schedule type interaction for PVT speed ($F_{4,4170}$ = 6.343, p < 0.001; Figure 7). All schedule types showed a significant decrease in PVT from Pre-Hitch to Post-Hitch (daytime: b = 0.335, SE = 0.028, $p < 0.001$; nighttime: b = 0.234, SE = 0.029, $p < 0.001$; mixed: b = 0.368, SE = 0.029, $p < 0.001$). However, only daytime pilots showed a significant decrease in speed from Pre-Hitch to Hitch (b = 0.151, SE – 0.023, p <0.001).

PVT lapses showed a significant main effect of study phase ($\chi^2(2, 4293) = 68.131$, $p < 0.001$) and no significant main effect of schedule type ($\chi^2(2, 4293) = 1.264$, $p = 0.531$). There was an interaction between study phase and schedule type ($\chi^2(4, 4293) = 11.656$, $p = 0.020$). Similar to PVT speed, all pilots showed an increase in lapses from Pre-Hitch to Post-Hitch periods (daytime: b = -0.839, SE = 0.189, $p < 0.001$; nighttime: b -0.673, SE = 0.169, $p = 0.002$; mixed: b = -0.836, SE = 0.190, $p < 0.001$), while only daytime pilots showed an increase in lapses from Pre-Hitch to Hitch (b = -0.300, SE 0.086, $p = 0.014$).

SP fatigue ratings and KSS ratings both showed a significant main effect of study phase (SP: $\chi^2(2, 4395) = 36.170$, $p < 0.001$; KSS: $\chi^2(2, 4600) = 9.018$, $p = 0.011$), with no main effect of schedule type (SP: $\chi^2(2, 4395) = 3.454$, $p = 0.178$; KSS: $\chi^2(2, 4600) = 1.127$, $p = 0.569$). There was a significant interaction between phases of study and schedule types for both SP and KSS (SP: $\chi^2(4, 4395) = 34.011$, $p < 0.001$; KSS: $\chi^2(4, 4600) = 21.480$, $p < 0.001$). Daytime and mixed schedule pilots showed increases in SP scores from Pre-Hitch to Post-Hitch (daytime: b = -0.780, SE = 0.134, $p < 0.001$; mixed: b = -1.242, SE = 0.151, $p < 0.001$) while only mixed schedule pilots showed this increase in KSS scores (b = -0.662, SE – 0.144, $p < 0.001$).

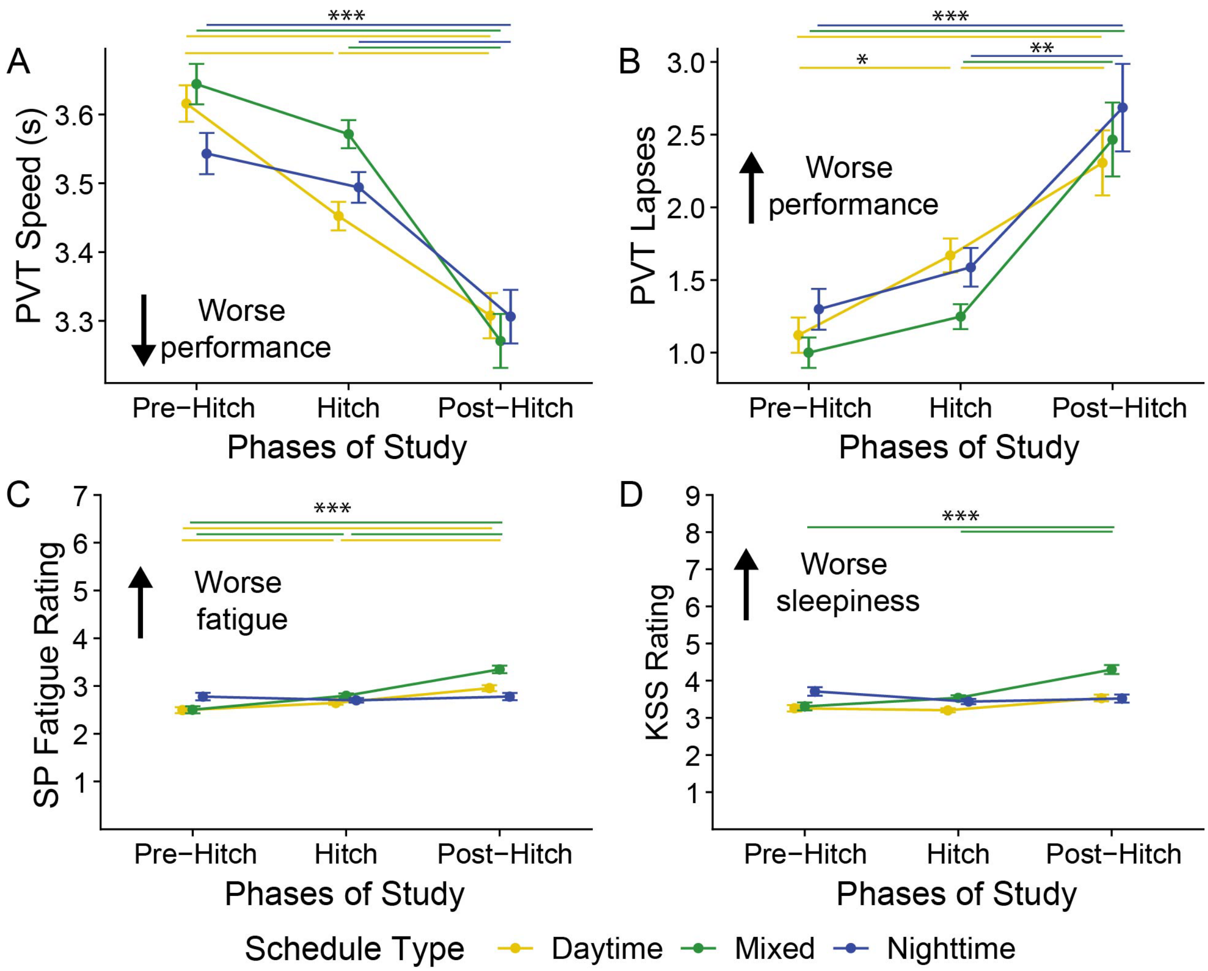

Figure 9. Outcome variables across phases of study by schedule type.

*Across the Pre-Hitch, Duty Period, and Post-Hitch phases of the study, PVT speed (A) decreased, and PVT lapses (B) increased for all schedule types. Only daytime pilots showed changes between Pre-Hitch and Duty Periods. SP fatigue (C) ratings increased across study phases for daytime and mixed schedule pilots, but not nighttime pilots. KSS (D) ratings only increased across phases for mixed schedule pilots compared to Pre-Hitch and between the Duty Period and Post-hitch periods. PVT = Psychomotor Vigilance Task; SP = Samn-Perelli fatigue scale; KSS = Karolinska Sleepiness Scale. Means ± SEM shown. Colored lines signify significant within schedule type post-hoc comparisons between phases. *p<0.05, **p<0.01, ***p<0.001.*

3.5 Research Q2B. Circadian disruption from WOCL incursions

Overall, performance, sleepiness, fatigue, and workload ratings were collected upon return to base (post-trip) for 516 trips. The timing of flight requests was analyzed to examine the role of circadian disruption due to the WOCL. In all, 87 flight requests encroached on the WOCL (0200-0600). Encroachment included any part of the flight request and subsequent trip, starting from the initial call to return to base (for nighttime duties only). These trips were compared against trips that also occurred during nighttime Duty Days (1900-0700), but outside of the WOCL window (n = 113). When trips encroached upon the WOCL, pilots showed slower PVT speed (3.36 ± 0.66; b = -0.19, CI = -0.28, -0.08, p < 0.001) than when trips did not overlap with the WOCL (3.46 ± 0.66; Figure 10; see Table B-9 in the appendix). There were also statistically significantly more PVT lapses between WOCL (2.27 ± 5.24) and non-WOCL night trips (1.86 ± 4.27; IRR = 1.81, CI = 1.21, 2.70, p = 0.004). Pilots reported higher SP fatigue (3.59 ± 1.33; OR = 5.81, CI = 2.94, 11.49, p < 0.001) and KSS ratings (3.72 ± 2.26; OR = 6.81, CI = 3.41, 13.63, p < 0.001) for trips that encroached upon the WOCL versus non-WOCL night trips (SP: 2.92 ± 1.30; KSS: 2.77 ± 1.76; Figure 8).

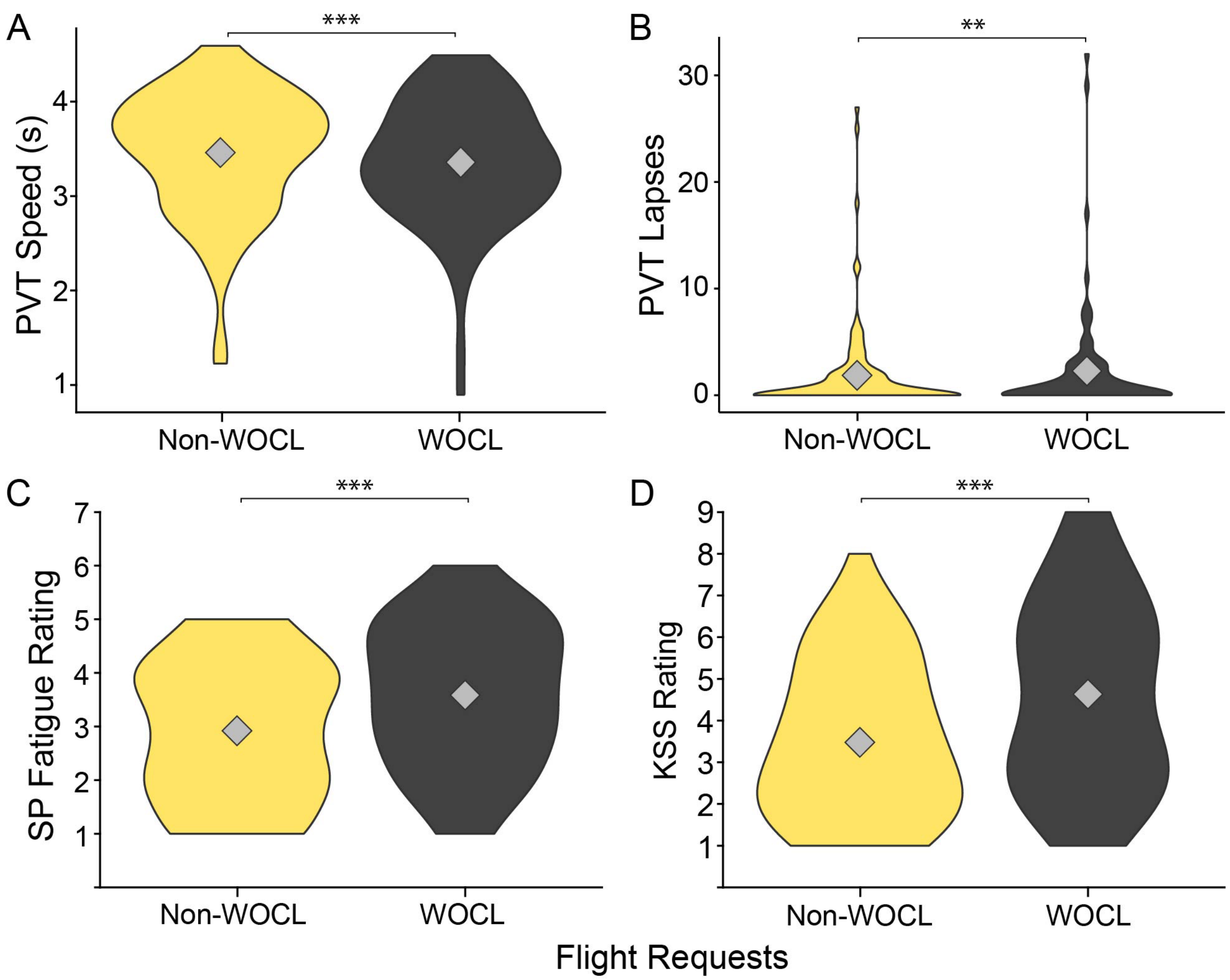

Figure 10. Outcome variables comparing trips during the WOCL to non-WOCL night trips.

Performance, fatigue, and sleepiness upon returning to base post-trip were compared for trips that encroached upon the window of circadian low (WOCL; 0200-0600, n = 90) to trips that did *not overlap with the WOCL but occurred between 1900-0200 and 0600-0700 (n = 157). Overall, trips that encroached on the WOCL showed slower PVT speed (A), more PVT lapses (B), and were associated with pilots reporting higher SP fatigue ratings (C) and KSS ratings (D) compared to night trips completed outside the WOCL. KSS = Karolinska Sleepiness Scale; PVT = Psychomotor Vigilance Task; SP = Samn-Perelli fatigue scale; WOCL = window of circadian low. Violin plots show the distribution and probability density of each population, with a diamond displaying each population's mean. **p < 0.01, ***p <0.001.*

Workload

Following each trip, pilots also completed the NASA TLX to evaluate subjective workload experienced on each trip. There was no overall significant difference in weighted average workload scores between WOCL (n = 87; 47.06 ± 19.00) and non-WOCL night flights (n = 113; 49.75 ± 16.04; b = 1.12; CI = -2.15, 4. 39; p = 0.499). Of the subcomponents of workload, only Mental Demand was significantly higher for WOCL flights (45.75 ± 23.95) compared to non-WOCL night flights (42.48 ± 22.70, b = 5.59; CI = 0.67, 10.51, p = 0.026). There were no significant differences between trip timing for the other subcomponents of workload (Physical Demand, Temporal Demand, Performance, Effort, or Frustration; Figure 11).

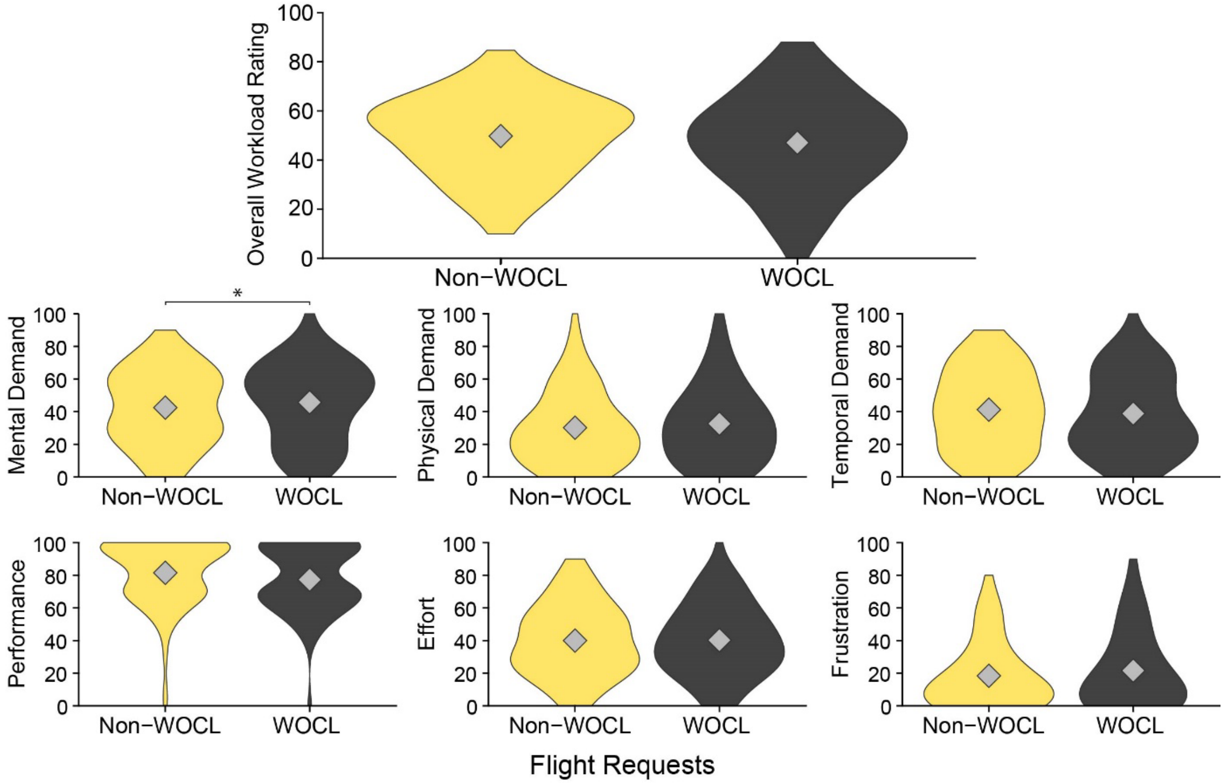

Figure 11. NASA-TLX workload ratings following trips during the WOCL compared to non-WOCL night trips.

*Pilots completed the NASA TLX upon returning from every trip to rate different subcomponents of workload. There was no overall difference in average weighted workload ratings (top) for trips during the WOCL (n = 90) versus non-WOCL night trips (n = 157). Raw ratings of subcomponents, including Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, and Frustration, are displayed below. Only scores for Mental Demand significantly differed between WOCL and non-WOCL night trips, with slightly higher ratings on WOCL trips. WOCL = window of circadian low. Violin plots show the distribution and probability density of each population, with a diamond displaying each population's mean. *p < 0.05.*

3.6 Research Q3. Sleep inertia

Following each trip, pilots were asked to consider how they felt at the time they received the flight request and to report their retrospective SP fatigue and KSS ratings for that time. Cases where pilots were awoken by the flight request (n = 66) were compared to cases where pilots reported that they were already awake at the time of the flight request (n = 450). Pilots reported higher SP fatigue ratings (3.68 ± 1.33; OR = 19.26, CI = 10.49, 35.36, p < 0.001) and KSS ratings (5.11 ± 2.22; OR = 23.96, CI = 12.95, 44.34, p < 0.001) when awoken by the flight request versus cases where they were already awake (SP: 2.19 ± 1.08; KSS: 2.69 ± 1.50;

Figure 12; see Table B-10 in appendix). Ratings were also collected reflecting how pilots felt at the time upon returning to base post-trip. KSS ratings remained significantly higher post-trip when pilots were awoken (4.15 ± 2.20; OR = 1.93, *CI* = 1.13, 3.27, $p = 0.015$) versus when they were awake (3.45 ± 1.77; Figure 10). SP fatigue ratings were not significantly different between conditions (asleep: 3.17 ± 1.43, awake: 2.93 ± 1.27; OR = 1.33, *CI* = 0.79, 2.26, $p = 0.285$).

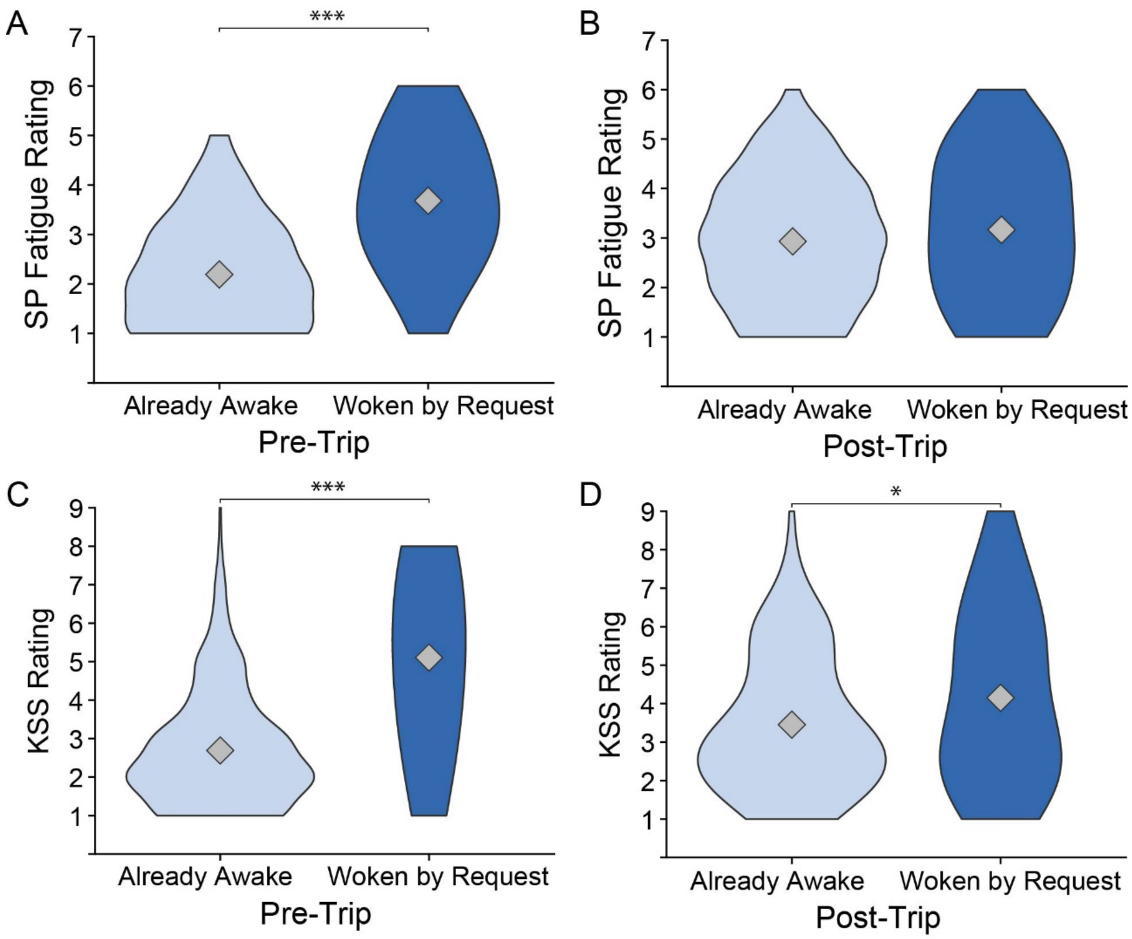

Figure 12. Self-reported fatigue and sleepiness pre- and post-trip comparing flight requests received during sleep (woken by request) and wake (already awake).

After returning to base post-flight, pilots were asked to retrospectively report on their fatigue and sleepiness levels at the time of the initial flight request. Pilots retrospectively reported higher fatigue (A) and sleepiness (C) levels for flight requests that woke them up versus cases when they were already awake. Pilots additionally reported their fatigue (B) and sleepiness (D) levels post-trip, with higher sleepiness ratings found following flight requests received when asleep versus awake. KSS = Karolinska Sleepiness Scale; SP = Samn-Perelli fatigue scale. Violin plots show the distribution and probability density of each population, with a diamond displaying each population's mean. $^{**}p < 0.01$, $^{***}p < 0.001$.

4. Discussion

This report describes the largest field study known to date on fatigue in US HAA pilots and identifies key components of current operations that may be targeted for fatigue management. Previous field study research in HAA pilots has highlighted fatigue and excessive sleepiness as issues in European pilot populations (Flaa, et al., 2019; 2021; 2022; Radstaak et al., 2014a). Self-report surveys of US HAA pilots have echoed these issues (Gregory et al., 2010; Haber Kamine et al., 2022), but there has been no comprehensive field study with objective data collection methods in this group. The current study updates prior surveys and adds important objective sleep and performance data, as well as on-shift subjective alertness measures, to this discussion and highlights specific areas where fatigue may be of particular risk during common HAA pilot scheduling practices. The current study found that (i) half of the HAA pilots surveyed have poor quality sleep; (ii) cumulative fatigue builds across a 7-day hitch, affecting performance on all schedule types; (iii) pilot subjective fatigue and sleepiness ratings remained consistent across the hitch, even when objective measures of performance worsened; (iv) pilots obtain less sleep during a hitch than on days off on all schedule types despite taking extra naps during night duties; (v) fatigue accumulates faster across a duty for night and mixed schedules compared to day schedules; (vi) fatigue accumulated across a hitch persists into recovery days; (vii) circadian disruptions associated with trips during the WOCL negatively impact performance; and (ix) pilots experience sleep inertia effects when awoken by a flight request.

4.1 Perceptions of fatigue

Pilots initially answered sleep-related questionnaires to understand base demographics about the HAA pilot population, including sleep quality, preferences, and daytime sleepiness levels. The pre-study sleep questionnaires did indicate minor sleep-related issues in the study population, with most ESS scores >6 indicating higher levels of daytime sleepiness (Johns, 1991) and about half of PSQI scores >5 indicating some level of disturbed sleep (Buysse et al., 1989). However, these ESS scores are lower than those that found excessive daytime sleepiness in other helicopter responder groups (Akter et al., 2021; Zakariassen et al., 2019) and in larger studies looking at EMS workers more broadly (Patterson et al., 2015a). Previous work has established that PSQI scores above 5 correlate with poor sleep and indicate sleep disturbances in a range of populations (Buysse et al., 1989; Beck et al., 2004). Over half of pilots in the current sample (53%) reported scores above 5, suggesting that sleep disturbances are common in this population, which is expected given sleep quality impacts observed in other shiftwork populations (van Mark et al., 2010; Lim et al., 2020). Additionally, most pilots reported either “Moderate morning” or “Intermediate” preferences on the Morningness-Eveningness Questionnaire, which may make nighttime shiftwork more difficult for this population (Hilliker et al., 1992; Vetter et al., 2015).

The current study included questions related to fatigue specific to HAA operations, some of which are based on previous survey studies completed in US HAA pilots in coordination with NEMSPA (Gregory et al., 2010; Haber Kamine et al., 2022). The current results largely align with the previous survey studies’ findings, including findings about nodding off in flight. Head nodding is a symptom of microsleep, representing the body’s transition from wake to sleep during which postural muscles relax, causing the head to nod (Peiris, et al., 2006). This is a late-stage indicator of sleepiness, indicating that before head nodding occurs, the effects of fatigue, such as delayed reaction times and poor decision-making, are already present. In the current study, while the majority of pilots reported never having nodded off in flight, 33% reported this experience. This finding is in line with previous work in which a third of pilots reported having “nodded off” during a flight (Gregory et al., 2010; Haber Kamine et al., 2022), which may indicate that this is an issue that has not been effectively addressed since it was highlighted 15 years ago. However, the current study, like previous surveys, asked about career experiences of nodding off in flight and not experiences within the past year, making it difficult to interpret these findings over time. Regardless, given that most of the pilots in the current sample are flying single-pilot operations (99%), this data point underscores the importance of mitigating and managing fatigue in HAA operations. While other aviation operations with 2-pilot crews have safeguards in place for head-nodding and associated microsleeps, the frequency of single-pilot operations, lower flight levels, and increased proximity to obstacles highlight the potential severity of this occurrence in HAA. Additional safeguards, such as official standard operating procedures for the occurrence of head nodding, may be appropriate.

A little over one-third of pilots reported turning down a flight due to fatigue, while a similar proportion reported that, in retrospect, there are flights they should have turned down due to fatigue. This number is lower than in previous reports in which ~65% of pilots reported that they should have turned down a flight due to fatigue in the past (Gregory et al., 2010; Haber Kamine et al., 2022), which may indicate some improvement among the pilot community in feeling comfortable calling out fatigued. Calling out fatigued may be influenced by many factors, including pilot experience, company safety culture, pressure to perform by management, and lack of education on self-assessment of fatigue. More research is required to determine which factors influenced the pilots who did call out fatigued and which factors may be at play in situations where pilots feel they should have called out fatigued. Given that HAA operations will assuredly cause some amount of circadian disruption, regular fatigue reporting is a sign of a healthy organizational culture that promotes safety and should be assessed within each operator.

Pilots also provided perceptions about which characteristics of hitches are likely to contribute to fatigue. Overall, the majority of pilots reported that, of the stages of a trip, fatigue is most prevalent on the return to base flight after patient drop-off. This adds to previous work that identified the enroute phase of flight (compared to takeoff or landing, for example) as the most susceptible to fatigue (Gregory et al., 2010; Haber Kamine et al., 2022). Further, this perception that fatigue sets in after the patient has been safely transported to the hospital could indicate that excitatory factors (i.e., psychological and physiological responses to the critical nature of the task) wear off after a critical series of flights. The drop in urgency during this leg of flight may unmask latent sleepiness that was already present during the other stages, though pilots may not have been subjectively aware due to excitatory factors. The absence of an engaging task causes increased subjective and objective sleepiness, even with similar sleep/wake conditions (Flynn-Evans et al., 2021), indicating that the relationship between workload and perceived fatigue may be relevant to this finding. It may be beneficial to incorporate training or education for pilots to raise awareness concerning sleepiness on the last leg and to remind pilots to reassess their fitness at every leg of the trip.

Pilots also provided their opinions about how long into a given duty day fatigue becomes an issue. Pilots reported that the maximum duty day length should be less than 14 hours, regardless of the timing of the shift, but with a slightly shorter duration for nighttime duties. Determining maximum shift duration is a complex decision that must balance risk factors, safety, and competing goals (Gurubhagavatula et al., 2021). Objective data on the effects of different shift durations vary widely between, and even within, specific industries (Patterson et al., 2018). While 14 hours may be too long for a shift worker doing continuous work (e.g., factory work), the downtime and potential time for naps associated with the on-call nature of HAA operations may make 14 hours more suitable. All of the currently analyzed shifts were scheduled for 12 hours, within the reported 14-hour maximum suggested by pilots. Future research is needed to specifically examine the relationship between time on shift and fatigue in HAA pilots.

Finally, when asked about the number of flight requests on the night shift, most pilots reported that fatigue would likely become an issue after 3 flight requests. While regulations for scheduling limits and maximum duty periods for Part 121 airline pilots do take into account time of day and the number of flights flown, current regulations and guidance for HAA operations under Part 135 limit only the total amount of flight time. Whether formally, through regulatory limits, or informally through operator policy, it may be pertinent to consider both time of day and the number of flights flown in each duty period when determining schedule limits. Additionally, pre-flight risk assessments may benefit from considering the number of flights already flown that duty day or the urgency of the flight (e.g., a scene call versus a non-urgent transfer) after 3 flight requests have already been completed.

4.2 Research Q1. Cumulative fatigue

Across all shift types, response speed and the number of lapses of attention on the PVT got worse across the 7 days on duty. By Duty Day 4, performance was significantly worse than on the first day of duty, and this decrease continued across all 7 duty days. These findings are in line with previous research showing decrements in performance due to cumulative sleep debt across consecutive days on shift (Flynn-Evans et al., 2018; Åkerstedt et al., 2021). Further, these findings support an opportunity for pre-flight risk assessments to consider cumulative fatigue by accounting for the pilot's current number of days on duty. Conversely, there was no clear or reliable increase in self-reported fatigue and sleepiness scores across duty days. This highlights a discrepancy between objective and subjective measures of fatigue within this population, as seen in previous chronic sleep restriction studies (Van Dongen, et al., 2003). There was, however, an interaction between schedule type and days on duty, whereby pilots working the mixed schedules gave higher ratings towards the end of the hitch. That is, there was an increase in fatigue and sleepiness when pilots transitioned from days to nights mid-hitch. Switching between early start times during daytime shifts and late finishes during nighttime shifts during a hitch may be particularly fatiguing for mixed schedule pilots due to the sudden, significant change in shift timing. Circadian rhythms, however, only shift slowly (~1-1.5h/day), suggesting a degree of circadian misalignment, especially during the first few nights of the duty period (Mills et al., 1978; Knauth et al., 1978; Stone et al., 2018). Specific training and education on maximizing sleep opportunities during these mid-hitch swaps may be beneficial for pilots with mixed schedules. While some studies have failed to detect a change in KSS ratings across a 7-day duty period in HAA pilots (Flaa et al., 2022) and other pilots (Åkerstedt et al., 2021), other studies have found that KSS scores increase across a 14-day shift period in offshore shift workers (Riethmeister et al., 2019). Combined, these studies highlight the variability in subjective ratings across study designs and operational types. Altogether, the current findings underscore the importance of pairing subjective ratings with objective performance measures, such as PVT, to inform the reliability of self-assessments, such as fitness-for-duty checks.

The current performance decrements seen across days of duty may be tied to a lack of adequate sleep during a hitch. Total daily sleep fell from an average of 7 hours per day on days off Pre-Hitch to 6.6 hours on average during the hitch. Therefore, pilots were obtaining below the average recommended sleep amount of 7-9 hours per day (Hirshkowitz, et al., 2015) for 7 days, leading to an accumulated sleep debt across the hitch. Our findings are in contrast to previous work showing that HAA pilots obtained sufficient sleep on both on- and off-duty days among Norwegian and Austrian pilots (Zakariassen et al., 2019). However, this prior study was based on different scheduling patterns, such as 24h shifts, and may have included bases with different operational tempos, allowing for greater sleep opportunities. While there were no significant differences in total sleep duration during a hitch based on schedule type, there was an observable trend of nighttime pilots averaging less total sleep on the first 2 days of the hitch (Figure 6). This is a common observation known as the "first night effect," whereby the amount of sleep obtained prior to the first night shift is often reduced due to difficulties sleeping at times when the body is usually awake (i.e., during the daytime), together with low sleep pressure from adequate sleep the nights before.

The current data underscore that 12-hr nighttime shifts require different sleep strategies, with nighttime and mixed schedule pilots changing their sleep patterns in ways that cause circadian disruptions. During night duty, these pilots often shifted their sleep patterns to get most of their sleep during the day. Additionally, nighttime and mixed schedule pilots showed an increase in the average number of sleep periods per day, indicating a nighttime napping strategy to maintain similar levels of sleep during a hitch as daytime schedules. While this indicates that pilots are adapting their sleep patterns to maximize sleep opportunities in an effort to preserve total sleep per 24 hours, the total amount of sleep was still reduced during the hitch for all schedules compared to days off. Another important consideration beyond sleep duration is sleep regularity (consistent timing of sleep episodes across consecutive days). This sleep metric has recently emerged as an important factor for health and performance, and is a stronger predictor of all-cause mortality than sleep duration itself (Sletten et al., 2023; Windred et al., 2023; Lunsford-Avery et al., 2018). As 12-hr shifts are standard for pilots in the US, some changes to sleep patterns are unavoidable, and managing that fatigue is key to operational success. Alternatively, other personnel (e.g., medical crews) and some international pilots in air ambulance or similar industries operate 24-hr shifts, where sleep is largely maintained during the biological night (Fletcher et al., 2022; Flaa et al., 2022; Frakes & Kelly, 2007). However, operational tempo differences in US pilots make 24-hr shifts in air ambulance operations less feasible, and more direct research would be necessary to compare these schedule types in pilots. It is clear that the sleep obtained on-duty for nighttime and mixed schedules is critical for maintaining overall sleep during a hitch, and thus, the opportunity to sleep on duty should be protected. However, obtaining sleep during the night may be unreliable if operational demands interrupt napping opportunities. Therefore, training to promote best strategies for circadian-misaligned (i.e., daytime) sleep is needed, as well as guidance on how to protect and make the most of napping opportunities at night from both personal and operator perspectives.

4.3 Research Q2A. Circadian disruptions

Overall, fatigue increased across the duty day from duty start to mid-duty and duty end. The pattern of performance change, however, was different for the nighttime and mixed schedules in comparison to pilots working the daytime schedules. Interestingly, the nighttime and mixed schedules started their duties with better PVT speed than the daytime schedules, likely due to night duties starting in the evening during high circadian wakefulness versus daytime duties that begin in the early morning near the end of the WOCL. However, throughout the duty, nighttime and mixed schedules showed a greater decrement in performance and increased fatigue/sleepiness ratings at both mid-duty (around 0100) and duty end (~0700). Daytime schedules had relatively stable performance from pre- to mid-duty but showed the worst performance at duty end (~1900). This finding is similar to previous research on HAA medical crews, in which PVT response speed increased over a given shift (Rose et al., 2023). Our findings suggest that circadian effects are driving the pattern of fatigue effects across different schedule types and present different targets for fatigue awareness training and intervention approaches.

Across all schedule types, performance on the PVT and subjective sleepiness and fatigue ratings worsened from Pre-hitch to Post-hitch. This suggests that pilots do not recover fully after

3 days off-duty, which is aligned with in-laboratory cumulative partial sleep loss research (Belenky et al., 2003). Our sleep data showed that pilots obtain 6.9 hours of sleep on average during the Post-hitch period after 7 days of reduced sleep, which may be a factor in the reduced performance and ratings observed Post-hitch. Research shows that one night of recovery sleep isn't enough to fully recover from multiple days of sleep restriction, though the magnitude of the recovery response is affected by the amount of recovery sleep obtained (Banks et al., 2010). Ultimately, the 6.9 hours of total sleep time observed during the Post-hitch period in the current study are likely not enough to fully recover from the partial chronic sleep restriction experienced across the hitch. Previous research has highlighted the nuanced recovery trajectory of EMS shift workers and noted particularly difficult recovery periods following individual 12-hr shifts compared with 24-hr shifts (Patterson et al., 2015a). However, given that the Pre-hitch period includes the last 3 days off following the pilot's last worked hitch, there is clearly improvement across the 7 days off-duty. This suggests that the full week of recovery between hitches is a benefit of the rotating schedules and that sleep opportunities during these off weeks should be protected.

4.4 Research Q2B. Circadian disruptions from WOCL incursions

Pilots are at particular risk of fatigue when flight and job duties occur during the WOCL, when alertness is least promoted physiologically. The current findings support this, as trips that encroached on the WOCL (0200-0600) were associated with slower reaction times, more lapses, and higher sleepiness and fatigue ratings than nighttime trips that did not encroach on the WOCL (i.e., during 1900-0200 and 0600-0700). This is in line with previous research, which found that more errors occurred during the WOCL period across all personnel types in HAA operations (Mollicone et al., 2023). Additionally, subjective ratings align with work showing that pilots report flying or any duties outside daytime hours, such as the WOCL, as being particularly fatiguing (Gander et al., 1998; Hilditch et al., 2023b).

The relationship between fatigue, sleepiness, and workload is nuanced and depends on the task at hand. For example, both high and low workloads can increase experienced fatigue under certain conditions (Grech et al., 2009; Arsintescu et al., 2020; Dorian et al., 2011; Matthews & Desmond, 2002). The relationship between workload and fatigue is complex and can change even over the course of consecutive days on duty (Grech et al., 2009). Within HAA operations, previous research has found that KSS decreased with higher workload scores (Flaa et al., 2019), while high workload in short-haul pilots was associated with worse PVT scores

(Arsintescu et al., 2020). In the current data, overall weighted workload ratings were not significantly different between WOCL and non-WOCL flights. However, ratings for the Mental Demand subcomponent of the NASA TLX were higher for WOCL flights, indicating that this aspect of workload may be particularly relevant during the WOCL. The NASA TLX defines Mental Demand using the question: "How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)?" Therefore, lowering the mental task demand for pilots may be particularly beneficial during the WOCL, which may include options such as having the OCC provide weather or other pertinent information to the pilot up front.

4.5 Research Q3. Sleep inertia

In the pre-study survey, sleep inertia was highlighted as a consistent issue by pilots, with over 50% reporting being 'sometimes' or more frequently affected by sleep inertia. In line with the survey results, the field study showed that pilots rate themselves as sleepier and more fatigued when awoken by a flight request (as opposed to already being awake), suggesting that sleep inertia may be an issue during those trips. Indeed, even sleepiness ratings post-trip were higher after trips following an awakening, suggesting there may be long-lasting inertia effects. Long-lasting sleep inertia may be compounded by the unmasking of latent sleepiness on the return-to-base leg of a trip, highlighting the need to focus on fatigue management strategies in these scenarios. Additionally, sleep inertia effects may be worsened by other co-occurring fatigue risks that are common in shift work, such as cumulative sleep loss and waking during the physiological night (McHill et al., 2019; Scheer et al., 2008), highlighting the need to address it within HAA operations.

Sleep inertia can be operationally addressed at multiple levels, including minimizing the chance of sleep inertia occurring, managing the severity of sleep inertia effects, or minimizing the risk of errors that could occur due to sleep inertia (Kovac et al., 2023a). It is important to consider end-user perspectives when designing and implementing countermeasures to sleep inertia (Kovac et al., 2023b). To this end, pilots were offered the opportunity to provide suggested mitigation strategies through open-ended questions. Suggestions included avoiding non-urgent interagency facility transports during the circadian low (during which time the biological drive for sleep is highest) or implementing a 10-minute buffer between calls and take-off to allow dissipation of the most severe sleep inertia symptoms. While the time pressure involved in emergency response operations makes some strategies difficult to implement

(Kovac et al., 2022), simply re-ordering tasks within the first few minutes could be effective. For example, using the first few minutes to get dressed and use the restroom before receiving operational information, instead of receiving information immediately upon waking up and then getting ready. Given the frequency of reported sleep inertia issues, particularly on nighttime duty, it may be worth investigating these mitigation strategies further.

4.6 Study limitations

While the current dataset provides the most comprehensive fatigue assessment of US HAA operations to date, there are limitations to note. First, the maturity of fatigue risk management as well as operational tempo varies across operators. While we sought to include a representative sample of the US HAA field, some of these fatigue risks may apply more to some operators than others. Additionally, the current study was restricted to pilots working their assigned 7-day hitches. Therefore, the effects of overtime or 14-day duty periods could not be assessed. However, the effects of increasingly poorer performance across the 7-day duty period suggest that working longer shift durations or over 7 days would likely show continued worsening effects. Additionally, the finding that pilots showed the worst performance during the 3-day post-hitch period may be impacted by the small number of pilots (n = 20) who were working multiple jobs.

It is also worth noting that, in general, subjective sleepiness and fatigue ratings were low across the study and showed little variance, with pilots averaging below 3 for the SP ("Some vitality") and below 4 for the KSS ("Rather alert"). Along with the relatively small effect sizes of changes in KSS and SP, these findings may suggest that pilots largely perceive themselves as alert throughout their duty periods. However, this may also indicate a reluctance to report higher levels of fatigue or sleepiness. While we took care to explain the confidential and anonymized nature of the data, it is possible that under-reporting of fatigue may have occurred. Similarly, while the lower PVT performance observed during the Post-hitch period may be due to chronic partial sleep loss experienced across the hitch, it is also possible that task fatigue (due to completing the PVT multiple times per day for several days) contributed to the reduced performance on this task at the end of the study.

As our sample was limited to pilots who chose and met the schedule requirements to enroll, individual differences may impact the results. For example, though known as a fatigue risk among operations, there was a limited number of pilots who enrolled who reported having an additional job. Therefore, the specific contribution of this demographic could not be fully explored. Finally, pilots retrospectively assessed their sleepiness and fatigue experienced upon receipt of the flight request by rating these factors after returning from a trip. While this was an operationally necessary procedure in order to avoid any delays in responding to flight requests, it may have reduced the accuracy of such assessments and thus limited our interpretation of the sleep inertia data. However, pilots were aware that they would need to provide these ratings and therefore had the ability to mentally note their state at the time to record later.

4.7 Future research

The current research establishes a benchmark for fatigue risk in HAA operations and suggests a number of routes for future research. Previous work has identified differences in HAA-related fatigue due to season and time of year in Scandinavian countries, likely related to light availability through different points in the year (Flaa et al., 2021; Fletcher et al., 2022). Given the role of environmental factors and geography in HAA operational complexity (Baumgartner et al., 2025), future research could similarly look at differences in fatigue due to time of year and base locations across the US. Additionally, the relationship between workload and fatigue in these operations deserves more attention in future work. Workload factors, including the number of flight requests, overtime, the use of night vision goggles, or other operational factors that may be specific to HAA operations, deserve consideration (Radstaak, et al., 2014b; Bushmaker et al., 2019). Further investigation of tailored mitigations for fatigue in this population is necessary, potentially including techniques such as napping (Martin-Gill et al., 2018), banking sleep before shifts (Patterson et al., 2019a), exercise (Zakariassen et al., 2019), and fatigue training targeting individual health in EMS shift workers (Barger et al. 2018). Finally, fatigue is not limited to pilots within HAA operations, and the different schedule types and workloads of personnel, including medical crews, maintainers, and operational control specialists, should be evaluated to mitigate fatigue risks within these operations.

4.8 Conclusion

The current data offer a comprehensive benchmark assessment of fatigue risk within the US HAA pilot population. Overall, much of the current data support that, in general, there are few observable differences between pilots on daytime, nighttime, or mixed schedule duties. Pilots used napping strategies to maintain a similar amount of sleep on night shift in comparison to days, indicating that on-duty naps are critical to maintaining overall sleep patterns. However, small but significant effects of fatigue were observed across the days on duty, within duty days, and across phases of study. Altogether, the current findings indicate the presence of cumulative fatigue across consecutive duty days, fatigue due to circadian disruption at different times of the day, and the effects of sleep inertia for pilots waking up for flight requests. While these effects were relatively small, suggesting that fatigue is largely managed within these operations, there are still areas of improvement to address the observed fatigue findings.

Altogether, these results offer the most comprehensive assessment of US HAA pilot fatigue since the introduction of updated HAA regulations in 2014 and offer a number of potential fatigue mitigation opportunities for the industry.

Our results are limited to 7-day on/7-day off 12-hour duty schedules but suggest that extending the duty period beyond 7 days or reducing the recovery period under 7 days may result in significant further increases to fatigue and would require additional fatigue mitigation strategies.

Specific recommendations to operators that stem from this work include considering the following factors as part of pre-flight risk assessments:

- Whether flights occur during the window of circadian low (WOCL, 0200 – 0600), and reschedule non-time sensitive requests;
- Whether the pilot just woke up (i.e., may be suffering from sleep inertia), and provide extra time before the pilot engages in safety-critical tasks;
- How many days a pilot has been on duty, as performance significantly worsened by day 4 of a duty period; and
- How many previous flight requests have been accepted during a night duty, given that >3 trips were noted as potentially fatiguing (although objective data are needed to confirm these reports).

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Appendix A. Survey questions

Definitions

- **Shift:** a duty period that is typically 12 hours in duration.
- **Hitch:** a series of shifts that is typically scheduled for 7 to 14 days in a row.

Survey Question Items

Organization Characteristics

1. About how many HAA pilots are currently employed at your company? [[numeric]]

2. Is an operational control center (OCC) required at your company? [[multiple choice]]
   - Yes
   - No
   - Don't know / not sure

3. Do you mostly fly single-pilot or dual-pilot? [[multiple choice]]
   - I always fly single-pilot
   - I mostly fly single-pilot
   - I sometimes fly single-pilot
   - I rarely fly single-pilot
   - I never fly single-pilot

4. How many years of experience do you have in your current role as HAA pilot? [[numeric]]

   _______(years)

5. What make/model helicopter(s) do you fly for HAA operations? [[textbox entry]]

Approximately how many flight hours do you have with your most frequently flown helicopter model (and state the type)? [[numeric, text entry]]

   _______(hours), type: _______

6. For most HAA operations that your company flies, how many crewmembers are on your team?

7. How long is the average HAA flight/transport at your company? [[numeric time]]

   _______(minutes)

8. How many missions do you fly during a typical hitch?

Missions for a hitch consisting of day shifts: _______ [[numeric]]

Missions for a hitch consisting of night shifts: _______ [[numeric]]

Other Hitch (please specify) _______ [[numeric]] [[text box]]

Base Characteristics

9. In which time zone is your base located? [[multiple choice]]
   - Atlantic (AT)
   - Eastern (ET)
   - Central (CT)
   - Mountain (MT)
   - Pacific (PT)
   - Alaska (AKT)
   - Hawaii-Aleutian (HT)
   - Samoa (ST)
   - Chamorro [Guam] (ChT)
   - Other (please specify)

10. In which time zone is your home located? [[multiple choice]]
   - Atlantic (AT)
   - Eastern (ET)
   - Central (CT)
   - Mountain (MT)
   - Pacific (PT)
   - Alaska (AKT)
   - Hawaii-Aleutian (HT)
   - Samoa (ST)
   - Chamorro [Guam] (ChT)
   - Other (please specify)

11. What is your primary mode of transportation when going to work? [[multiple choice]]
   - Drive a personal motor vehicle (e.g., car, truck, motorcycle)
   - Take public transit (e.g., bus, train)
   - Carpool or rideshare
   - Bicycle
   - Fly, as a passenger
   - Fly, as a pilot
   - Other (please specify) [[text box]]

12. How long is your commute to work?

    ________(minutes)

13. Where do you primarily stay/sleep between shifts during your hitches? [[multiple choice]]
   - I stay at home between shifts.

- I stay at base between shifts.
- I stay elsewhere between shifts (please describe). [[text box]]

Preparation for Shift

14. What sleep strategies do you use (if any) to prepare for a hitch with daytime shifts? [[text box]]

15. What sleep strategies do you use (if any) to prepare for a hitch with nighttime shifts? [[text box]]

16. How much do you typically sleep on-shift during a:

    Daytime Shift _______ (hours) [[numeric entry]]

    Nighttime Shift _______ (hours) [[numeric entry]]

Other Work

17. Do you currently hold another job in addition to your HAA flying job? [[multiple choice]]
    - Yes
    - No

[[if "Yes" to previous item]] How many hours do you spend at your additional job(s) during a typical month? [[numeric]]

_______ (hours)

Fatigue Perceptions

18. What is the longest shift duty duration you feel comfortable working with regard to fatigue?

    Longest Daytime Shift _______ (hours) [[numeric entry]]

    Longest Nighttime Shift _______ (hours) [[numeric entry]]

19. What is the maximum number of flight requests you would accept on a given night shift before fatigue becomes a risk? [[numeric entry]]

    _______ (number of flights)

20. How often do you experience fatigue while on duty during: [[multiple choice]]
    a) Daytime Shifts
        - All of the time
        - Frequently
        - Some of the time
        - Occasionally
        - Never
    b) Nighttime Shifts
        - All of the time
        - Often

- Sometimes
- Rarely
- Never

21. Which of the following factors do you think contributed to your fatigue while on duty? [Mark all that apply]
    - Workload
    - Work pace
    - Work schedule
    - Timing of shift
    - Number of flight requests
    - Family demands
    - Physical health
    - Other (Please specify)

22. When your flight performance is affected by fatigue, which phase of flight is most affected? [[multiple choice]]
    - Pre-flight
    - Pickup leg
    - Dropoff leg
    - Reposition leg
    - Return to base leg
    - Post-flight
    - N/A

23. How often do you catch yourself "nodding off" during a flight? [[multiple choice]]
    - All of the time
    - Often
    - Sometimes
    - Rarely
    - Never

24. Have you ever turned down an HAA flight request because of fatigue? [[multiple choice]]
    - Yes
    - No
    - Prefer not to say

25. In retrospect, are there HAA flights that you should have turned down because of fatigue? [[multiple choice]]
    - Yes
    - No
    - Prefer not to say

26. Have you had an accident or incident because of excessive fatigue? [[multiple choice]]

- Yes
- No
- Prefer not to say

27. Sleep inertia is defined as the grogginess that you feel immediately after waking up. Sleep inertia can significantly affect your performance for anywhere from 10 minutes to 2 hours after waking up, although most of these effects appear to subside within about 20 minutes.

    In your role as an HAA pilot, how often does sleep inertia affect your performance? [[Multiple choice]]

    - All of the time
    - Often
    - Sometimes
    - Rarely
    - Never

Other

Please add any additional comments or suggestions you may have. Note that these comments may be eventually shared throughout the HAA industry but will be anonymized. [[text box]]

Morningness-Eveningness Questionnaire (MEQ)

1. Considering only your own "feeling best" rhythm, at what time would you get up if you were entirely free to plan your day? [[time]]
2. Considering only your own "feeling best" rhythm, at what time would you go to bed if you were entirely free to plan your evening? [[time]]
3. If there is a specific time at which you have to get up in the morning, to what extent are you dependent on being woken up by an alarm clock? [[multiple choice]]
    - Not at all dependent
    - Slightly dependent
    - Fairly dependent
    - Very dependent
4. Assuming adequate environmental conditions, how easy do you find getting up in the mornings? [[multiple choice]]
    - Not at all easy
    - Not very easy
    - Fairly easy
    - Very easy
5. How alert do you feel during the first half hour after having woken in the mornings? [[multiple choice]]
    - Not at all alert
    - Slightly alert
    - Fairly alert
    - Very alert
6. How is your appetite during the first half-hour after having woken in the mornings? [[multiple choice]]
    - Very poor

- Fairly poor
- Fairly good
- Very good

7. During the first half-hour after having woken in the morning, how tired do you feel? [[multiple choice]]
    - Very tired
    - Fairly tired
    - Fairly refreshed
    - Very refreshed
8. If you have no commitments the next day, what time would you go to bed compared to your usual bedtime? [[multiple choice]]
    - Seldom or never later
    - Less than one hour later
    - 1-2 hours later
    - More than two hours later
9. You have decided to engage in some physical exercise. A friend suggests that you do this for one hour twice a week and the best time for him is between 7:00 – 8:00 am. Bearing in mind nothing but your own internal “clock”, how do you think you would perform? [[multiple choice]]
    - Would be on good form
    - Would be on reasonable form
    - Would find it difficult
    - Would find it very difficult
10. At what time of day do you feel you become tired as a result of need for sleep? [[time]]
11. You want to be at your peak performance for a test that you know is going to be mentally exhausting and will last for two hours. You are entirely free to plan your day. Considering only your own internal “clock”, which ONE of the four testing times would you choose? [[multiple choice]]
    - 8:00-10:00am
    - 11:00am-1:00pm
    - 3:00-5:00pm
    - 7:00-9:00pm
12. If you got into bed at 11:00 PM, how tired would you be? [[multiple choice]]
    - Not at all tired
    - A little tired
    - Fairly tired
    - Very tired
13. For some reason you have gone to bed several hours later than usual, but there is no need to get up at any particular time the next morning. Which ONE of the following are you most likely to do? [[multiple choice]]
    - Will wake up at usual time and will NOT fall asleep
    - Will wake up at usual time and will doze thereafter
    - Will wake up at usual time but will fall asleep again
    - Will NOT wake up until later than usual
14. One night you have to remain awake between 4:00 – 6:00 AM in order to carry out a night watch. You have no commitments the next day. Which ONE of the alternatives will suit you best? [[multiple choice]]

- Would NOT go to bed until watch was over
- Would take a nap before and sleep after
- Would take a good sleep before and nap after
- Would take ALL sleep before watch

15. You have to do two hours of hard physical work. You are entirely free to plan your day and considering only your own internal "clock" which ONE of the following time would you choose? [[multiple choice]]
    - 8:00-10:00am
    - 11:00am-1:00pm
    - 3:00-5:00pm
    - 7:00-9:00pm
16. You have decided to engage in hard physical exercise. A friend suggests that you do this for one hour twice a week and the best time for him is between 10:00 – 11:00 PM. Bearing in mind nothing else but your own internal "clock" how well do you think you would perform? [[multiple choice]]
    - Would be on good form
    - Would be on reasonable form
    - Would find it difficult
    - Would find it very difficult
17. Suppose that you can choose your own work hours. Assume that you worked a FIVE hour day (including breaks) and that your job was interesting and paid by results). Which FIVE CONSECUTIVE HOURS would you select? [[select hours on a midnight-to-midnight timeline]]
18. At what time of the day do you think that you reach your "feeling best" peak? [[time]]
19. One hears about "morning" and "evening" types of people. Which ONE of these types do you consider yourself to be? [[multiple choice]]
    - Definitely a "morning" type
    - Rather more a "morning" than an evening type
    - Rather more an "evening" than a "morning" type
    - Definitely an "evening" type

Epworth Sleepiness Scale (ESS)

How Sleepy Are You?

How likely are you to doze off or fall asleep in the following situations? You should rate your chances of dozing off, not just feeling tired. Even if you have not done some of these things recently try to determine how they would have affected you. For each situation, decide whether or not you would have:

- No chance of dozing
- Slight chance of dozing
- Moderate chance of dozing
- High chance of dozing

1. Sitting and reading [[multiple choice]]
    a. No chance of dozing

b. Slight chance of dozing
c. Moderate chance of dozing
d. High chance of dozing

2. Watching TV [[multiple choice]]
    a. No chance of dozing
    b. Slight chance of dozing
    c. Moderate chance of dozing
    d. High chance of dozing
3. Sitting inactive in a public place (e.g., a theater or a meeting) [[multiple choice]]
    a. No chance of dozing
    b. Slight chance of dozing
    c. Moderate chance of dozing
    d. High chance of dozing
4. As a passenger in a car for an hour without a break [[multiple choice]]
    a. No chance of dozing
    b. Slight chance of dozing
    c. Moderate chance of dozing
    d. High chance of dozing
5. Lying down to rest in the afternoon when circumstances permit [[multiple choice]]
    a. No chance of dozing
    b. Slight chance of dozing
    c. Moderate chance of dozing
    d. High chance of dozing
6. Sitting and talking to someone [[multiple choice]]
    a. No chance of dozing
    b. Slight chance of dozing
    c. Moderate chance of dozing
    d. High chance of dozing
7. Sitting quietly after a lunch without alcohol [[multiple choice]]
    a. No chance of dozing
    b. Slight chance of dozing
    c. Moderate chance of dozing
    d. High chance of dozing
8. In a car, while stopped for a few minutes in traffic [[multiple choice]]
    a. No chance of dozing
    b. Slight chance of dozing
    c. Moderate chance of dozing
    d. High chance of dozing

Pittsburgh Sleep Quality Index

The following questions relate to your usual sleep habits during the past month only. Your answers should indicate the most accurate reply for the majority of days and nights in the past month. Please answer all questions.

1. During the past month, what time have you usually gone to bed at night? [[time]]
    a. BED TIME ___________

2. During the past month, how long (in minutes) has it usually taken you to fall asleep each night? [[numeric minutes]]
    a. NUMBER OF MINUTES ___________
3. During the past month, what time have you usually gotten up in the morning? [[time]]
    a. GETTING UP TIME ___________
4. During the past month, how many hours of actual sleep did you get at night? (This may be different than the number of hours you spent in bed.) [[numeric hours]]
    a. HOURS OF SLEEP PER NIGHT ___________

For each of the remaining questions, check the one best response. Please answer all questions.

5. During the past month, how often have you had trouble sleeping because you…
    a. Cannot get to sleep within 30 minutes of getting in bed [[multiple choice]]
        i. Not during the past month
        ii. Less than once a week
        iii. Once or twice a week
        iv. Three or more times a week
    b. Wake up in the middle of the night or early morning [[multiple choice]]
        i. Not during the past month
        ii. Less than once a week
        iii. Once or twice a week
        iv. Three or more times a week
    c. Have to get up to use the bathroom [[multiple choice]]
        i. Not during the past month
        ii. Less than once a week
        iii. Once or twice a week
        iv. Three or more times a week
    d. Cannot breathe comfortably [[multiple choice]]
        i. Not during the past month
        ii. Less than once a week
        iii. Once or twice a week
        iv. Three or more times a week
    e. Cough or snore loudly [[multiple choice]]
        i. Not during the past month
        ii. Less than once a week
        iii. Once or twice a week
        iv. Three or more times a week
    f. Feel too cold [[multiple choice]]
        i. Not during the past month
        ii. Less than once a week
        iii. Once or twice a week
        iv. Three or more times a week
    g. Feel too hot [[multiple choice]]
        i. Not during the past month
        ii. Less than once a week
        iii. Once or twice a week
        iv. Three or more times a week
    h. Had bad dreams [[multiple choice]]

        i. Not during the past month
        ii. Less than once a week
        iii. Once or twice a week
        iv. Three or more times a week
    i. Have pain [[multiple choice]]
        i. Not during the past month
        ii. Less than once a week
        iii. Once or twice a week
        iv. Three or more times a week
    j. Other reason(s), please describe [[text box]]
    How often during the past month have you had trouble sleeping because of this? [[multiple choice]]
        i. Not during the past month
        ii. Less than once a week
        iii. Once or twice a week
        iv. Three or more times a week
6. During the past month, how would you rate your sleep quality overall? [[multiple choice]]
    a. Very good
    b. Fairly good
    c. Fairly bad
    d. Very bad
7. During the past month, how often have you taken medicine to help you sleep (prescribed or "over the counter")? [[multiple choice]]
    a. Not during the past month
    b. Less than once a week
    c. Once or twice a week
    d. Three or more times a week
8. During the past month, how often have you had trouble staying awake while driving, eating meals, or engaging in social activity? [[multiple choice]]
    a. Not during the past month
    b. Less than once a week
    c. Once or twice a week
    d. Three or more times a week
9. During the past month, how much of a problem has it been for you to keep up enough enthusiasm to get things done? [[multiple choice]]
    a. No problem at all
    b. Only a very slight problem
    c. Somewhat of a problem
    d. A very big problem
10. Do you have a bed partner or room mate? [[multiple choice]]
    a. No bed partner or room mate
    b. Partner/room mate in other room
    c. Partner in same room, but not same bed
    d. Partner in same bed

If you have a room mate or bed partner, ask him/her how often in the past month you have had…

a. Loud snoring [[multiple choice]]
    a. Not during the past month
    b. Less than once a week
    c. Once or twice a week
    d. Three or more times a week
b. Long pauses between breaths while asleep [[multiple choice]]
    a. Not during the past month
    b. Less than once a week
    c. Once or twice a week
    d. Three or more times a week
c. Legs twitching or jerking while you sleep [[multiple choice]]
    a. Not during the past month
    b. Less than once a week
    c. Once or twice a week
    d. Three or more times a week
d. Episodes of disorientation or confusion during sleep [[multiple choice]]
    a. Not during the past month
    b. Less than once a week
    c. Once or twice a week
    d. Three or more times a week
e. Other restlessness while you sleep; please describe [[text box]] [[multiple choice]]
    a. Not during the past month
    b. Less than once a week
    c. Once or twice a week
    d. Three or more times a week

Appendix B. Supplemental data tables

Table B-1. Summary of schedule type differences for demographic data

Variable	Kruskal – Wallis Rank Sum Test		
	χ^2	df	*p*-value
Age (yrs)	0.183	2	0.913
HAA experience (yrs)	2.349	2	0.309
HAA flight hours	0.896	2	0.639
MEQ Score	0.677	2	0.713
ESS Score	1.915	2	0.384
PSQI Score	0.622	2	0.733

Variable	Pearson's Chi-Squared Test		
	χ^2	df	*p*-value
Sex - Male	0.124	2	0.940
Additional job	5.223	2	0.073
Single pilot	3.778	4	0.437
Has an OCC	6.253	4	0.181

Summary of baseline group comparisons between daytime, nighttime, and mixed schedule type workers. Kruskal – Wallis Rank Sum Test was used for numerical data and Pearson's Chi-Squared Test was used for categorical data. HAA = helicopter air ambulance; MEQ = Morningness-Eveningness Questionairre; ESS = Epworth Sleepiness Scale; PSQI = Pittsburgh Sleep Quality Index; OCC = Operational Control Center.

Table B-2. Backwards stepwise mixed-effects models for retained covariates

Outcome	Variable	OR	*CI*	*p*	R^2_M (R^2_C)
SP	PSQI	1.16	1.06, 1.26	<0.001	0.032 (0.277)
	Gender	0.44	0.21, 0.93	0.032	
KSS	PSQI	1.18	1.07, 1.29	<0.001	0.041 (0.314)
	Gender	0.44	0.20, 1.00	0.051	

Note. OR = Odds ratio; *CI* = confidence intervals; R^2_M = marginal R^2; R^2_C = conditional R^2; PVT = Psychomotor Vigilance Task; SP = Samn-Perelli scale; KSS = Karolinska Sleepiness Scale; PSQI = Pittsburgh Sleep Quality Index. All data used for analyses.

Table B-3. Analysis of days on duty by schedule type on performance.

Outcome	R^2_M (R^2_C)	p-Values		
		Days on duty	Schedule type	Days on duty * Schedule type
PVT Speed	0.019 (0.707)	<0.001	0.593	0.943
PVT Lapses	0.038 (0.718)	<0.001	0.398	0.526
SP	0.046 (0.331)	0.217	0.094	0.003
KSS	0.042 (0.322)	0.815	0.097	0.004
Total sleep time (h)	0.026 (0.225)	0.478	0.469	0.319
Sleep periods	0.140 (0.320)	0.203	<0.001	<0.001

Note. R^2_M = marginal R^2; R^2_C = conditional R^2; PVT = Psychomotor Vigilance Task; SP = Samn-Perelli scale; KSS = Karolinska Sleepiness Scale.

Table B-4. Predictors of days on duty by schedule type.

Outcome	Comparison	*b*	*CI*	*p*
PVT Speed	Duty Day 1 – Duty Day 2	0.02	-0.07, 0.10	0.705
	Duty Day 1 – Duty Day 3	-0.05	-0.14, 0.04	0.252
	Duty Day 1 – Duty Day 4	-0.12	-0.20, -0.03	0.008
	Duty Day 1 – Duty Day 5	-0.10	-0.19, -0.02	0.019
	Duty Day 1 – Duty Day 6	-0.15	-0.24, -0.07	<0.001
	Duty Day 1 – Duty Day 7	-0.22	-0.31, -0.13	<0.001
Outcome	**Comparison**	**IRR**	**CI**	***p***
PVT Lapses	Duty Day 1 – Duty Day 2	0.66	0.43, 0.93	0.017
	Duty Day 1 – Duty Day 3	1.06	0.77, 1.45	0.726
	Duty Day 1 – Duty Day 4	1.29	0.94, 1.76	0.118
	Duty Day 1 – Duty Day 5	1.23	0.89, 1.68	0.208
	Duty Day 1 – Duty Day 6	1.44	1.06, 1.97	0.021
	Duty Day 1 – Duty Day 7	1.82	1.35, 2.46	<0.001
Outcome	**Comparison**	**OR**	**CI**	***p***
SP	Duty Day 1 – Duty Day 2	1.02	0.66 1.59	0.916
	Duty Day 1 – Duty Day 3	1.19	0.77, 1.84	0.444
	Duty Day 1 – Duty Day 4	1.35	0.86, 2.11	0.189
	Duty Day 1 – Duty Day 5	1.63	1.05, 2.52	0.029
	Duty Day 1 – Duty Day 6	1.52	0.99, 2.35	0.057
	Duty Day 1 – Duty Day 7	1.23	0.79, 1.91	0.367
KSS	Duty Day 1 – Duty Day 2	1.01	0.67, 1.53	0.963

	Duty Day 1 – Duty Day 3	1.03	0.68, 1.57	0.876
	Duty Day 1 – Duty Day 4	1.02	0.67, 1.56	0.915
	Duty Day 1 – Duty Day 5	1.17	0.77, 1.78	0.451
	Duty Day 1 – Duty Day 6	1.15	0.76, 1.74	0.508
	Duty Day 1 – Duty Day 7	0.85	0.56, 1.29	0.453
Total sleep time (h)	Duty Day 1 – Duty Day 2	-0.12	-0.78, 0.55	0.726
	Duty Day 1 – Duty Day 3	-0.03	-0.69, 0.63	0.928
	Duty Day 1 – Duty Day 4	-0.14	-0.80, 0.53	0.682
	Duty Day 1 – Duty Day 5	-0.25	-0.92, 0.41	0.455
	Duty Day 1 – Duty Day 6	-0.37	-1.03, 0.29	0.275
	Duty Day 1 – Duty Day 7	0.09	-0.57, 0.76	0.786
Sleep periods	Duty Day 1 – Duty Day 2	-0.17	-0.43, 0.09	0.198
	Duty Day 1 – Duty Day 3	-0.06	-0.32, 0.20	0.667
	Duty Day 1 – Duty Day 4	-0.14	-0.40, 0.12	0.283
	Duty Day 1 – Duty Day 5	-0.11	-0.38, 0.15	0.390
	Duty Day 1 – Duty Day 6	-0.20	-0.46, 0.06	0.133
	Duty Day 1 – Duty Day 7	-0.29	-0.55, -0.02	0.032

Note. *CI* = confidence interval; PVT = Psychomotor Vigilance Task; SP = Samn-Perelli scale; KSS = Karolinska Sleepiness Scale; IRR = Incidence Rate Ratio; OR = Odds ratio.

Table B-5. Analysis of time in shift by schedule type

Outcome	R^2_M (R^2_C)	**p-Values**		
		Time in shift	**Schedule type**	**Time in shift * Schedule type**
PVT Speed	0.015 (0.633)	<0.001	0.667	<0.001
PVT Lapses	0.018 (0.720)	<0.001	0.614	<0.001
SP	0.122 (0.374)	<0.001	0.629	<0.001
KSS	0.076 (0.314)	<0.001	0.642	<0.001

Note. R^2_M = marginal R^2; R^2_C = conditional R^2; PVT = Psychomotor Vigilance Task; SP = Samn-Perelli scale; KSS = Karolinska Sleepiness Scale.

Table B-6. Post-hoc comparisons of time in shift.

Outcome	**Comparison**	***b* (*SE*)**	**df**	***T/Z ratio***	$P_{corrected}$
PVT Speed	Start Day – Mid Day	-0.031 (0.024)	4170	-1.314	1.000
	Start Day – End Day	0.090 (0.024)	4170	3.753	0.006
	Mid Day – End Day	0.121 (0.024)	4169	5.068	<0.001

	Start Night – Mid Night	0.189 (0.024)	4169	7.761	<0.001
	Start Night – End Night	0.136 (0.024)	4169	5.581	<0.001
	Mid Night – End Night	-0.053 (0.024)	4169	-2.205	0.991
	Start Mixed – Mid Mixed	0.131 (0.025)	4169	5.332	<0.001
	Start Mixed – End Mixed	0.110 (0.024)	4169	4.514	<0.001
	Mid Mixed – End Mixed	-0.021 (0.025)	4169	-0.845	1.000
PVT Lapses	Start Day – Mid Day	0.032 (0.077)	Inf	0.416	1.000
	Start Day – End Day	-0.305 (0.105)	Inf	-2.910	0.086
	Mid Day – End Day	-0.338 (0.107)	Inf	-3.149	0.043
	Start Night – Mid Night	-0.252 (0.091)	Inf	-2.781	0.121
	Start Night – End Night	-0.198 (0.084)	Inf	-2.369	0.301
	Mid Night – End Night	0.054 (0.084)	Inf	0.643	0.999
	Start Mixed – Mid Mixed	-0.339 (0.096)	Inf	-3.546	0.012
	Start Mixed – End Mixed	-0.171 (0.071)	Inf	-2.395	0.286
	Mid Mixed – End Mixed	0.168 (0.083)	Inf	-0.137	1.000
SP	Start Day – Mid Day	-0.044 (0.111)	Inf	-0.394	1.000
	Start Day – End Day	-0.980 (0.111)	Inf	-8.844	<0.001
	Mid Day – End Day	-0.936 (0.110)	Inf	-8.501	<0.001
	Start Night – Mid Night	-2.287 (0.127)	Inf	-18.033	<0.001
	Start Night – End Night	-1.839 (0.125)	Inf	-14.688	<0.001
	Mid Night – End Night	0.449 (0.119)	Inf	3.766	0.005
	Start Mixed – Mid Mixed	-1.009 (0.127)	Inf	-7.947	<0.001
	Start Mixed – End Mixed	-1.081 (0.121)	Inf	-8.920	<0.001
	Mid Mixed – End Mixed	-0.071 (0.126)	Inf	-0.564	1.000
KSS	Start Day – Mid Day	0.002 (0.104)	Inf	0.023	1.000
	Start Day – End Day	-0.686 (0.103)	Inf	-6.650	<0.001
	Mid Day – End Day	-0.689 (0.103)	Inf	-6.677	<0.001
	Start Night – Mid Night	-1.637 (0.113)	Inf	-14.457	<0.001
	Start Night – End Night	-1.454 (0.112)	Inf	-13.036	<0.001
	Mid Night – End Night	0.182 (0.113)	Inf	1.613	0.798
	Start Mixed – Mid Mixed	-0.557 (0.121)	Inf	-4.605	<0.001
	Start Mixed – End Mixed	-0.828 (0.115)	Inf	-7.208	<0.001
	Mid Mixed – End Mixed	-0.272 (0.122)	Inf	-2.227	0.388

Note. SE = standard error; df = degrees of freedom; PVT = Psychomotor Vigilance Task; SP = Samn-Perelli scale; KSS = Karolinska Sleepiness Scale. *p*-values corrected using Bonferroni method.

Table B-7. Analysis of phase of study by schedule type.

Outcome	R^2_M (R^2_C)	*p*-Values		
		Phase of study	Schedule type	Phase of study * Schedule type
PVT Speed	0.038 (0.656)	<0.001	0.726	<0.001

PVT Lapses	0.050 (0.730)	<0.001	0.531	0.020
SP	0.049 (0.291)	<0.001	0.178	<0.001
KSS	0.029 (0.263)	0.011	0.569	<0.001
Total sleep time (h)	0.019 (0.200)	<0.001	0.959	0.116
Sleep periods	0.165 (0.261)	<0.001	0.002	<0.001

Note. R^2_M = marginal R^2; R^2_C = conditional R^2; PVT = Psychomotor Vigilance Task; SP = Samn-Perelli scale; KSS = Karolinska Sleepiness Scale.

Table B-8. Post-hoc comparison of phases of study.

Outcome	**Comparison**	***b* (*SE*)**	**df**	***T/Z* ratio**	$P_{corrected}$
PVT Speed	Pre-Hitch Day – Hitch Day	0.151 (0.023)	4170	6.502	<0.001
	Pre-Hitch Day – Post-Hitch Day	0.335 (0.028)	4170	12.009	<0.001
	Hitch Day – Post-Hitch Day	0.184 (0.024)	4172	7.700	<0.001
	Pre-Hitch Night – Hitch Night	0.035 (0.024)	4170	1.454	1.000
	Pre-Hitch Night – Post-Hitch Night	0.234 (0.029)	4173	8.113	<0.001
	Hitch Night – Post-Hitch Night	0.199 (0.024)	4172	8.157	<0.001
	Pre-Hitch Mixed – Hitch Mixed	0.069 (0.024)	4169	2.899	0.135
	Pre-Hitch Mixed – Post-Hitch Mixed	0368 (0.029)	4171	12.679	<0.001
	Hitch Mixed – Post-Hitch Mixed	0.300 (0.025)	4172	12.028	<0.001
PVT Lapses	Pre-Hitch Day – Hitch Day	-0.300 (0.086)	Inf	-3.488	0.014
	Pre-Hitch Day – Post-Hitch Day	-0.839 (0.189)	Inf	-4.452	<0.001
	Hitch Day – Post-Hitch Day	-0.540 (0.146)	Inf	-3.701	0.007
	Pre-Hitch Night – Hitch Night	-0.022 (0.067)	Inf	-0.328	1.000
	Pre-Hitch Night – Post-Hitch Night	-0.673 (0.169)	Inf	-3.976	0.002
	Hitch Night – Post-Hitch Night	-0.651 (0.160)	Inf	-4.058	0.002
	Pre-Hitch Mixed – Hitch Mixed	-0.142 (0.060)	Inf	-2.358	0.307
	Pre-Hitch Mixed – Post-Hitch Mixed	-0.836 (0.190)	Inf	-4.392	<0.001
	Hitch Mixed – Post-Hitch Mixed	-0.695 (0.166)	Inf	-4.181	0.001
SP	Pre-Hitch Day – Hitch Day	-0.266 (0.112)	Inf	-2.365	0.304
	Pre-Hitch Day – Post-Hitch Day	-0.780 (0.134)	Inf	-5.831	<0.001
	Hitch Day – Post-Hitch Day	-0.514 (0.111)	Inf	-4.639	<0.001
	Pre-Hitch Night – Hitch Night	0.051 (0.123)	Inf	0.412	1.000
	Pre-Hitch Night – Post-Hitch Night	-0.032 (0.147)	Inf	-0.215	1.000
	Hitch Night – Post-Hitch Night	-0.082 (0.124)	Inf	-0.665	0.999
	Pre-Hitch Mixed – Hitch Mixed	-0.494 (0.125)	Inf	-3.970	0.002
	Pre-Hitch Mixed – Post-Hitch Mixed	-1.242 (0.151)	Inf	-8.244	<0.001
	Hitch Mixed – Post-Hitch Mixed	-0.748 (0.127)	Inf	-5.908	<0.001
KSS	Pre-Hitch Day – Hitch Day	-0.017 (0.105)	Inf	-0.158	1.000
	Pre-Hitch Day – Post-Hitch Day	-0.313 (0.126)	Inf	-2.493	0.235
	Hitch Day – Post-Hitch Day	-0.296 (0.105)	Inf	-2.829	0.107
	Pre-Hitch Night – Hitch Night	0.062 (0.116)	Inf	0.536	1.000
	Pre-Hitch Night – Post-Hitch Night	0.178 (0.137)	Inf	1.291	0.934

	Hitch Night – Post-Hitch Night	0.115 (0.114)	Inf	1.006	0.985
	Pre-Hitch Mixed – Hitch Mixed	-0.113 (0.118)	Inf	-0.957	0.990
	Pre-Hitch Mixed – Post-Hitch Mixed	-0.662 (0.144)	Inf	-4.590	<0.001
	Hitch Mixed – Post-Hitch Mixed	-0.549 (0.123)	Inf	-4.454	<0.001
Total sleep time (h)	Pre-Hitch – Hitch	0.410 (0.097)	1163	4.297	<0.001
	Pre-Hitch – Post-Hitch	0.113 (0.114)	1166	0.995	0.960
	Hitch – Post-Hitch	-0.297 (0.096)	1167	-3.081	0.006
Sleep periods	Pre-Hitch Day – Hitch Day	-0.112 (0.061)	1163	-1.832	1.000
	Pre-Hitch Day – Post-Hitch Day	0.062 (0.073)	1163	0.852	1.000
	Hitch Day – Post-Hitch Day	0.174 (0.062)	1163	2.825	0.173
	Pre-Hitch Night – Hitch Night	-0.518 (0.069)	1163	-7.560	<0.001
	Pre-Hitch Night – Post-Hitch Night	-0.012 (0.082)	1163	-0.151	1.000
	Hitch Night – Post-Hitch Night	0.506 (0.069)	1173	7.291	<0.001
	Pre-Hitch Mixed – Hitch Mixed	-0.482 (0.062)	1163	-7.860	<0.001
	Pre-Hitch Mixed – Post-Hitch Mixed	0.091 (0.073)	116	1.248	1.000
	Hitch Mixed – Post-Hitch Mixed	0.573 (0.062)	1168	9.238	<0.001

Note. SE = standard error; df = degrees of freedom; PVT = Psychomotor Vigilance Task; SP = Samn-Perelli scale; KSS = Karolinska Sleepiness Scale. *p*-values corrected using Bonferroni method.

Table B-9. Performance and workload in WOCL versus non-WOCL nighttime trips

Outcome	R^2_M (R^2_C)	***b***	***CI***	***p***
PVT Speed	0.020 (0.768)	-0.1	-0.29, -0.08	<0.001
Weighted Workload Average	0.001 (0.689)	1.12	-2.15, 4.39	0.499
Mental Demand	0.013 (0.593)	5.59	0.67, 10.51	0.026
Physical Demand	0.004 (0.646)	2.96	-1.55, 7.48	0.197
Temporal Demand	0.001 (0.349)	1.67	-4.41, 7.75	0.588
Performance	0.005 (0.433)	-2.76	-7.27, 1.75	0.230
Effort	0.002 (0.570)	2.18	-2.57, 6.93	0.367
Frustration	0.011 (0.462)	4.73	-0.32, 9.77	0.066
Outcome	R^2_M (R^2_C)	**IRR**	***CI***	***p***
PVT Lapses	0.028 (0.812)	1.81	1.21, 2.70	0.004
Outcome	R^2_M (R^2_C)	**OR**	***CI***	***p***
SP Post-flight	0.121 (613)	5.81	2.94, 11.49	<0.001
KSS Post-flight	0.151 (0.619)	6.81	3.41, 13.63	<0.001

Note. WOCL = window of circadian low; R^2_M = marginal R^2; R^2_C = conditional R^2; *CI* = confidence interval; PVT = Psychomotor Vigilance Task; IRR = Incidence rate ratio; SP = Samn-Perelli scale; KSS = Karolinska Sleepiness Scale; OR = Odds ratio.

Table B-10. Sleepiness and fatigue ratings when woken by flight requests.

Outcome	R^2_M (R^2_C)	**OR**	***CI***	***p***

SP Pre-flight	0.188 (0.519)	19.26	10.49, 35.36	<0.001
KSS Pre-flight	0.212 (0.561)	23.96	12.95, 44.34	<0.001
SP Post-flight	0.048 (0.386)	1.33	0.79, 2.26	0.285
KSS Post-flight	0.074 (0.486)	1.93	1.13, 3.27	0.015

Note. R^2_M = marginal R^2; R^2_C = conditional R^2; OR = Odds rtaio; *CI* = confidence interval; PVT = Psychomotor Vigilance Task; SP = Samn-Perelli scale; KSS = Karolinska Sleepiness Scale.