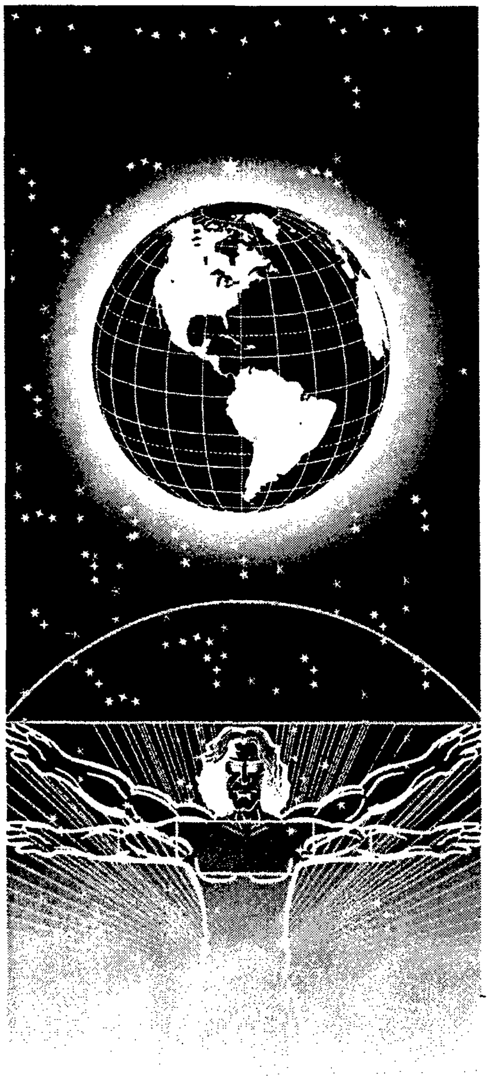
HSW-PE-BR-TR-2006-0001



UNITED STATES AIR FORCE
311th Human Systems Wing

Effects of Shift Work and Sustained Operations: Operator Performance in Remotely Piloted Aircraft (OP-REPAIR)

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January 2006

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
01-04-2006

2. REPORT TYPE
Final

3. DATES COVERED *(From - To)*
Mar 2005 - Jan 2006

4. TITLE AND SUBTITLE
Effects of Shift Work and Sustained Operations: Operator Performance in Remotely Piloted Aircraft (OP-REPAIR)

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
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Nadia Lopez (2)
Patrick Hickey (2)
Christina DaLuz (2)
William T. Thompson (3)
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5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
1) 311 HSW/PE, 2485 Gillingham Drive, Brooks City-Base, TX 78235
2) AFRL/HEPF, 2485 Gillingham Drive, Brooks City-Base, TX 78235
3) Terra Health, Inc., 1222 North Main Avenue, San Antonio, TX 78212

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
311th Performance Enhancement Directorate
Performance Enhancement Research Division
2485 Gillingham Drive, Brooks City-Base, TX 78235-5105

10. SPONSOR/MONITOR'S ACRONYM(S)
311 HSW/PE

11. SPONSORING/MONITORING AGENCY REPORT NUMBER
HSW-PE-BR-TR-2006-0001

12. DISTRIBUTION AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The introduction of unmanned aircraft systems (UAS) with "inhuman endurance" has led to operational requirements for extended duty days and varying shift schedules which are likely to reduce operator effectiveness because of fatigue. This study assessed MQ-1 Predator crews involved in rotational shift work during a period of sustained operations. Crews reported decreased mood and quality of life as well as increased fatigue, emotional exhaustion, and burnout. Decrements in mood and cognitive and vigilance performance were observed over the duration of a shift and were prevalent across all shifts and shift rotation schedules. There was a tendency for the adverse effects of shift work to be more pronounced on both day and night relative to evening shift and on rapid versus slow shift rotation schedules. Additionally, crews reported moderate to high levels of task-related boredom. Overall, the environment created by conducting UAS operations using shift work in the context of a sustained contingency operations tempo significantly increased the likelihood of personnel reporting symptoms consistent with Shift Work Sleep Disorder.

15. SUBJECT TERMS
Unmanned Aerial Vehicles, Uninhabited Aerial Vehicles, Remotely Piloted Aircraft, Remotely Piloted Vehicles, Unmanned Aircraft Systems, Human Factors, Shift Work, Fatigue, Circadian, Mood, Vigilance, Alertness, Cognitive Performance, Boredom

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
			UL	56	Maj Anthony P. Tvaryanas
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPONE NUMBER *(Include area code)*
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED			210-536-4446; DSN 240-4446

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI-Std Z39-18

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EXECUTIVE SUMMARY

Purpose: Objectively evaluate the impact of rotational shift work during a period of sustained operations on fatigue, alertness, cognition, and piloting performance of MQ-1 Predator crews.

Background: The introduction of unmanned aircraft systems with "inhuman endurance" has also led to operational requirements for extended duty days and varying shift schedules which are likely to reduce operator effectiveness because of fatigue. This topic was originally submitted by 15 RS/SGP due to concerns about shift worker fatigue.

Key Study Areas:
1. Effects of shift work and sustained operations tempo on cumulative fatigue.
2. Effects of shift work on piloting and cognitive performance.
3. Alertness changes over the course of a shift.
4. Task-related boredom in the highly automated ground control station (GCS) environment.
5. Correlation between fatigue and flying hour histories.

Methodology: A field study was conducted of 28 pilots, sensor operators, and intelligence personnel at Nellis AFB, Nevada directly involved in USAF MQ-1 Predator missions in support of Operations ENDURING FREEDOM and IRAQI FREEDOM during the period from 10 April 2005 to 17 May 2005.

Overall Assessment: Based on data collected, the investigators noted the following:

- The environment created by shift work in the context of a sustained contingency operations tempo of greater than three years duration significantly increased the likelihood of personnel reporting symptoms consistent with Shift Work Sleep Disorder (SWSD). Nearly 55 percent of participants potentially met criteria for SWSD.

- Crews reported decreased mood and quality of life as well as increased fatigue, emotional exhaustion, and burnout relative to traditional aircrew from other "high demand-low density" weapon systems subject to frequent and lengthy deployments.

- Decrements in mood, cognitive and piloting performance, and alertness were observed over the duration of a shift and were prevalent across all shifts and shift rotation schedules. There was a tendency for the adverse effects of shift work to be more pronounced on both day and night relative to evening shift and on rapid versus slow shift rotation schedules.

- The GCS task environment was associated with a moderate or greater level of subjective boredom, a fact that has important implications for both morale and performance as higher boredom levels were associated with slower response times.

- Flying time limitations appeared to have significant shortcomings as a safeguard against fatigue when applied to aviation personnel involved in shift work.

ACKNOWLEDGEMENTS

The authors thank LtCol Harris, LtCol Bannon, and LtCol Landsman at the 15th Reconnaissance Squadron for their assistance in planning and conducting this research and for the utilization of their facilities. The views and opinions are those of the authors and do not necessarily represent the views of the U.S. Air Force, the Department of Defense, or any other government agency.

EFFECTS OF SHIFT WORK AND SUSTAINED OPERATIONS: OPERATOR PERFORMANCE IN REMOTELY PILOTED AIRCRAFT (OP-REPAIR)

INTRODUCTION

Background

Given the United States (US) military's experience with unmanned aircraft system (UAS) mishap rates which are many times higher than those for manned aircraft (Office of the Secretary of Defense [OSD], 2003), the importance of carefully considering crew policies should be self-evident (Tvaryanas, Thompson, & Constable, 2005). The advent of UASs has created a host of new human factors challenges arising primarily because the vehicle and the operator are no longer necessarily co-located (Gawron, 1998; McCarley & Wickens, 2004). The most recent Department of Defense (DoD) UAS roadmap noted this fact as a significant advantage of UAS systems, concluding "crew duty periods are now irrelevant to aircraft endurance since crew changes can be made on cycles based on optimum periods of sustained human performance and attention" (OSD, 2005, p. 73). However, a review of the existing scientific literature on the human factors of unmanned flight found inadequate research was available to establish duty limits for UAS operators (McCarley & Wickens, 2005). Additionally, compared to the pilot of a manned aircraft, a UAS operator can be said to perform in relative "sensory isolation" from the vehicle under their control (McCarley & Wickens, 2004), the ramifications of which are still being debated and studied. Clearly, human factors considerations will remain pertinent to establishing guidelines for safe UAS operations.

In highly automated systems such as UASs, much of the operator's task load is supervisory in nature, consisting mainly of passive monitoring of system parameters and remaining alert for malfunctions (Mouloua, Gilson, Kring, & Hancock, 2001; Van Erp, 2000). This trend towards placing the operator in the role of passive monitor has continued despite years of vigilance research demonstrating such roles make maintaining a constant level of alertness exceedingly difficult (Davies & Parasuraman, 1982; Makeig, Elliott, & Postal, 1993; Parasuraman, 1987; Wiener, 1987) and predispose to "hazardous states of awareness" (Pope & Bogart, 1992, p. 449). Studies of vigilance tasks have consistently demonstrated a vigilance decrement beginning as early as 20-35 minutes after initiation of a task and characterized by declining numbers of correct responses, increasing response times, or both (Davies & Parasuraman, 1982; Krueger, 1991; Wickens & Hollands, 2000). One study found declining response rates after only 2-3 minutes of task performance, with response rates eventually plateauing at 70-80 percent of initial rates (Makeig, Elliott, Inlow, & Kobus, 1990). Prolonged vigilance work generally invokes subjective feelings of boredom and monotony and invariably induces decreased levels of physiologic arousal. Boredom in particular can become apparent within minutes of the onset of a monotonous task and is associated with decreased performance efficiency and increased drowsiness (Kass, Vodanovich, Stanny, & Taylor, 2001; Sawin & Scerbo, 1995). However, when coupled with the need to maintain high levels of alertness, vigilance tasks can be perceived as quite stressful (Krueger, 1991; Thackray, 1980). This stress predisposes to short term fatigue which typically manifests as prolonged response times, missed signals, and brief interruptions in performance due to gaps or lapses in attention (Schroeder, Touchstone, Stern, Stoliarov, & Thackray, 1994) as well as increased decision errors and decreased cognitive throughput (Krueger, 1991). Thus, it should be expected that tasks requiring the sustained attention of UAS operators will be susceptible to degraded performance and increased risk for operator error (Mouloua et al., 2001).

Although initial research (Kidd & Kinkade, 1959; Shaw, 1955) with complex monitoring tasks typical of the air traffic control (ATC) task environment suggested vigilance decrements did not occur, more recent studies are supportive of the vigilance decrement in both simple and complex monitoring tasks (Davies & Parasuraman, 1982; Molloy & Parasuraman, 1996; Schroeder et al., 1994; Thackray & Touchstone, 1988). The validity of these concerns in UAS operations was demonstrated in a study of Army UAS operator performance under two experimental conditions involving 8 to 10-hour versus 3-hour flights (Barnes & Matz, 1998). Target detection and recognition performance as well as crew reaction times were significantly degraded during nocturnal operations involving the longer flights while no nocturnal changes were observed for the shorter flights. Likewise, two studies (Schroeder et al., 1994; Thackray & Touchstone, 1988) using an ATC task found the time to detect and the frequency of missed traffic conflicts increased significantly over the course of just two hours.

One of the best ways to overcome these effects is change, whether using work breaks, rest pauses, or split shifts, although the benefits of rest pauses may derive more from subjective factors such as relief of boredom (Krueger, 1991). Warm (1984) in particular recommended continuous vigilance monitoring tasks be kept to less than four hours in duration. Although the obvious solution is to give crewmembers breaks, this entails migration of UAS operator control which in itself constitutes a critical and potentially high workload phase for UAS operators (McCarley & Wickens, 2005). For example, several military UAS mishaps have occurred either directly during or indirectly as the result of changeovers or handoffs (McCarley & Wickens, 2005; Tvaryanas et al., 2005; Williams, 2004). There is concern for an acute decrement in crew situational awareness and performance when control is transferred to a crew not currently involved in the ongoing mission (Tvaryanas, in press). Kidd and Kinkade (1959) demonstrated the existence of such an operator change-over performance decrement in the ATC environment. Controller performance was markedly decreased over the first 5-minute period following assumption of controller duties. Another study examining operational errors in ATC found errors were most frequent during the first 15 minutes after assuming controller duties and nearly half occurred within the first 30 minutes on position (Della Rocco, Cruz, & Clemens, 1999). Likewise, a study of Army UAS operators (Barnes & Matz, 1998) found operators preferred longer over shorter rotations because they perceived the longer rotations allowed for better situational awareness of the tactical environment. Since there are obvious tradeoffs in risks, it would be very desirable to know the rate and severity of degradation in alertness in UAS operators in real world environments.

The introduction of UASs with "inhuman endurance" (OSD, 2005, p. 72) has also led to operational requirements for "extended duty days, reduced crew size, and varying shift schedules" which are "likely to reduce operator effectiveness because of fatigue" (Walters, Huber, French, & Barnes, 2002, p. 13). Serious public health concerns have been raised regarding the association between the documented effects of shift work, such as sleep loss, circadian disruption, and subsequent fatigue, and degraded job performance and an increased risk for errors and accidents (Folkard & Åkerstedt, 2004; Mitler, Dinges, & Dement, 1994; Office of Technology Assessment [OTA], 1991). While there has been substantial study of fatigue in aircrew, especially with regards to extended flight operations (Caldwell, 1997; Caldwell et al., 2003a; Caldwell & Caldwell, 2005; Caldwell, Caldwell, & Darlington, 2004; Cornum, Caldwell, & Cornum, 1997), the fielding of UASs has brought about the need to also consider sustained shift work. For example, an assessment of an Air Force UAS unit found they were conducting continuous 24-hour operations at surge capability for over 1,000 days and unit personnel had accrued more than 1,000 days of unused leave time (J. Miller, personal communication, November 23, 2004; G. Landsman, personal communication, July 24, 2004). Although there is a substantial body of literature on performance and sustained shift work in aviation as it pertains to air traffic control specialists (Boquet et al., 2002; Cruz, Detwiler, Nesthus, & Boquet, 2002; Cruz & Della Rocco, 1995; Della Rocco, Comperatore, Caldwell, & Cruz, 2000; Della Rocco & Cruz, 1995; Della Rocco & Cruz, 1996; Melton, 1985; Melton et al., 1973; Melton et al., 1975; Saldivar, Hoffman, & Melton, 1977; Schroeder, Rosa, & Witt, 1995), there is scant research addressing this issue in UAS operations (Barnes & Matz, 1998; Walters et al., 2002). Also, the shift work schedules used in ATC differ substantially from those currently employed by United States Air Force (USAF) UAS operators, limiting the external validity of the findings from these ATC studies.

UAS crews typically work multiple, rotating, or both shift types unlike traditional aircrew who typically work day or irregular shifts. As noted by Jansen, Van Amelsvoort, Kristensen, Van den Brandt, and Kant (2003) in a large 32-month prospective study of fatigue and work schedules, the prevalence of fatigue in rotating shift workers was 24-29 percent compared to 18 percent for day workers and 19 percent for irregular shift workers. Since worker fatigue has been described as a function of shift timing, length, frequency, and regularity as well as intra-shift and inter-shift recovery opportunities (Jansen et al., 2003; Rosa, 2001; Smith, Macdonald, Folkard, & Tucker, 1998), it is likely UAS operations are more fatigue-prone than long-haul flight operations given their chronic and periodic nature. Additionally, the "extensive use of Predator remote split operations where flights launched by the forward deployed [launch and recovery element] were then handed over to Nellis Air Force Base (AFB) operators" (OSD, 2005, p. C3) has resulted in a wartime operations tempo becoming the routine for UAS operators, raising concerns for chronic fatigue (Dooley, 2004) and burnout.

Rationale for Present Study

This technical report was developed from a collaborative effort between the 311th Human Systems Wing's Performance Enhancement Directorate (311 HSW/PE) and the Air Force Research Laboratory's Warfighter Fatigue Countermeasures Team (AFRL/HEPF). Meetings between these organizations identified several important areas of needed research: 1) assessment of the extent and impact of fatigue in UAS operations; 2) survey UAS personnel for shift work schedules and issues related to coping with shift work; 3) education and training for alertness management and shift work coping strategies; 4) fatigue countermeasures as they relate to the UAS work environment; 5) acute and cumulative sleep loss effects; and 6) burnout.

Objectives

The purpose of this study was to provide an assessment of the status of MQ-1 Predator crews regarding: 1) the effects of shift work and sustained operations tempo (>1000 days) on cumulative fatigue, 2) the effects of shift work on piloting and cognitive performance, 3) alertness changes over the course of a shift and correlation with boredom proneness, 4) the assessment of boredom in the highly automated and low threat ground control station (GCS) environment, and 5) the correlation between fatigue and flying hour histories.

METHODS

Participants

The study protocol was approved by the Brooks City-Base Institutional Review Board in accordance with 32 Code of Federal Regulations (CFR) 219 and Air Force Instruction (AFI) 40-402. The study design was an observational field study with external reference (control) groups. Participants were solicited from the local population of pilots, sensor operators, and intelligence personnel at Nellis AFB, Nevada directly involved in USAF MQ-1 Predator missions in support of Operations ENDURING FREEDOM (Afghanistan) and IRAQI FREEDOM (Iraq) during the period from 10 April 2005 to 17 May 2005. Inclusion criteria were permanently assigned, fulltime personnel involved in shift work for at least three months. Participants were excluded if they were disqualified or limited in their assigned duties for any active medical conditions. Participants were not restricted from the study based on a history of using tobacco or caffeinated products nor were they restricted from using these substances during the study. This had the advantage of allowing the study to more accurately assess the real status of crew members. Additionally, it was highly desirable not to potentially degrade the performance of participants involved in combat support operations during the course of the study. Thirty participants volunteered for the study and their voluntary, fully informed consent was obtained as required by 32 CFR 219 and AFI 40-402. Twenty-eight participants completed the study protocol; the data for the two participants who withdrew were censored.

Apparatus

Fatigue Evaluations

Fatigue was assessed using the composite fatigue scale (CFS) which is a 52-item self-report survey arranged on a Likert-type scale developed in-house to elicit the four major Diagnostics and Statistics Manual of Mental Disorders – fourth edition (DSM-IV) criteria for the diagnosis of circadian rhythm sleep disorder – shift work type (American Psychiatric Association [APA], 1994), also known as shift work sleep disorder (SWSD). The CFS incorporates the fatigue assessment scale (FAS) (Michielsen, De Vries, & Van Heck, 2003), fatigue scale (FS) (Chalder et al., 1993), checklist individual strength concentration subscale (CIS-CON) (Beurskens et al., 2000), World Health Organization quality of life assessment energy and fatigue subscale (EF-WHOQOL) (World Health Organization [WHO], n.d.), and Maslach burnout inventory emotional exhaustion subscale (MBI-EE) (Barnett, Brennan, & Gareis, 1999). The presence of sleep disorders was evaluated by a sleep disorder score (SDS) drawn from indicators of insomnia, breathing disorders, periodic limb movements and restless leg syndrome, and hypersomnia (Garbarino et al., 2002).

Sleep Evaluations

The Actiwatch® (Mini Mitter Company, Inc., Sunriver, OR) is a 16-gram, 28 x 27 x 10-millimeter wrist watch-like device worn on the non-dominant wrist that objectively measures activity and rest patterns. With each participant movement a highly sensitive accelerometer generates a variable voltage that is digitally processed and sampled at a frequency of 32 Hertz. The signal is integrated over a user-selected epoch and a value expressed as activity counts is record in on-board memory. Data are downloaded to a computer and may be expressed graphically as an actogram or reported in American standard code for information interchange (ASCII) format numerically as total activity counts per epoch.

Additionally, a standardized sleep/activity log was used to collect sleep and work histories for analysis using the fatigue avoidance scheduling tool (FAST) (NTI, Inc., Fairborn, OH). FAST allows easy data entry of work and sleep schedules and generates graphical predictions of performance along with tables of estimated effectiveness scores based on the sleep, activity, fatigue, and task effectiveness (SAFTE™) model (Hursh et al., 2004). The SAFTE™ model projects the combined effects of time of day and sleep history as contributing factors on performance at a specified time. Model predictions have been validated against laboratory data. FAST operates on a standard Windows™-based desktop computer.

Piloting Performance

The unmanned aerial vehicle synthetic task environment (UAV STE) (Parker International, Las Vegas, NV) design and capabilities are described in detail in Schreiber, Lyon, Martin, and Confer (2002). The UAV STE is a high fidelity simulation of the Predator RQ-1A with built in basic maneuvering, landing, and reconnaissance tasks and data collection capabilities. Each task is comprised of multiple scenarios which manipulate various performance requirements and external conditions. The basic maneuvering task requires the operator to make very precise, constant-rate changes in airspeed, altitude, heading, or a combination of the three without reference to the external environment. Tasks are presented on two side-by-side color monitors, the left monitor presenting the head-up display (HUD) instrumentation overlaid on a pure black screen and the right monitor displaying other information pertinent to the task. During performance of a task, the values of approximately 100 variables are recorded every 200 milliseconds. Outcome measures such as root mean square deviation from desired altitude, heading, or airspeed are saved following every trial. The UAV STE utilizes an IBM™ compatible computer running Windows NT™ and two 21-inch monitors with a joystick and throttle add on (Gluck, n.d.).

Cognitive Performance

The automated neuropsychological assessment metrics (ANAM) (Reeves, Kane, Winter, Ransford, & Pancella, 1993) serial math subtest is a self-paced mental arithmetic task designed to test a participant's information processing resources associated with working memory. In this task, participants perform two mathematical operations (addition, subtraction, or both) on sets of three single-digit numbers (e.g., 5 + 3 - 4 = ?). The participant is instructed to read and calculate from left to right, determine whether the answer is greater than or less than the number five, and respond by clicking the left or right mouse button. Stimuli (five in the practice session and 25 in the actual test) are displayed for up to 14,900 milliseconds with 15,000 milliseconds allowed for response. This test is controlled by a standard Pentium-based desktop computer equipped with a keyboard and a mouse. Data is stored and analyzed via computer using the STATVIEW™ analysis software program.

Vigilance Performance

The Psychomotor Vigilance Task Monitor 192 PVT (Ambulatory Monitoring, Inc., Ardsley, NY) is a simple reaction time test. It requires sustained attention and discrete motor responses and is known to be sensitive to sleep loss (Dinges, Pack, & Williams, 1997). The 8 x 4.5 x 2.4-inch portable, battery-operated device visually displays numbers counted up by milliseconds in a window. The stimulus is presented for up to 1.5 seconds, allowing the participant to respond. The participant presses a microswitch which allows reaction time to the stimulus to be recorded. The interstimulus interval varies randomly from 1 to 10 seconds. Data is stored and analyzed via computer using the REACT™ analysis software program.

Boredom Evaluations

The boredom proneness scale (BPS) (Farmer & Sundberg, 1986) is a general assessment tool to measure the tendency to experience boredom. It is a 28-item dichotomous self-report scale that asks participants to answer "yes" or "no" to each item. Items include statements such as "It is easy for me to concentrate on my activities" and "It takes more stimulation to get me going than most people." The task-related boredom scale (TrBS) (Scerbo, Rettig, & Budd-Lewis, 1994) addresses eight factors thought to contribute to feelings of boredom: stress, irritation, relaxation, sleepiness, alertness, concentration, passage of time, and satiation. In addition, respondents are also asked to provide an estimation of their overall feeling of boredom. A total boredom score is calculated by summing all the subscales. The sleepiness, time passage, and desire to end are reverse scored.

Mood Evaluations

The profile of mood states (POMS) (McNair, Lorr, & Droppleman, 1981) was used to assess subjective mood. The computerized version of this questionnaire consists of 65 items which measure affect on six scales: 1) tension-anxiety, 2) depression-dejection, 3) anger-hostility, 4) vigor-activity, 5) fatigue-inertia, and 6) confusion-bewilderment. The answers are automatically scored by computer and stored for later analysis.

Subjective mood was also measured by means of an adaptation of the visual analog scale (VAS) developed by Penetar et al. (1993). The VAS questionnaire consists of several 100-millimeter lines, each of which is labeled at one end with the words "not at all" and at the other end with the word "extremely." Centered under each line are the test adjectives which are as follows: "alert/able to concentrate," "anxious," "energetic," "feel confident," "irritable," "jittery/nervous," "sleepy," and "talkative." Participants indicate the point on the line that corresponds to how they feel along the specified continuum at the time at which the test is taken. The score for each item consists of the number of millimeters from the left side of the line to the location at which the participant places their mark.

Procedures

General

During the initial session, each participant received a full briefing on the purposes of the study and assurances about the confidentiality of the data. Once informed consent was obtained, each participant completed an initial study questionnaire (ISQ) which gathered background biographical information and addressed study inclusion/exclusion criteria, the BPS was administered, and a sleep/activity log and Actiwatch® were issued. Flight hour histories were collected from squadron flight records for pilot and sensor operator participants. Subsequently, each participant completed several training and test sessions consisting of cognitive and vigilance evaluations, flight simulation, and questionnaires regarding fatigue, mood, and boredom. The training and testing schedule is shown in Table 1.

TABLE 1. Testing schedule.

	Day 1 Initial	Day 2 Training	Day 3 Training	Day 4 Training	Day 5 Testing	Day 6 Testing
Preshift					Actiwatch® CFS UAV STE[†] UAV STE[†] UAV STE[†]	ANAM POMS VAS PVT Actiwatch® S/A log
Postshift	Inf Con ISQ BPS Actiwatch® S/A log	ANAM ANAM ANAM POMS VAS	Actiwatch® ANAM ANAM ANAM UAV STE[†] UAV STE[†] UAV STE[†]	ANAM ANAM ANAM PVT	TrBS UAV STE[†] UAV STE[†] UAV STE[†]	ANAM POMS VAS PVT Debrief

[†] Pilots only.

ANAM - automated neuropsychological assessment metrics serial math subtest; BPS - boredom proneness scale; CFS - composite fatigue scale; Inf Con - informed consent; ISQ - initial study questionnaire; POMS - profile of mood states; PVT - psychomotor vigilance task; S/A Log - sleep/activity log; TrBS - task-related boredom scale; UAV STE - unmanned aerial vehicle synthetic task environment; VAS - visual analog scale.

The squadron shift schedule was structured such that pilots and intelligence personnel were on a relatively fast shift rotation schedule, rotating every 7 to 14 days, as compared to sensor operators who rotated shifts every 90 days. The day shift included the period from 0630 to 1500 hours, evening shift the period from 1430 to 2300 hours, and night shift the period from 2230 to 0700 hours. Because this was an observational study of personnel involved in ongoing combat support operations, it was not possible to rigidly control the timing of sessions. The study had to be conducted on a strictly non-interference basis which meant existing participant duty schedules were followed, participants were tested when they were available, and testing time requirements were minimized. It was preferred to accomplish preshift testing prior to the mission briefing conducted at the start of each shift. However, testing was also accomplished after the mission briefing if a participant had insufficient time prior to the briefing to complete testing. Postshift testing was accomplished whenever the participant's duty day ended, which was dependent on a multitude of factors including when they were relieved by the next shift, when the dynamics of a particular mission allowed for a crew change in the GCS, and whether control was transferred to an in-theater crew for air vehicle recovery. If a participant's shift ended early, testing was accomplished at that time to avoid extending the participant's duty day. Participants were followed for longer than six days if testing was not completed by Day 6 because of mission cancellations (e.g., weather or maintenance), missed sessions (e.g., participant failed to show for scheduled testing), or other scheduling constraints. Overall, the inability to rigorously control the timing of test sessions and thus the length of the preshift-postshift testing interval potentially added variability to the data which needed to be addressed in the statistical analysis.

Sleep Evaluations

Participants were issued an Actiwatch® on Day 1 in order to track sleep/activity rhythms in a relatively unobtrusive fashion. Participants were asked to wear the Actiwatch® continuously on the wrist of their non-dominant hand during all awake and sleeping periods and not to remove it for bathing. The Actiwatch® was collected from each participant on Days 3, 5, and 6 for downloading of data and reinitialization of the data collection mode. Once the data collection period was complete, the data were taken back to the laboratory, scored for sleep times, and graphed. Participants were also given a standardized sleep/activity log on Day 1 and were reminded at each subsequent encounter to document sleep and activity periods. Once the data collection period was complete, the data from the logs were entered into FAST for analysis.

Piloting Performance

Participants completed a scenario from the UAV STE basic maneuvering task serially three times on Day 3 for training and familiarization. Additional serial sets of three trials were completed immediately preshift and postshift on Day 5. This task was administered only to pilots. The profile consisted of a 10-second straight and level lead in period followed by a 90-second maneuver period during which the participant was instructed to decrease altitude from 15,300 to 15,000 feet, increase airspeed from 62 to 67 knots, and change heading from 270 to 0 degrees. All changes in altitude, airspeed, and heading were to be made at a constant rate such that the desired end state was reached just prior to the end of the trial. A computer timer counting down the seconds for each period was displayed on a monitor adjacent to the monitor with the HUD instrumentation. The computer terminated the trial at 100 seconds and calculated root mean square deviations for altitude, airspeed, and heading for the 90-second maneuver period. This feedback was masked from the participant. Each serial set of three trials took approximately seven minutes to administer. Each flight was coordinated and controlled by a study investigator who instructed the participant at the start of each trial in a uniform manner. Participants generally reported the maneuver task was not very difficult although only one participant achieved criterion (e.g., minimum passing) performance as established by Schreiber et al. (2002) in their study on the impact of prior flight experience on learning Predator operator skills.

Cognitive Performance

Participants completed a set of three serial iterations of the ANAM serial math subtest on Days 2, 3, and 4 in order to achieve the nine trials necessary for asymptotic performance (Perez, Masline, Ramsey, & Urban, 1987). After this training was complete, additional tests were administered immediately preshift and postshift on Day 6. During each test, participants responded to 25 stimuli consisting of two mathematical operations (addition, subtraction, or both) by clicking the left or right mouse button with their dominant hand. Each test took approximately five minutes to administer and yielded data on: 1) mean, standard deviation, and median reaction time for correct responses (RTCR), 2) for all responses, 3) performance accuracy, and 4) throughput.

Vigilance Performance

Participants performed a 10-minute block of the psychomotor vigilance task (PVT) once on Day 4 for familiarization and immediately preshift and postshift on Day 6. Testing was accomplished with participants in a seated position and wearing earmuffs covering the outer ear to help mitigate environmental noise which could not be controlled (e.g., aircraft engine noise, etc.). Participants responded to the visual stimulus in this reaction time task by pressing a button with their right hand. Reaction time was recorded for each stimulus and analyzed in the following manner: 1) the number of reaction times greater than 500 milliseconds (lapses), 2) overall reaction time (RT), 3) the fastest 10 percent reaction times (FRT) per trial, and 4) the slowest 10 percent reaction times (SRT) per trial.

Mood Evaluations

The POMS was administered once on Day 2 for participant familiarization. Additional tests were administered immediately preshift and postshift on Day 6. Participants indicated how well each of 65 adjectives described the way they were feeling at the time by checking a box with the computer cursor. The test took approximately three minutes to administer and yielded scores on the factors tension-anxiety, depression-dejection, anger-hostility, vigor-activity, fatigue-inertia, and confusion-bewilderment.

The VAS was administered immediately following the POMS once on Day 2 for participant familiarization. Additional tests were administered immediately preshift and postshift on Day 6. Participants indicated how well each of eight adjectives described the way they were feeling by indicating the point on a 100-millimeter line that corresponded to how they felt along the specified continuum at the time at which the test was taken. The test took approximately two minutes to administer and yielded scores on the factors of alert/able to concentrate, anxious, energetic, feel confident, irritable, jittery/nervous, sleepy, and talkative.

Statistical Analysis

Data from this study were analyzed using Statistical Package for the Social Sciences (SPSS Inc., Chicago, IL) version 11.5. All data were assessed for normalcy and parametric and nonparametric approaches to analysis used accordingly. All repeated measures were assessed for one within-subject difference (pre/postshift) and two between-subject differences (shift and shift rotation schedule). When data were normally distributed, repeated measures analyses of variance (ANOVAs) were conducted, the results of which were examined to determine whether there were sphericity violations of sufficient magnitude to warrant the use of Huynh-Feldt adjusted degrees of freedom (dfs). Additionally, power and effect size (η_p^2) were computed. The impact of variation in the pre/postshift test interval was assessed using linear regression where appropriate. Residual plots were evaluated to assess the fit of the regression models, determine the influence of outliers, and assure regression assumptions were not violated. Condition indices were used to evaluate collinearity between independent variables (Field, 2003; Statistical Package for the Social Sciences [SPSS], n.d.).

Due to the fact there were not sufficient cases to produce meaningful multivariate tests, univariate ANOVAs were utilized. Fatigue evaluation data consisted of eight scores calculated for each component of the CFS. For the purposes of classification, a reference group consisting of E-3B Sentry airborne warning and control system (AWACS) aircrew was used to define a normative range of plus or minus two standard deviations (SD) for scores on the seven fatigue dimensions, the SDS, and a question regarding the presence of symptoms of depression or anxiety; scores were reduced to dichotomous variables of normal (≤2SD) or abnormal (>2 SD). Scores for AWACS crewmembers were obtained from an unpublished dataset previously collected as part of another study (Tvaryanas, unpublished data). It was desirable to utilize data from AWACS versus other Air Force aviation populations to reduce potential confounding by crew composition (e.g., high prevalence of enlisted crewmembers), mission length and profile, and operations tempo. The response to questions regarding impact of work schedule on life activities (four questions regarding inadequate time with spouse, children, friends, or for recreation) and substance use (two questions regarding caffeine and tobacco use) were also reduced to dichotomous variables. These dichotomous variables were then collectively used to define a participant as potentially meeting the DSM-IV criteria for SWSD (APA, 1994). Sleep evaluation data consisted of average daily sleep, sleep efficiency, and predicted work effectiveness. UAV STE performance data consisted of scores calculated from each relevant parameter (e.g., airspeed, altitude, and heading). Data from the ANAM included mean and standard deviation of RTCR, accuracy, and throughput. Data from the PVT consisted of mean RT, FRT, SRT, and number of lapses, which were defined as responses greater than 500 milliseconds. The POMS data consisted of scores from each of the six test scales as well as a weighted aggregate score. Likewise, the VAS data consisted of scores for each of the eight test scales.

RESULTS

Participants

Participant characteristics are summarized in Table 2. Participants consisted of 12 pilots, 13 sensor operators, and three intelligence personnel. Intelligence personnel (10.7%) were relatively under-represented in the study sample in comparison to pilots (42.9%) and sensor operators (46.4%). Ages ranged from 19 to 48 years with a mean age of 31.9 ± 7.7 years. Twenty-three (82.1%) were males and 16 (57.1%) were officers. Participants had been at their present assignment from 3 to 90 months with a mean time of 20.8 ± 21.0 months. Total MQ-1 flying hours for pilots and sensor operators ranged from 160.8 to 1833.3 hours with a mean of 627.9 ± 387.0 hours. All pilots and sensor operators were within 30-day and 90-day maximum flying time limits as delineated in AFI 11-202V3 (United States Air Force [USAF], 2005).

TABLE 2. Baseline participant characteristics by shift and shift rotation schedule.

Parameter	Shift Day (n = 8)	 Evening (n = 9)	 Night (n = 11)	 p-value	Shift rotation schedule Rapid (n = 15)	 Slow (n = 13)	 p-value
Age, mean (SD)	33.5 (4.0)	29.6 (5.8)	32.6 (10.6)	0.541††	34.9 (6.5)	28.4 (7.6)	0.021**
Male gender, No (%)	7 (87.5)	7 (77.8)	9 (81.8)	0.872‡	15 (100.0)	8 (61.5)	0.013†
Months assigned, mean (SD)	18.0 (13.4)	27.9 (25.8)	16.6 (21.8)	0.212¶	16.0 (18.5)	25.9 (23.2)	0.084§
Officer, No (%)	6 (75.0)	4 (44.4)	6 (54.5)	0.435‡	14 (93.3)	2 (15.4)	<0.001†
Position, No (%)							
Pilot	4 (50.0)	4 (44.4)	4 (36.4)		12 (100.0)	0 (0)	
Sensor Operator	3 (37.5)	5 (55.6)	5 (45.5)	0.723‡	0 (0)	13 (100.0)	<0.001‡
Intelligence	1 (12.5)	0 (0.0)	2 (18.2)		3 (100.0)	0 (0)	
Flying hours, mean (SD)*							
30-day	41.6 (16.4)	40.4 (14.7)	52.6 (17.4)	0.241††	51.4 (15.2)	39.4 (16.1)	0.068**
60-day	77.5 (37.4)	73.8 (35.7)	118.2 (44.0)	0.051††	108.0 (29.6)	75.0 (48.5)	0.054**
90-day	99.4 (50.5)	102.8 (47.3)	157.2 (62.8)	0.066††	143.4 (44.3)	101.1 (64.2)	0.070**
Total	558.6 (360.1)	719.5 (259.3)	590.2 (519.1)	0.247¶	695.0 (471.1)	565.9 (295.6)	0.624§

*Flying hours pertain only to pilots and sensor operators
†Fisher's exact test
‡Cramer's V test
§Mann-Whitney test
¶Kruskal-Wallis test
**Student's t test
††One-way analysis of variance (ANOVA)

Participant characteristics did not differ across shifts although there was a trend towards greater flying hours for participants on the night shift. Participant characteristics did differ by shift rotation schedule, reflecting confounding by position as position determined shift rotation schedule. Since participants on the rapid shift rotation schedule were chiefly pilots, it was expected they would be older male officers reflecting the overall demographics of Air Force pilots, the years spent in initial pilot training, and the requirement for prior operational experience before being assigned to fly MQ-1 Predators. In contrast, participants on the slow rotation schedule were all sensor operators, a predominately enlisted career field necessitating substantially less training than pilots and for which there is no requirement for prior operational experience. There was also a nonsignificant trend towards more flying hours among participants on the rapid rotation schedule. This was reflective of the relative shortage of pilots in the squadron which resulted in pilots flying more hours than sensor operators.

Fatigue Evaluations

Table 3 summarizes the scores on components of the CFS by shift. The study sample had higher scores compared to an external reference group of AWACS aircrew on the FAS ($F_{3,68} = 6.146$, $p = 0.001$, $\eta_p^2 = 0.213$), FS ($F_{3,68} = 3.685$, $p = 0.016$, $\eta_p^2 = 0.140$), EF-WHOQOL ($F_{3,68} = 4.210$, $p = 0.009$, $\eta_p^2 = 0.157$), and MBI-EE ($F_{3,68} = 6.277$, $p = 0.001$, $\eta_p^2 = 0.217$). Differences existed between all shifts and the reference group on the FAS and MBI-EE subscales. Differences also existed between day and night shifts and the reference group on the FS physical fatigue subscale and between the day shift and the reference group on the FS mental fatigue and EF-WHOQOL subscales. There was no differences between shifts and the reference group on the CIS-CON ($\eta_p^2 = 0.073$, power = 0.443).

TABLE 3. Scores on components of the composite fatigue scale (CFS).

	Shift						Shift rotation schedule				
Scales	Day (n = 8)	p-value	Evening (n = 9)	p-value	Night (n = 11)	p-value	Rapid (n = 15)	p-value	Slow (n = 13)	p-value	Reference (n = 44)
FAS	29.13 (2.43)	0.004	26.89 (2.39)	0.036	28.09 (1.95)	0.004	29.00 (1.75)	0.001	26.85 (1.80)	0.010	21.80 (0.84)
FS	34.25 (2.33)	0.016	31.44 (3.25)	0.127	32.36 (2.34)	0.043	34.20 (1.94)	0.001	30.77 (2.31)	0.087	26.86 (1.03)
Physical fatigue	22.63 (1.83)	0.039	21.11 (1.93)	0.152	22.09 (1.84)	0.037	23.40 (1.31)	0.001	20.23 (1.62)	0.158	17.93 (0.78)
Mental fatigue	11.62 (0.78)	0.027	10.33 (1.62)	0.246	10.27 (0.84)	0.228	10.80 (0.87)	0.034	10.54 (0.99)	0.080	8.93 (0.38)
CIS-CON	18.62 (1.87)	0.154	16.44 (3.00)	0.553	18.82 (1.65)	0.083	18.47 (1.86)	0.051	17.64 (1.68)	0.176	15.07 (0.78)
EF-WHOQOL	13.38 (1.15)	0.004	11.33 (1.18)	0.196	11.91 (0.96)	0.053	12.13 (0.89)	0.011	12.15 (0.90)	0.014	9.66 (0.46)
MBI-EE	24.63 (1.69)	0.001	21.56 (2.17)	0.021	20.36 (1.75)	0.048	22.47 (1.29)	0.001	21.38 (1.91)	0.006	15.77 (0.99)

Scores expressed as mean (±standard error of the mean [SEM]); p-values for differences with the AWACS reference group (Dunnett's pairwise multiple comparison t test).

CIS-CON - checklist individual strength concentration subscale; EF-WHOQOL - World Health Organization quality of life assessment energy and fatigue subscale; FAS - fatigue assessment scale; FS - fatigue scale; MBI-EE - Maslach burnout inventory emotional exhaustion subscale.

Table 3 also summarizes the scores on components of the CFS by shift rotation schedule. The study sample had higher scores compared to the reference group on the FAS ($F_{2,69} = 9.548$, $p < 0.001$, $\eta_p^2 = 0.217$), FS ($F_{2,69} = 6.134$, $p = 0.004$, $\eta_p^2 = 0.151$), EF-WHOQOL ($F_{2,69} = 5.299$, $p = 0.007$, $\eta_p^2 = 0.133$), and MBI-EE ($F_{2,69} = 8.306$, $p = 0.001$, $\eta_p^2 = 0.194$). Differences existed between both shift rotation schedules and the reference group on the FAS, EF-WHOQOL, and MBI-EE. However, there was no difference between the slow shift rotation schedule and reference group on the FS to include the physical and mental fatigue subscales. There was no difference between either of the shift rotation schedules and the reference group on the CIS-CON ($\eta_p^2 = 0.217$, power = 0.976).

Compared to the AWACS reference group, the study sample was more likely to report their work schedule impacted life activities to include inadequate time with their spouse or significant other (Odds Ratio [OR] 11.538, 95% Confidence Interval [CI] 3.247 – 41.007), with their children (OR 6.474, 95% CI 1.572 – 26.658), with friends (OR 7.000, 95% CI 2.413 – 20.305), and for recreational activities (OR 21.111, 95% CI 5.764 – 77.326). Within the study sample, there was no difference between the slow and fast shift rotation schedules on the reported impact of work on life activities. However, there were differences between shifts. Relative to day shift, evening shift was less likely to report inadequate time with their spouse

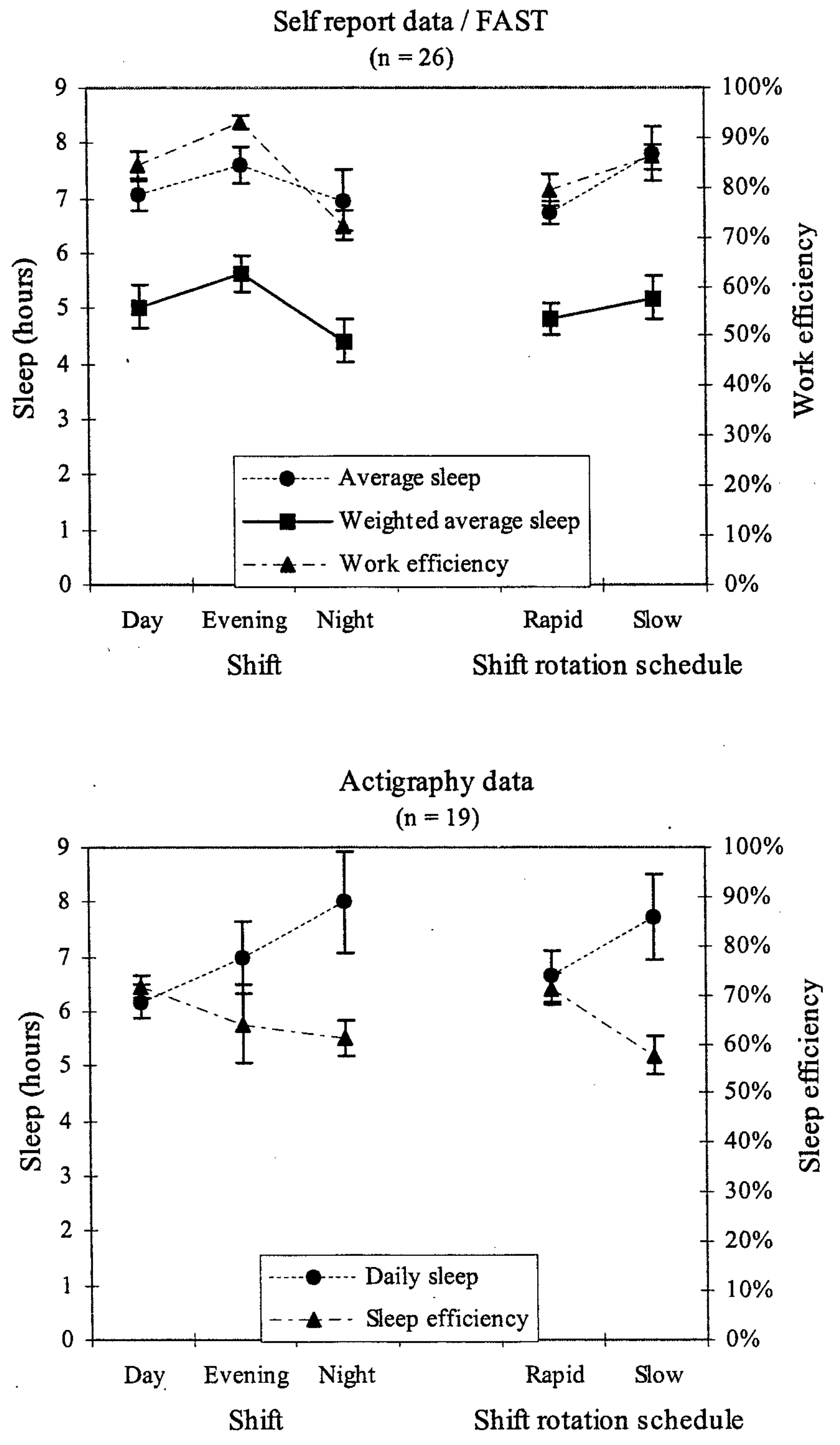
(OR 0.020, 95% CI 0.001 – 0.477) while night shift was more likely to report inadequate time with their friends (OR 16.667, 95% CI 1.361 – 204.043) but less likely to report inadequate time with their children (OR 0.060, 95% CI 0.005 – 0.735). All shifts were equally likely to report inadequate time for recreation.

The mean SDS for the study sample was 1.988 (± 0.575) as compared to 1.654 (± 0.511) for the reference group which was a significant difference ($t_{70df} = 2.575$, p= 0.012). There was no difference in SDS based on shift or shift rotation schedule. There was a greater prevalence of participants meeting the survey criteria for sleep disorders in the study sample (14.3%) versus the reference group (0%) (FET p = 0.020). The prevalence of participants meeting the survey criteria for SWSD was greater in the study sample (53.6%) versus the reference group (6.8%) (OR 15.769, 95% CI 3.937 - 63.167). There was no difference in the likelihood of being classified as a SWSD case based on shift or shift rotation schedule. Within the study sample, there was no difference between SWSD cases and non-cases in mean flight hours at 30 days, 60 days, or 90 days.

Sleep Evaluations

Two participants did not complete sleep/activity logs, leaving data analysis for a total of 26 participants. Some participants did not wear the Actiwatch® long enough to obtain data which would describe their sleep/activity schedule accurately. Additionally, the data from several participants were lost due to Actiwatch® malfunctions. In total, actigraphy data were missing or not collected for nine participants leaving data analysis for a total of 19 participants. Figure 1 summarizes the measured and calculated sleep parameters. There was no difference in the mean daily sleep for the overall study sample whether assessed using self-reported (7.192 ± 0.250 hours) or actigraphy (7.103 ± 0.433 hours) data. Participants slept less than the recommended eight hours per day based on the self-reported sleep data ($t_{25df} = -3.234$, p = 0.003) but not based on actigraphy data. There were no differences in mean daily sleep by shift or shift rotation schedule.

In addition to sleep and wake times, the sleep/activity log also asked participants to rate sleep quality during each sleep period as “poor,” “moderate,” or “excellent.” These ratings were dummy coded as $^1/_3$, $^2/_3$, and 1 respectively and a weighted sleep variable was calculated by multiplying self-reported sleep by the ordinal quality factor. Weighted sleep did not differ based on shift or shift rotation schedule. There was also no difference between shifts in sleep efficiency as measured by actigraphy data, but sleep efficiency was greater ($U = 12.000$, p = 0.008) for the rapid (71.3%) versus the slow (57.7%) shift rotation schedule.



Data points expressed as mean (±SEM); FAST – fatigue avoidance scheduling tool.

Figure 1. Measured and calculated parameters as determined by self report and actigraphy data.

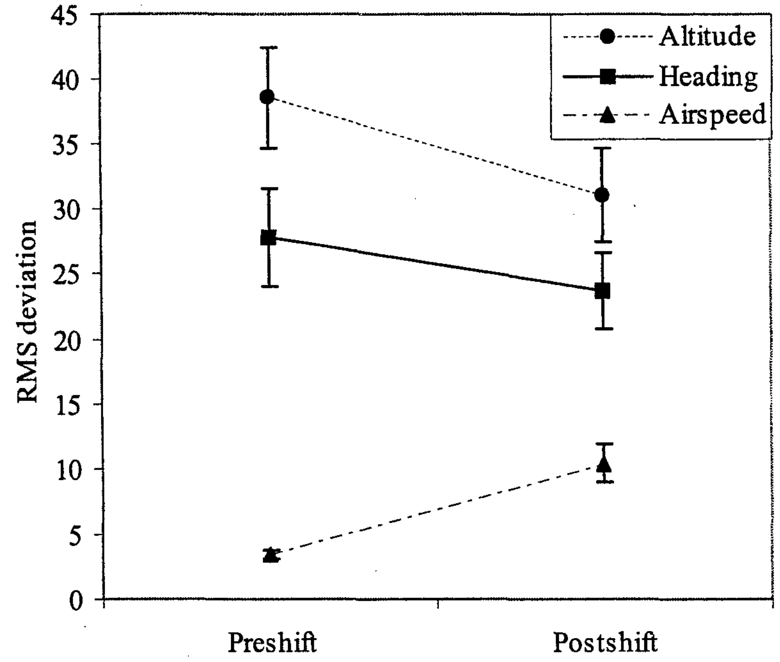
There were differences in predicted work effectiveness as determined using FAST based on shift ($F_{2,23} = 17.755$, $p < 0.001$, $\eta_p^2 = 0.607$) but not shift rotation schedule ($\eta_p^2 = 0.087$, power = 0.307). In particular, the effectiveness of the night shift was decreased relative to the day ($p = 0.006$) and evening ($p < 0.001$) shifts. Participants were classified as having occupationally significant diminished predicted work effectiveness if FAST estimated their work effectiveness to be less than 75 percent. There was no increased risk of diminished effectiveness between day and evening shifts, but there was a greater likelihood for the night shift (OR 12.250, 95% CI 1.080 - 138.995) relative to the day shift. There was also an increased likelihood of diminished effectiveness for the rapid relative to the slow shift rotation schedule (OR 10.500, 95% CI 1.076 - 102.478).

Piloting Performance

Figure 2 summarizes the UAV STE data for the pilot members of the study sample. Since the maneuver required constant rate changes in altitude, heading, and airspeed, the root mean square (RMS) deviations for these flight parameters were analyzed. Flight parameter RMS deviation values for the three trials in each session were averaged and this value was entered into the dataset for analysis. There were within-subject differences between preshift and postshift RMS deviation for altitude ($F_{1,9} = 6.989$, $p = 0.027$, $\eta_p^2 = 0.437$) and airspeed ($F_{1,9} = 35.081$, $p < 0.001$, $\eta_p^2 = 0.796$) but not heading ($\eta_p^2 = 0.154$, power = 0.209). There were no between-subject differences based on shift for altitude ($\eta_p^2 = 0.217$, power = 0.206), heading ($\eta_p^2 = 0.073$, power = 0.091), or airspeed ($\eta_p^2 = 0.116$, power = 0.120). In order to directly compare changes in flight parameters, the percent change from baseline for the RMS deviations were calculated to account for the effect of differences in scale (e.g., heading is expressed in degrees, altitude in feet, and airspeed in knots). From preshift to postshift, there was a -15.75 (± 31.56) percent change from baseline in RMS deviation for altitude, a -5.32 (± 48.90) percent change for heading, and a 184.56 (± 65.66) percent change for airspeed. There was a significant difference in percent change from baseline RMS deviation based on flight parameter ($F_{2,32} = 58.195$, $p < 0.001$, $\eta_p^2 = 0.784$), with differences noted on Bonferroni post hoc tests between altitude and airspeed ($p < 0.001$) and heading and airspeed ($p < 0.001$) but not altitude and heading.

Since there was a strong correlation between preshift and postshift RMS deviation ($r = 0.780$, $p < 0.001$) and given concerns regarding between-subject test interval variability, the relationship between postshift RMS deviation and preshift RMS deviation, flight parameter, shift, and test interval were assessed using multiple regression analysis. Shift and parameter were dummy coded as integer variables (day shift = 0, evening shift = 1, night shift = 2; altitude = 0, heading = 1, airspeed = 2). The final regression equation was as follows:

Postshift RMS deviation = 8.863 + 0.552(preshift RMS deviation); $F_{1,34} = 52.934$, $p < 0.001$, $R^2_{adj} = 0.597$.

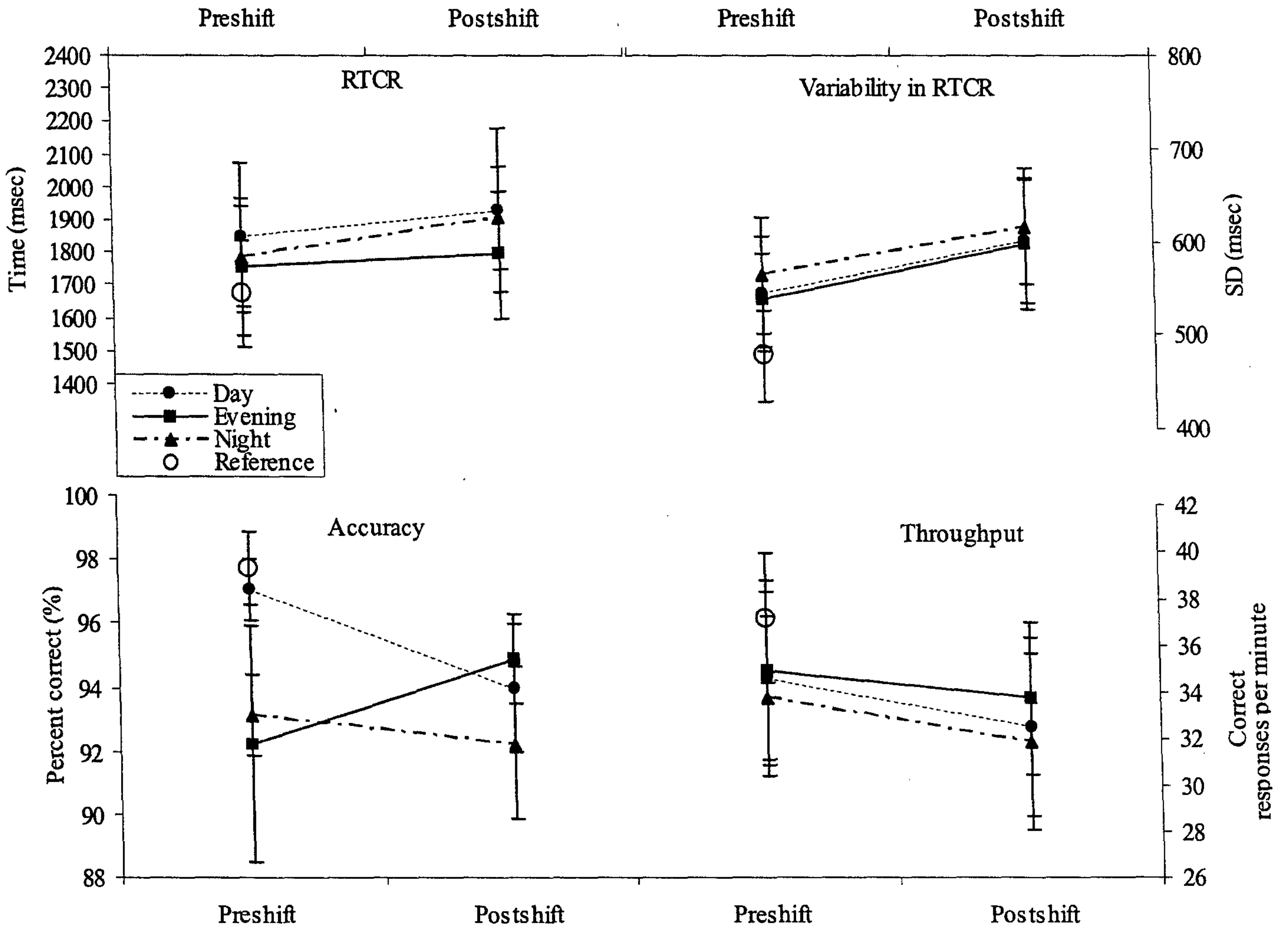


Data points expressed as mean (±SEM).

Figure 2. Effects of shift interval on piloting performance.

Cognitive Performance

Figure 3 summarizes the results for the ANAM serial math subtest. There was no difference in preshift RTCR, variability in RTCR, accuracy, or throughput between the study sample and an external reference group consisting of rested pilots who participated in another study (Caldwell et al., 2003a). For the study sample, RTCR and accuracy were not normally distributed necessitating a nonparametric approach to the analysis of the data. There was no difference in preshift and postshift RTCR or percent change in RTCR based on shift or shift rotation schedule. However, the variability in RTCR did increase from preshift to postshift ($F_{1,27} = 8.192$, $p = 0.009$, $\eta_p^2 = 0.271$). There was no difference in preshift and postshift accuracy or percent change in accuracy based on shift or shift rotation schedule. Graphical analysis of the accuracy data suggested an interaction effect for shift. Accuracy improved on the evening shift from preshift to postshift while it worsened on day and night shifts. Throughput, a combined measure of speed and accuracy reflecting the number of correct responses per minute, decreased 5.1% from preshift to postshift ($F_{1,27} = 7.683$, $p = 0.011$, $\eta_p^2 = 0.259$). There was no between-subject differences based on shift ($\eta_p^2 = 0.006$, power = 0.059) or shift rotation schedule ($\eta_p^2 = 0.012$, power = 0.079), nor were there any interaction effects.



Data points expressed as mean (±SEM); SD – standard deviation.

Figure 3. Effects of shift and shift interval on automated neuropsychological assessment metrics (ANAM) serial math subtest reaction time for correct responses (RTCR), variability in RTCR, accuracy, and throughput.

There was a strong positive linear correlation between preshift and postshift RTCR ($\tau = 0.799$, $p < 0.001$) as well as between preshift and postshift throughput ($r = 0.958$, $p < 0.001$). Given concerns over potential confounding by between-subject test interval variability, the relationship between postshift RTCR and preshift RTCR, shift, shift rotation schedule, and test interval were assessed using multiple regression analysis. Likewise, a similar analysis was accomplished for throughput. Shift and shift rotation schedule were dummy coded as integer variables (day shift = 0, evening shift = 1, night shift = 2; rapid rotation schedule = 0, slow rotation schedule =1). The final regression equations were as follows:

Postshift RTCR = 114.930 + 0.982(preshift RTCR); $F_{1,26} = 326.121$, $p < 0.001$, $R^2_{adj} = 0.923$

Postshift throughput = -0.617 + 0.967(preshift throughput); $F_{1,26} = 288.445$, $p < 0.001$, $R^2_{adj} = 0.914$

Vigilance Performance

Figure 4 summarizes the reaction time data from the PVT. There was no difference in preshift RT between the study sample and an external reference group consisting of rested pilots who participated in another study (Caldwell, Prazinko, Rowe, Norman, Hall, & Caldwell, 2003b). RT increased 10.9 percent from preshift to postshift ($F_{1,27} = 11.815$, $p = 0.002$, $\eta_p^2 = 0.349$). Although there was no between-subject differences based on shift ($\eta_p^2 = 0.106$, power = 0.251) or shift rotation schedule ($\eta_p^2 = 0.052$, power = 0.183), there was an interaction effect ($F_{2,25} = 3.564$, $p = 0.046$, $\eta_p^2 = 0.245$) between RT and shift. This was due to the night shift showing a large effect on the magnitude of the preshift to postshift change in RT relative to day and evening shifts.

FRT increased 7.1 percent from preshift to postshift ($F_{1,27} = 20.085$, $p < 0.001$, $\eta_p^2 = 0.477$). There was no between-subject differences based on shift ($\eta_p^2 = 0.080$, power = 0.194) or shift rotation schedule ($\eta_p^2 = 0.082$, power = 0.269). However, there was an interaction effect ($F_{2,25} = 6.370$, $p = 0.007$, $\eta_p^2 = 0.367$) between FRT and shift. This was due to day shift having no appreciable effect on the preshift to postshift change in FRT in contrast to the increase in FRT observed with the evening and night shifts.

SRT increased 17.8 percent from preshift to postshift ($Z = -2.118$, $p = 0.034$). Although SRT was not normally distributed and did not meet several assumptions for regression analysis, the slowest 10 percent reciprocal reaction time (SRRT) was normally distributed. As was found with the nonparametric approach, there was a within-subject difference from preshift to postshift ($F_{1,27} = 8.225$, $p = 0.009$, $\eta_p^2 = 0.272$). There were no between-subject differences based on shift ($\eta_p^2 = 0.065$, power = 0.164) or shift rotation schedule ($\eta_p^2 = 0.031$, power = 0.126) nor any interaction effects.

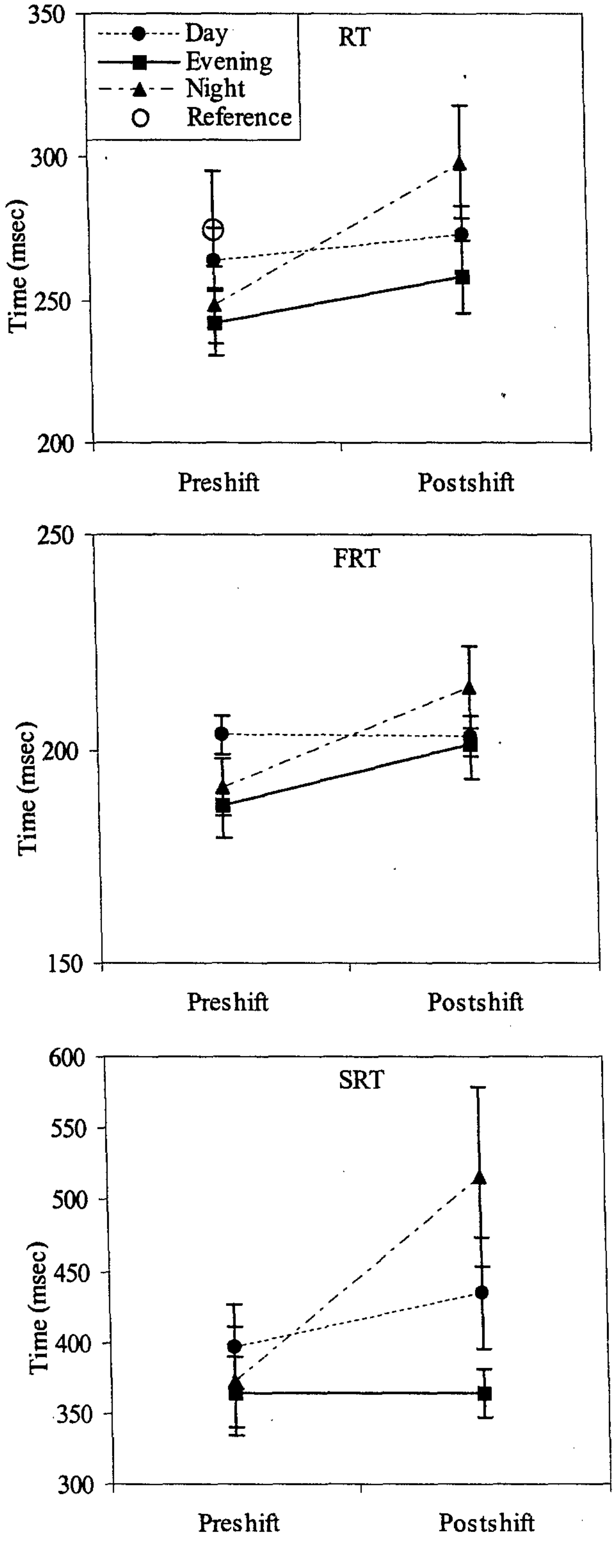
Given the strong positive associations between preshift and postshift RT ($r = 0.625$, $p < 0.001$), FRT ($r = 0.760$, $p < 0.001$), and SRRT ($r = 0.607$, $p = 0.001$) and concerns over potential confounding by preshift to postshift test interval variability, the relationship between postshift reaction times and preshift reaction times, shift, shift rotation schedule, and test interval were assessed using multiple regression analysis. Shift and shift rotation schedule were dummy coded as integer variables as in the analysis of the cognitive performance data. The final regression equations were as follows:

Postshift RT = 33.905 + 0.885(preshift RT) + 20.149(shift); $F_{2,25} = 12.616$, $p < 0.001$, $R^2_{adj} = 0.462$

Postshift FRT = -5.773 + 1.034(preshift FRT) + 11.687(shift); $F_{2,25} = 32.139$, $p < 0.001$, $R^2_{adj} = 0.698$

Postshift SRRT = 0.790+ 0.619(preshift SRRT); $F_{1,26} = 15.130$, $p = 0.001$, $R^2_{adj} = 0.344$

Lapses were not normally distributed which necessitated a nonparametric analysis. There was no within-subject difference between preshift and postshift lapses. Shifts did not differ in lapses at preshift, but evening shift had fewer lapses than day and night shifts at postshift ($\chi^2_{2df} = 10.747$, $p = 0.005$). There were no differences in lapses at preshift or postshift based on shift rotation schedule.



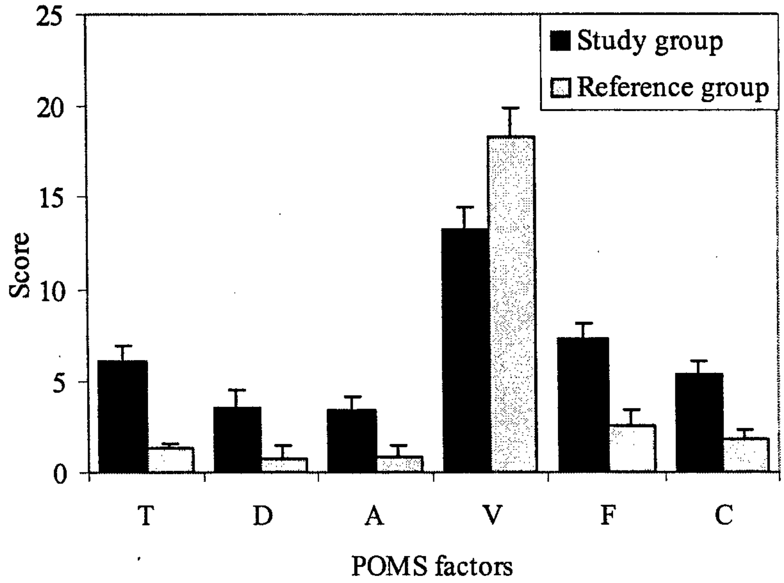
Data points expressed as mean (±SEM); RT – reaction time; FRT – fastest 10 percent reaction times; SRT – slowest 10 percent reaction times.

Figure 4. Effects of shift and shift interval on psychomotor vigilance task (PVT) reaction times.

Mood Evaluations

Profile of Mood States

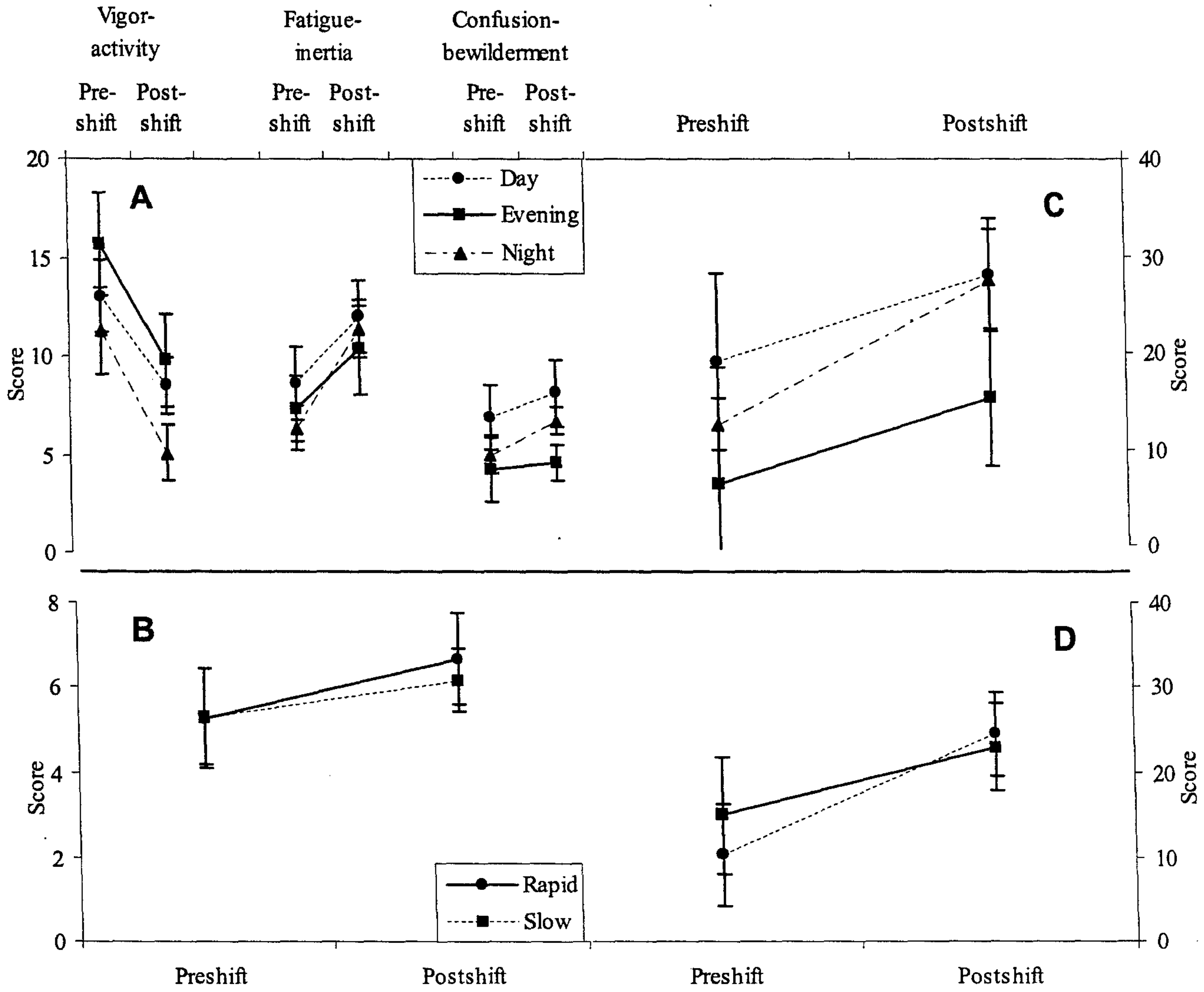
Some POMS factors scores had a normal distribution while others did not necessitating both parametric and nonparametric analyses. Figure 5 summarizes mean POMS factor scores for the study sample at preshift and an external reference group consisting of rested pilots who participated in another study (Caldwell et al., 2003a). In comparison to the reference group, the study sample had higher POMS factors scores for tension-anxiety ($U = 31.000$, $p < 0.001$), depression-dejection ($U = 69.500$, $p = 0.012$), anger-hostility ($U = 53.000$, $p = 0.003$), fatigue-inertia ($U = 52.000$, $p = 0.003$), and confusion-bewilderment ($U = 49.500$, $p = 0.002$) and a lower factor score for vigor-activity ($t_{36df} = -2.128$, $p = 0.040$).



Data points expressed as mean (±SEM); T - tension-anxiety; D - depression-dejection; A - anger-hostility; V - vigor-activity; F - fatigue-inertia; C - confusion-bewilderment.

Figure 5. Profile of mood states (POMS) factors scores for study sample versus an external reference group.

There were no differences between preshift and postshift tension-anxiety, depression-dejection, and anger-hostility POMS factors scores. There were also no differences among preshift and postshift scores for these same factors based on shift or shift rotation schedule. Vigor-activity scores decreased ($F_{1,27} = 40.560$, $p < 0.001$, $\eta_p^2 = 0.648$) while fatigue-inertia ($F_{1,27} = 17.076$, $p < 0.001$, $\eta_p^2 = 0.437$) and confusion-bewilderment ($Z = -2.528$, $p = 0.011$) scores increased from preshift to postshift (Figure 6A). There were no between-subject differences based on shift or shift rotation schedule for vigor-activity ($\eta_p^2 = 0.020\text{-}0.158$, power = 0.099-0.380) or fatigue-inertia ($\eta_p^2 = 0.002\text{-}0.033$, power = 0.055-0.104) factors scores. There were also no between-subject differences based on shift or shift rotation schedule for confusion-bewilderment factor scores, but there was an interaction effect for shift rotation schedule. Confusion-bewilderment factor scores increased from preshift to postshift for participants on a rapid shift rotation schedule ($Z = -2.430$, $p = 0.015$) but not for those participants on a slow shift rotation schedule (Figure 6B).



Data points expressed as mean (±SEM); A - Effects of shift and shift interval on selected profile of mood states (POMS) factors; B - Effects of shift rotation schedule and shift interval on confusion-bewilderment factor scores; C – Effects of shift and shift interval on mood disturbance scores (MDSs); D – Effects of shift rotation schedule and shift interval on MDSs.

Figure 6. Effects of shift, shift interval, and shift rotation schedule on selected profile of mood states (POMS) factors scores.

Mood disturbance scores (MDSs) were calculated for each participant by summing the POMS factors scores and negatively weighting POMS vigor-activity. MDSs are summarized in Figure 6C-D. Within participants, MDSs increased from preshift to postshift ($Z = -3.144$, $p = 0.002$). There was no difference between participants based on shift or shift rotation schedule, but there were interaction effects for shift and shift rotation schedule. MDSs increased from preshift to postshift for participants on the night shift ($Z = -2.446$, $p = 0.014$) but did not for those on day and evening shifts. Similarly, MDSs increased for participants on a rapid shift rotation schedule ($Z = -2.814$, $p = 0.005$) but did not for those on a slow rotation schedule. Thus, participants on night shift or a rapid shift rotation schedule drove the observed difference between preshift and postshift MDSs.

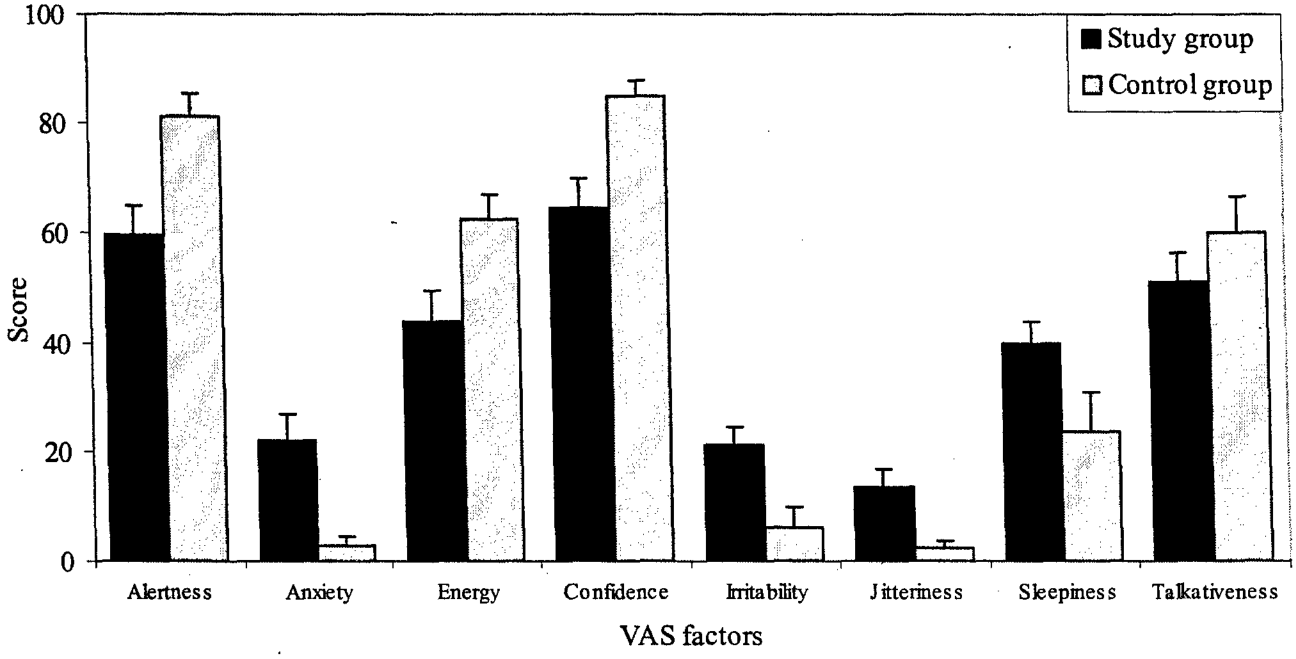
TABLE 4. Odds ratios for a mood disturbance score (MDS) greater than 95th percentile of reference group.

	Odds ratio	95% CI	p-value
Preshift	10.4	1.2, 93.3	0.025
Shift			
Day	15.0	1.2, 185.2	
Evening	4.5	0.4, 54.2	0.047
Night	15.8	1.4, 174.3	
Rotation schedule			
Fast	6.0	0.6, 60.4	0.017
Slow	20.3	1.9, 218.4	
Postshift	33.0	3.5, 314.5	<0.001
Shift			
Day	63.0	3.3, 1194.8	
Evening	11.3	1.0, 130.2	0.001
Night	90.0	4.9, 1659.5	
Rotation schedule			
Fast	36.0	3.2, 405.9	0.001
Slow	30.0	2.6, 342.8	

Since MDSs were not normally distributed, an abnormal or extreme MDS was defined as one greater than the 95th percentile. MDSs were recoded into the dichotomous variable, mood disturbance case, based on whether the MDS exceeded the 95th percentile of the external reference group. Table 4 summarizes the odds ratios for mood disturbance cases by shift and shift rotation schedule. The 95 percent confidence intervals were relatively wide because of the small sample size, but nevertheless many CIs were non-inclusive of one. There was a 10-fold increased likelihood of a participant in the study population being a mood disturbance case relative to the reference group and this likelihood increased 217.3 percent from preshift to postshift. The odds ratios for day and night shifts increased 320.0 and 469.6 percent respectively from preshift to postshift. The likelihood of a mood disturbance case on the evening shift was comparable to the reference group at both preshift and postshift. Although the likelihood of a mood disturbance case was elevated for participants on a slow rotation schedule at preshift, the odds ratios increased 500.0 and 47.8 percent for rapid and slow rotation schedules respectively such that the likelihood of a mood disturbance case was greatest for the rapid rotation schedule at postshift.

Visual Analog Scale

The majority of VAS factors scores were not normally distributed necessitating mostly nonparametric analyses. Figure 7 summarizes mean VAS factor scores for the study sample at preshift and the same external reference group used in the previous POMS analysis (Caldwell et al., 2003a). In comparison to the reference group, the study sample had higher VAS factors scores for anxiety ($U = 54.000$, $p = 0.004$), irritability ($U = 49.000$, $p = 0.002$), jitteriness ($U = 76.000$, $p = 0.031$), and sleepiness ($U = 67.000$, $p = 0.015$) and lower factors scores for alertness ($t_{33.9df} = -3.220$, $p = 0.003$) and energy ($t_{30.7df} = -2.568$, $p = 0.015$). There was no difference between groups in VAS factors scores for confidence or talkativeness.

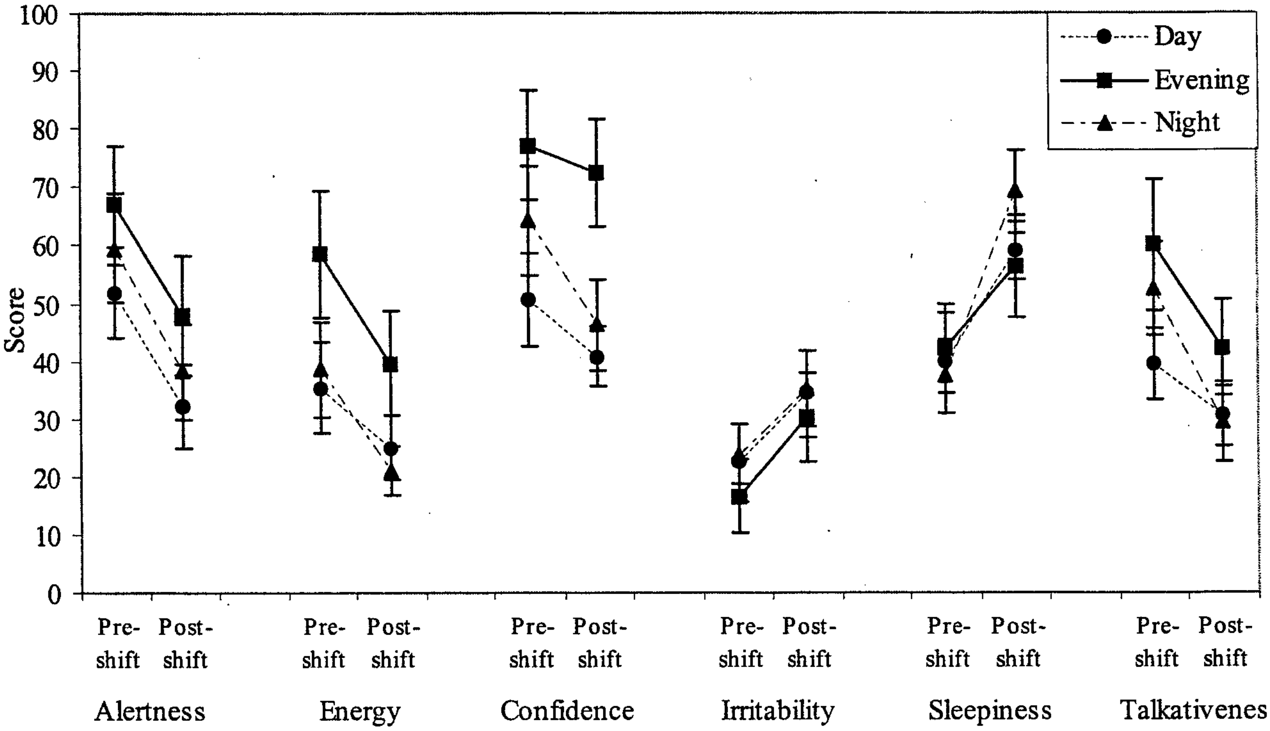


Data points expressed as mean (±SEM).

Figure 7. Visual analog scale (VAS) factors scores for study sample versus an external reference group.

Alertness ($F_{1,27} = 31.829$, $p < 0.001$, $\eta_p^2 = 0.591$), energy ($F_{1,27} = 22.925$, $p < 0.001$, $\eta_p^2 = 0.510$), confidence ($Z = -3.474$, $p = 0.001$), and talkativeness ($F_{1,27} = 18.285$, $p < 0.001$, $\eta_p^2 =$

0.454) factor scores decreased while irritability (Z = -2.471, p = 0.013), and sleepiness (Z = -3.337, p = 0.001) factor scores increased from preshift to postshift (Figure 8). There were no within-subject differences for anxiety and jitteriness factors. With the exception of the postshift confidence factor, there were no differences between participants in preshift or postshift VAS factor scores based on shift or shift rotation schedule. Although nonparametric tests don't allow for a direct analysis of interactions, graphical analysis of confidence scores suggested an interaction effect. There was little effect of day and evening shift on the preshift to postshift change in confidence scores. However, the effect of night shift was to increase the magnitude of the preshift to postshift decrement in confidence scores. This resulted in the observed difference in postshift confidence scores based on shift. Graphical analysis also suggested potential interaction effects for night shift on energy, sleepiness, and talkativeness scores. The effect of night shift was to magnify the preshift to postshift change in scores compared to the effects of day and evening shift.



Data points expressed as mean (±SEM).

Figure 8. Effects of shift and shift interval on selected visual analog scale (VAS) factors scores.

Boredom Evaluations

The TrBS and visual analog boredom scale scores were positively correlated, but neither was correlated with BPS scores (Table 5). The TrBS also correlated with preshift and postshift mean reaction time, but not the within-shift percent change in reaction time. Figure 9 summarizes the results of the visual analog boredom scale scores as a histogram. Although the correlation analysis did not demonstrate any associations between crew position and boredom, graphical analysis of subjective boredom ratings found 92 percent of pilots reported "moderate" to "total" boredom as compared to 62 percent of sensor operators. Overall, the histogram was negatively skewed (skewness = -0.780) with two-thirds of participants reporting moderate or greater boredom (binomial test p = 0.007).

TABLE 5. Boredom correlations.

	BPS	TrBS	Boredom rating
BPS	---	0.313	0.095
TrBS	0.313	---	0.433**
Boredom rating	0.095	0.433**	---
Preshift RT	0.186	0.430*	0.158
Postshift RT	0.381	0.423*	0.112
RT percent change	0.180	-0.130	-0.150
Shift	-0.050	0.196	0.208
Crew position	-0.192	0.021	-0.117

*p < 0.05; **p < 0.01.

BPS - boredom proneness scale; TrBS - task-related boredom scale; RT - reaction time.

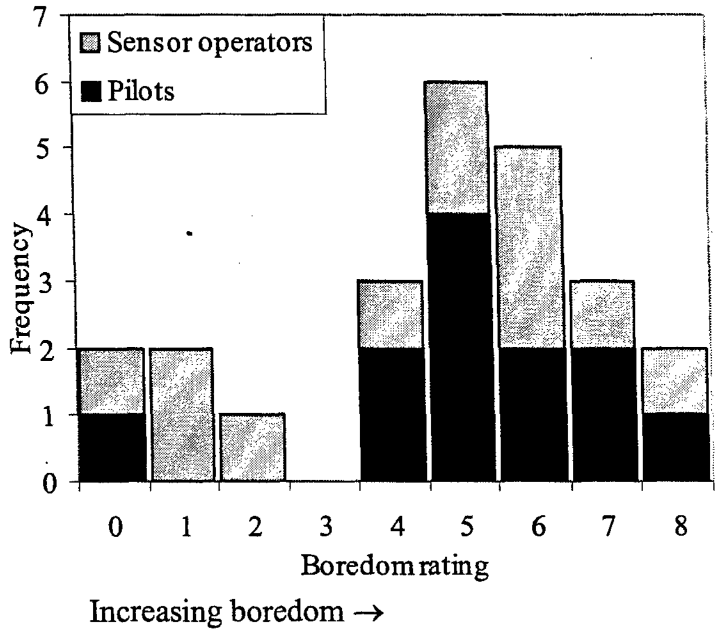


Figure 9. Histogram of subjective boredom ratings by crew position.

Flying Time Correlations

Table 6 summarizes the correlations between the various assessments made in this study and participants' 30-day, 60-day, and 90-day flying time histories. All participants were within 30-day and 90-day maximum flying time limits as delineated in AFI 11-202V3 (USAF, 2005). The objective measures of cognitive (ANAM serial math subtest) and vigilance (PVT) performance as well as the six subjective measures of fatigue (CFS) correlated poorly with flying

TABLE 6. Correlations between study assessments and flying time histories.

Parameter	Flight hours 30-day	60-day	90-day
Fatigue evaluations			
Fatigue assessment scale (FAS)	-0.046	0.186	0.111
Fatigue scale (FS)	-0.155	0.043	-0.014
CIS-CON	-0.253	-0.063	-0.103
EF-WHOQOL	-0.130	-0.016	-0.056
MBI-EE	-0.129	-0.163	-0.191
Sleep disorder score (SDS)	0.159	0.130	0.114
Sleep evaluations			
Average daily sleep	-0.014	-0.036	-0.029
Weighted average daily sleep	-0.074	-0.117	-0.171
Work effectiveness	-0.326	-0.465*	-0.435*
Cognitive evaluations			
ANAM serial math subtest throughput			
Preshift	-0.085	-0.233	-0.244
Percent change	-0.378	-0.290	-0.291
Vigilance evaluations			
Psychomotor vigilance task (PVT) mean reaction time			
Preshift	0.192	0.142	0.131
Percent change	-0.065	-0.023	-0.015
Mood evaluations			
Profile of mood states (POMS) fatigue-inertia factor			
Preshift	-0.548**	-0.338	-0.343
Percent change	-0.442*	-0.405*	-0.457*
Visual analog scale (VAS) sleepy factor			
Preshift	-0.269	-0.084	-0.097
Percent change	0.257	0.127	0.180

*p < 0.05; **p < 0.01

ANAM - automated neuropsychological assessment metric; CIS-CON – checklist individual strength concentration subscale; EF-WHOQOL – World Health Organization quality of life assessment energy and fatigue subscale; MBI-EE – Maslach burnout inventory emotional exhaustion subscale.

time histories. POMS preshift fatigue-inertia scores negatively correlated with 30-day flying time histories. Additionally, the percent change in fatigue-inertia scores from preshift to postshift also negatively correlated with 30-day, 60-day, and 90-day flying time histories. Sleep histories were poorly correlated with flight hours but work effectiveness as predicted by FAST was negatively correlated with 60-day and 90-day flying time histories. Overall, flying time histories were not positively correlated with any of the subjective or objective study assessments.

DISCUSSION

Shift workers are particularly vulnerable to increased sleepiness, chronic fatigue, and decreased alertness and performance both on and off the job (Hossain et al., 2004). This study quantitatively evaluated the impact of shift work on subjective fatigue, alertness, cognition, and piloting performance of U.S. Air Force UAS crews. To the authors' knowledge, it is the only assessment of its type conducted to specifically address the impact of shift work on current MQ-1 Predator crews. This study is particularly valuable in that assessments were made during real world combat support missions which included the potential for weapons release. Thus, there is little question of this study's external validity with regards to current Air Force UAS operations. The results indicated a variety of operationally-relevant effects of shift work which UAS crews, commanders, and Air Force planners may wish to consider in developing training programs, scheduling current crews, and structuring and manning future units.

Fatigue Evaluations

The CFS provided a thorough assessment of subjective fatigue utilizing six fatigue assessment instruments which have been shown to have good reliability and validity in working populations (De Vries, Michielsen, & Van Heck, 2003). Fatigue was pervasive in the study sample irrespective of shift or shift rotation schedule. Although fatigue scores were similar across shifts, there was a nonsignificant though regular trend for day shift to have the highest fatigue scores. This is consistent with other studies which have found morning shifts, especially when associated with early rising, to be strongly associated with increased sleepiness during the rest of the day (Åkerstedt, 2003; Åkerstedt, Kecklund, & Knutsson, 1991; Folkard & Barton, 1993; Kecklund & Åkerstedt, 1993). Likewise, while fatigue scores were similar across shift rotation schedules, there was a nonsignificant but consistent trend for the rapid shift rotation schedule to have higher fatigue scores than the slow shift rotation schedule. Collectively, the results from the six assessment instruments in the CFS were indicative of chronic fatigue. Compared to the AWACS reference group, the study sample had higher scores on the FAS which is specifically purported to be a measure of chronic fatigue (Michielsen, De Vries, Van Heck, Van de Vijver, & Sijtsma, 2004). Additionally, chronic fatigue is known to predispose workers to chronic job stress and burnout, the most common fatigue-related component of which is emotional exhaustion (Michielsen et al., 2003). This effect was also observed in the study sample which had higher scores than the AWACS reference group on the two assessments of emotional exhaustion and burnout, the EF-WHOQOL and MBI-EE. Since workers in shift systems require more time to recover than those working only day shifts, the observed chronic fatigue is likely reflective of inadequate opportunity for restorative sleep.

The items contained in the CFS do not discriminate definite pathological conditions, but rather select participants in whom some signs of sleep disorders could be important evidence of a general sleep disruption or particular type of disorder. With that said, the study sample had a higher prevalence of individuals with evidence for intrinsic sleep disorders than the reference group. This is consistent with the findings of Garbarino et al. (2002) that shift work conditions enhance sleep disorders. However, the prevalence in this study was only 40 percent and 54 percent of that reported by Garbarino et al. for shift workers and non-shift workers respectively. This may reflect a selection bias in the present study because aviation personnel must pass initial as well as recurrent medical examinations for which sleep disorders are disqualifying conditions. Alternatively, it may reflect a reporting bias since aviators tend to underreport medical symptomatology. However, the study sample was also 44 times more likely to report their work schedule negatively impacted life activities as compared to a reference group known for high operations tempo and both frequent and lengthy periods of temporary duty. The most significant finding was a 54 percent prevalence of individuals in the study sample with evidence for SWSD. This is two to five times higher than the prevalence reported for shift workers in general (Czeisler et al., 2005; Drake, Roehrs, Richardson, Walsh, & Roth, 2004; Schorr, 2004).

Sleep Evaluations

The fatigue reported on the CFS did not appear to be caused by voluntary sleep restriction as mean daily sleep was greater than seven hours whether determined by self report data or actigraphy. When sleep was weighted for quality, daily sleep ranged from 4.4-5.6 hours, suggesting disturbed, non-restorative sleep. This is consistent with the findings of Åkerstedt et al. (1991) of reduced stage two, rapid-eye-movement, and slow wave (stages 3-4) sleep in connection with morning and night shifts. Such chronic partial sleep deprivation could explain the excess fatigue reported on the CFS. Studies have shown that a week with 4.5 hours of sleep per day may yield sleepiness close to levels seen with total sleep deprivation (Åkerstedt, 2003; Carskadon & Dement, 1981). The combination of partial sleep deprivation and the influences of the homeostatic and circadian systems significantly increased the risk for diminished predicted work effectiveness for crewmembers on the night shift and on the rapid shift rotation schedule.

Piloting Performance

Results of piloting performance on the UAV STE were not straightforward, and were therefore difficult to interpret. In general, changes in simulator performance from preshift to postshift were mixed and involved stable, improved, or degraded performance depending on the flight parameters assessed. Improvements in flight simulator performance with serial testing despite increasing acute fatigue has been noted in other studies and likely reflects the practice-related tendency to improve masking the effects of fatigue (Caldwell et al., 2003b). In this study, the most notable effect of shift interval was to decrease performance on the airspeed portion of the simulator task. To understand this observation, it is important to note that rate of change information is available on the Predator HUD for altitude (e.g., vertical speed indicator) and heading (turn rate indicator), but not for airspeed. Thus, pilots mainly utilized simple tracking skills to null out deviations from target values on the vertical speed and turn rate indicators during the study maneuver. However, constant rate changes in airspeed required greater mental loading because of the need to calculate and monitor airspeed changes throughout the maneuver. Additionally, the aerodynamics of the Predator makes airspeed control challenging, especially during a descent. This more complex task appeared to be susceptible to performance degradation secondary to acute fatigue accumulated over the course of a shift interval. This represents a potential mechanism by which fatigue can contribute to mishaps, particularly in phases of flight such as landings where airspeed control is critical.

The effect of the chronic fatigue documented by the CFS on piloting performance was unknown because of the lack of a reference group. There was quite broad within-subjects and between-subjects variability in performance, which in itself may have been a manifestation of chronic fatigue. Suggestive of a chronic fatigue effect was the observation that only one participant obtained criterion performance on the UAV STE as established by Schreiber et al. (2002). Participant performance in this study was worse than that reported by Schreiber et al. for their sample of Predator pilots performing the entire UAV STE basic maneuvering task. Unfortunately, Schreiber et al. provided no information regarding the fatigue status of their study sample.

Cognitive Performance

Overall, the cognitive task (ANAM serial math subtest) was relatively insensitive to circadian or acute fatigue effects associated with shift and shift interval. However, the serial math subtest has been criticized as tending to have overall high scores with little variability which compromises its measurements (Schlegel, Gilliland, & Crabtree, 1992). In this study, performance became more variable and throughput declined over the shift interval. However, the decrement in throughput was relatively modest as the predicted postshift performance was nearly equal to preshift performance as estimated by the regression analysis. There was a trend to maintain performance accuracy at the expense of performance speed which is consistent with past research (Krueger, 1991).

Vigilance Performance

In contrast to the ANAM serial math subtest, the PVT was sensitive to the circadian effects of shift and acute fatigue effects of shift interval. There was greater degradation in reaction time vigilance performance over a shift interval for night shift relative to day and evening shifts. An obvious reason for this was night shift participants were working at a well-established nadir in their circadian cycle. Additionally, the time awake before a night shift is often extended compared to other shifts. Alertness starts to fall immediately after termination of sleep and continues for the duration of wakefulness (Åkerstedt, 2003). Performance was predicted to be most degraded for the night shift followed by evening and day shifts respectively based on the regression analyses. Differences in performance resulted from more frequent lapses in attention versus a general slowing of response time which is consistent with past research (Schroeder et al., 1994). Lapses in attention were most prevalent at the end of the day and night shifts, suggesting the early morning and mid-afternoon periods were particularly high risk times for crews to miss information.

Mood Evaluations

Partial sleep loss, changes in sleep/wakefulness cycles, or both experienced in shift work often result in changes in mood, increased feelings of fatigue and irritability, and an inability to concentrate (Paley & Tepas, 1994). Therefore, it was not unexpected that the study sample reported being more tense, anxious, irritable, jittery, depressed, angry, sleepy, fatigued, and confused as well as less alert, energetic, and vigorous compared to other Air Force aviators. The acute fatigue effects of shift interval manifested as subjective reports of increased fatigue and confusion and decreased vigor. Aggregate undesirable mood states tended to be particularly magnified over the course of a shift interval for those on night shift or a rapid shift rotation schedule, likely reflecting the increased circadian stressors associated with these shift work factors. These same factors were also associated with an increased risk for participants having extreme undesirable mood states relative to the reference group of aviators. Levels of undesirable mood tended to be highest at postshift for both the day and night shifts. This trend is consistent with previous research which has shown both day and night shifts interfere with sleep (Åkerstedt, 2003; Åkerstedt et al., 1991).

Boredom Evaluations

Subjective reports of boredom from the TrBS and visual analog boredom rating indicated the majority of pilots and sensor operators found their job tasks boring. Ratings of boredom on the visual analog scale most differentiated pilots and sensor operators with pilots as a group tending to be more uniform in reporting their job tasks as at least moderately boring. Boredom and monotony are widely recognized as undesirable side effects of repetitious or understimulating work, conditions which are difficult to eliminate in highly automated systems such as UASs. Besides being an undesirable affective state, boredom has been show to have negative effects on morale, performance, and quality of work (Thackray, 1980). For example, Thackray, Powell, Bailey, and Touchstone (1975) found individuals who reported high boredom in monitoring tasks such as ATC were more likely to exhibit performance decrements such as lapses and slow reaction times as compared to those reporting low boredom. Likewise, this study found participants reporting greater subjective task-related boredom tended to have slower reaction times. However, while other research has demonstrated an individual predisposition to boredom (Farmer & Sundberg, 1986) and associated performance decrements (Kass et al., 2001; Sawin & Scerbo, 1995), no such relationship was observed in the present study.

Flying Time Correlations

The U.S. Air Force has established maximum flying time limits (USAF, 2005) in order to afford aircrew sufficient opportunity for recovery from the effects of fatigue, thereby preventing chronic fatigue, chronic job stress, and burnout. The problem with this approach is that it assumes fatigue is highly and positively correlated with time on task in the workplace. However, field research with industrial shift workers as well as laboratory research has consistently demonstrated time-of-day differences in sleep, sleepiness, mood, and performance, indicating that all hours of the day are not equal and interchangeable (Paley & Tepas, 1994). The present study utilized objective measures focusing on performance and subjective assessments of fatigue and found a high prevalence of fatigue and potential burnout in this sample of shift working UAS crews. Chronic fatigue in shift workers is often caused by inadequate opportunities for recovery sleep, usually resulting from working too many shifts in succession, having too short a period of rest between two shifts, or having to sacrifice days off (Hossain et al., 2004; Jansen et al., 2003). Since none of the measures utilized in this study were meaningfully correlated with flying time, flying time appears to have significant shortcomings as a surrogate metric for fatigue when applied to aviation personnel involved in shift work.

Study Limitations

This study was conducted utilizing a relatively small sample size (< 30 participants) which limits the power of statistical tests and increases the likelihood of false negative results when examining differences between shifts or shift rotation schedules. This may explain several of the nonsignificant trends observed in the data. Although small, the study sample represented a large fraction of the entire population of USAF MQ-1 Predator crewmembers supporting Operations ENDURING FREEDOM and IRAQI FREEDOM. Since this was a field study, it was not possible to standardize the exposure (e.g., shift content) or test interval duration, nor was it possible to control other, non-exposure related factors such as tobacco or caffeine use and tolerance, prior cumulative sleep debt, or motivation. This likely contributed to the variability of the data, further decreasing the power of statistical tests. However, it was noteworthy that test interval duration was not retained in any of the linear regressions for the objective performance assessments, suggesting it did not account for a significant amount of the variation in postshift test results. Thus, the observed pre-to-postshift changes likely occurred earlier rather than later during a shift interval. Finally, there were no non-exposed members in the study population which required the use of external rather than internal control groups, increasing the risk controls might differ from participants based on other factors besides work schedule.

CONCLUSIONS

United States Air Force MQ-1 Predator crews involved in home-based teleoperations and sustained rotational shift work reported decreased mood and quality of life as well as increased fatigue, emotional exhaustion, and burnout relative to traditional aircrew from other "high demand-low density" weapon systems subject to frequent and lengthy deployments. Decrements in mood, cognitive function, and alertness were observed over the duration of a shift and were prevalent across all shifts and shift rotation schedules. However, there was a tendency for the adverse effects of shift work to be most pronounced on both day and night shifts relative to evening shift and on rapid versus slow shift rotation schedules. Additionally, the GCS task environment was associated with moderate to high levels of subjective boredom, a fact that has important implications for morale and performance. Overall, the environment created by conducting UAS operations using shift work in the context of a sustained operations tempo of greater than three years duration significantly increased the likelihood of personnel reporting symptoms consistent with SWSD. This is consistent with prior research which has found the combination of shift work and high workload, inadequate manpower, or both enhances the negative effects of shift work on health, alertness, and performance (Knauth & Hornberger, 2003).

A critical point highlighted by the present study was the high prevalence of chronic fatigue in an aircrew population involved in shift work despite being in compliance with Air Force fatigue management policy and guidance. In particular, flying time limits were not an effective metric for ensuring adequate opportunities for recovery sleep in order to mitigate the development of chronic fatigue. This is all the more important given the recommendation by a 2003 Air Force investigation into shift worker fatigue to develop fatigue management policy and guidance for ground personnel which emulates that used for aircrew (Air Force Inspection Agency [AFIA], 2004). Overall, the presence or awareness of policy and guidance regarding shift work is minimal, even for aircrew.

All of these points serve to highlight the importance of providing formal education and training on sleep hygiene, alertness management, and coping strategies to shift workers, schedulers, and supervisors. In addition, this study suggests the need to apply science-based shift scheduling techniques when developing manpower requirements and developing duty time and crew rest requirements. Since UAS operations are forecast to become an ever larger portion of military aviation, increased attention should be devoted by the research community to developing tailored fatigue countermeasures for the shift work-prone UAS environment. Finally, this study demonstrates the value of assessing aircrew in their actual work environment even though such environments invariably bring a multitude of operational constraints.

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ACRONYMS

AFB	Air Force Base
AFI	Air Force Instruction
AFIA	Air Force Inspection Agency
ANAM	Automated Neuropsychological Assessment Metrics
ANOVA	Analysis of Variance
APA	American Psychiatric Association
ASCII	American Standard Code for Information Interchange
ATC	Air Traffic Control
AWACS	Airborne Warning and Control System
BPS	Boredom Proneness Scale
CFR	Code of Federal Regulations
CFS	Composite Fatigue Scale
CI	Confidence Interval
CIS-CON	Checklist Individual Strength Concentration Subscale
DoD	Department of Defense
DSM-IV	Diagnostic and Statistical Manual of Mental Disorders - Fourth Edition
EF-WHOQOL	World Health Organization Qualify of Life Assessment Energy and Fatigue Subscale
FAS	Fatigue Assessment Scale
FAST	Fatigue Avoidance Scheduling Tool
FRT	Fastest 10 Percent Reaction Times
FS	Fatigue Scale
GCS	Ground Control Station
HUD	Head-up Display
IBM	International Business Machines
ISQ	Initial Study Questionnaire
MBI-EE	Maslach Burnout Inventory Emotional Exhaustion Subscale
MDS	Mood Disturbance Score
OR	Odds Ratio
OSD	Office of the Secretary of Defense
OTA	Office of Technology Assessment
POMS	Profile of Mood States
PVT	Psychomotor Vigilance Task
RMS	Root Mean Square
RT	Reaction Time
RTCR	Reaction Time for Correct Responses
SAFTE™	Sleep, Activity, Fatigue, and Task Effectiveness
SD	Standard Deviation
SDS	Sleep Disorder Score
SEM	Standard Error of the Mean
SRRT	Slowest 10 Percent Reciprocal Reaction Times
SRT	Slowest 10 Percent Reaction Times
SWSD	Shift Work Sleep Disorder

TrBS	Task-related Boredom Scale
UAS	Unmanned Aircraft System
UAV STE	Unmanned Aerial Vehicle Synthetic Task Environment
US	United States
USAF	United States Air Force
VAS	Visual Analog Scale