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Fatigue in Pilots of Remotely Piloted Aircraft Before and After Shift Work Adjustment

Anthony P. Tvaryanas and Glen D. MacPherson

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Background: Remotely piloted aircraft (RPA) with long endurance allow near-continuous operations, necessitating the implementation of shift work for crewmembers to provide the necessary manning of ground control stations. Shift work has a well-known association with fatigue, degraded work performance, and an increased risk for errors and accidents. This study presents the results of a follow-up survey of a particular population of shift-working RPA crewmembers 1 yr after modification of their shift work schedule. ***Methods:*** A cross-sectional survey of 66 RPA crewmembers was conducted using a collection of validated fatigue scales. This data was compared to survey data collected a year prior from the same population and from a reference group of non-shift-working aircrew. Shift system features and individual and situational differences associated with fatigue were explored. Additionally, several alternative types of shift schedules were assessed through modeling and simulation. ***Results:*** The study found no significant reduction in reported fatigue despite prior modifications to the shift work schedule to increase opportunities for recovery. Months shift working, sleep quality, and disturbances in family and social activities were associated with overall fatigue scores. Approximately half of those surveyed met criteria for occupationally significant fatigue. Months shift working, use of on-duty napping, and fatigue scores were predictive of those with occupationally significant fatigue. Modeling of feasible variants of the current shift work schedule failed to reveal a significantly improved alternative schedule. ***Conclusions:*** Collectively, the results demonstrate a persistent problem with chronic fatigue in this study population, likely reflective of continued inadequate opportunities for recovery and restorative sleep.

Keywords: human factors, circadian periodicity, shift work and shift rotations, sleep, pilots, sensor operators, unmanned aircraft systems.

REMOTELY PILOTED aircraft (RPA) with long endurance allow near-continuous operations, necessitating the implementation of shift work for crewmembers to provide the necessary manning of ground control stations. However, serious public health concerns have been raised regarding the association between shift work and degraded work performance and an increased risk for errors and accidents (17). It is known that shift workers experience a wide range of problems from acute disturbances of circadian rhythms and sleep to diminished family and social lives, which can adversely influence mood, performance, physical health, and safety (3). Some of these concerns were borne out in a study of shift-working MQ-1 Predator RPA crewmembers that found increased fatigue, emotional exhaustion, and burnout relative to traditional aircrew from another "high-demand, low density" weapon system (25). It is also understood that greater shift-work-related disturbances may be produced by certain types of shift systems, features of systems, or work context issues (3). In the same study of RPA crewmembers, it was observed that pilots used a three-shift, weekly (rapid), clockwise rotating schedule and sensor operators used a 3-mo (slow), clockwise rotating schedule. Numerous subjective and objective assessments identified a tendency for adverse effects of shift work to be more pronounced on day and night shifts relative to the evening shift and for those on the rapid versus slow shift rotation schedule (24). The squadron work schedule was redesigned, but preferred shift work practices were not fully implemented because of manpower constraints and crewmembers' preferences. In the end, the squadron elected for a 6W:3F shift plan with a monthly, clockwise rotating shift system for both pilots and sensor operators [the shift plan defines the ratio of days worked to days free (*N*W:*N*F) and the shift system defines the sequence of shifts; the reader is referred to Miller (15) for more details]. The risks and benefits of this shift work schedule were discussed and it was decided to resurvey the squadron after a minimum period of 1 yr. The present study extends the findings of this prior work by quantitatively reassessing fatigue levels in these RPA crewmembers supporting continuous teleoperations using rotational shift work. The following research questions (Q) and hypotheses (H) are adopted for the present study:

- Q1: Did the work schedule modifications, which emphasized consecutive days off to provide opportunities for recovery sleep, ameliorate fatigue?
- H1: Fatigue scores for this study group will be 1) lower than the RPA group surveyed 1 yr ago, but 2) higher than a reference group of previously surveyed non-shift-working aircrew (25).
- Q2: Considering the shift work fatigue literature (1,3,5,6,15–17), what variables best explain the variance in individual fatigue scores in this population of RPA crewmembers?
- H2A: Fatigue scores are positively associated with age, gender (relative to male), months involved in shift work, current shift (relative to day shift), crew position (relative to pilot), and inadequate time for life activities.

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H2B: Fatigue scores are negatively associated with hours slept, sleep quality (relative to poor sleep quality), use of naps during duty, and maintenance of work wake/sleep cycles on days off.

Q3: What variables are most "predictive" of excessive on-the-job sleepiness in this population of RPA crewmembers?

H3A: The odds of excessive on-the-job sleepiness increase with age, gender (relative to male), months involved in shift work, current shift (relative to day shift), crew position (relative to pilot), fatigue scores, and inadequate time for life activities (i.e., diminished family and social lives).

H3B: The odds of excessive on-the-job sleepiness decrease with hours slept, sleep quality (relative to poor sleep quality), use of naps during duty, and maintenance of work wake/sleep cycles on days off.

Q4: Given strong preference for the 6W:3F shift plan, are there alternative shift systems based on the 6W:3F shift plan that are better in terms of crewmember predicted effectiveness?

H4: Based on modeling and simulation, the percent work time where predicted cognitive performance effectiveness will be below a specified criterion will be 1) less for a fast versus slow rotation schedule; 2) less for a fixed schedule, assuming good worker compliance with work/sleep guidelines, versus a slow rotation schedule; and 3) less for a fast or slow rotation schedule versus a fixed schedule, assuming poor worker compliance with work/sleep guidelines.

METHODS

Study Design

The study protocol was approved by the Brooks City-Base Institutional Review Board in accordance with federal and USAF regulations on the protection of human subjects in behavioral and biomedical research. The target population for this cross-sectional survey of fatigue was all MQ-1 Predator RPA personnel assigned to a particular squadron supporting Operations Enduring Freedom (Afghanistan) and Iraqi Freedom (Iraq) in December 2006. Inclusion criteria were permanently assigned, full-time personnel involved in shift work for at least 1 mo. Squadron-wide solicitation of volunteers was conducted through site electronic communications. In early December 2006, an informational e-mail message was sent to squadron members explaining the general nature of the study, the voluntary nature of participation, and identifying the URL to access the web page for the electronic study questionnaire. Each squadron member who wished to participate completed the study questionnaire at their convenience. The opening web page preceding the actual questionnaire informed study participants that the purpose of the study was a follow-up to a prior fatigue survey and reiterated that participation was voluntary and anonymous. The questionnaire consisted of 51 items and required 10-15 min to complete. The web site was maintained for a 30-d period, although all participants who completed the survey did so within the initial 10 d. The data from this questionnaire was subsequently combined with prior survey data collected on Predator RPA and E-3B Sentry Airborne Warning and Control System (AWACS) crewmembers in 2005 (25). For purposes of this paper, only data associated with participants who were pilots and sensor operators was used in order to avoid confounding by flight status and applicable hours of service rules when making comparisons between the present and prior studies.

Study Apparatus

Sleep and fatigue survey: The study questionnaire has been described in detail elsewhere (25). Briefly, the questionnaire collected demographic data and fatigue assessments based on six validated fatigue (sub)scales purported to evaluate different dimensions of fatigue: fatigue scale [consisting of physical (FS-physical) and mental fatigue (FS-mental) subscales], checklist individual strength concentration subscale (CON), fatigue assessment scale (FAS), World Health Organization quality of life assessment energy and fatigue subscale (QOL), and Maslach burnout inventory emotional exhaustion subscale (EE). Additionally this survey included the Epworth Sleepiness Scale (ESS); an 8-item scale commonly used to diagnose sleep disorders and considered a valid and reliable self-report of sleepiness (8). Based on concerns identified in a prior study (24), an additional, non-validated question eliciting the likelihood of falling asleep during a period of high boredom in the ground control station (GCS) was added among the ESS items, but was scored separately. Finally, two questions assessed the use of naps during or at the end of duty periods and one question evaluated the tendency to maintain work wake and sleep times on days off (i.e., circadian adaptation).

Fatigue and performance modeling: In addition to the fatigue questionnaire, shift work schedules were analyzed using the Fatigue Avoidance Scheduling Tool (FAST) version 1.6.00T (NTI, Inc., Fairborn, OH). FAST allows easy data entry of work and sleep schedules and generates graphical predictions of cognitive performance effectiveness along with tables of estimated performance effectiveness scores based on the Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE™) model. 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 (7) (Eddy DR, Hursh SR; Report no.: AFRL-HE-BR-TR-2006-0015, 2006. Eddy DR, Hursh SR; Report no.: AFRL-HE-BR-TR-2006-0040, 2006).

Statistical Analysis

Data were analyzed using Statistical Package for the Social Sciences (SPSS Inc., Chicago, IL) version 11.5. Kolmogorov-Smirnov one-sample tests, Shapiro-Wilk tests, and normal quantile-quantile plots were all used to assess normalcy. A multivariate analysis of variance (MANOVA) was used to test whether the mean scores of groups differed across the six fatigue scales simultaneously. Box's M and Levene's tests were used to assure the multivariate assumptions of equality of covariance matrices and equality of error variances across groups were not violated. The model was unbalanced and type III sum of squares was used. Univariate ANOVAs with Tukey post hoc tests were used to test for between group differences on each fatigue scale in the study questionnaire. Linear regression analyses were then used to quantitatively assess the association between variables assessed in the study questionnaire and fatigue scores. Categorical variables such as gender, rank, crew position, and sleep quality were dummy coded and included, along with continuous variables such as age and months of shift work, in the regression analyses. 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. Binary logistic regression analyses were used to calculate odds ratios and 95% confidence intervals (CI) for the association between variables assessed in the study questionnaire and the outcome of occupationally significant fatigue, defined as an ESS score greater than 10. The percent work time below criterion for several shift work schedules was extracted from FAST summary tables into SPSS and a Kruskal-Wallis test was used to test for differences across schedules. Multiple post hoc pairwise comparisons between schedules were accomplished using the Mann-Whitney U-test with a Bonferroni correction (18,21).

TABLE I. SUMMARY OF PARTICIPANT RESPONSES TO SELECT QUESTIONS.

Question	Number of Participants	Percentage ($N = 66$)
Inadequate time for life activities (# yes)	55	83.3
Inadequate time for spouse (# yes)	43	65.2
Inadequate time for children (# yes)	23	34.8
Inadequate time for friends (# yes)	35	53.0
Inadequate time for recreation (# yes)	43	65.2
Likelihood of falling asleep in GCS		
Never	17	25.8
Seldom	22	33.3
Moderate	15	22.7
High	12	18.2
Use of napping during duty		
Never	27	40.9
Rarely	19	28.8
Sometimes	16	24.2
Often	4	6.1
Use napping prior to driving home		
Never	37	56.1
Rarely	15	22.7
Sometimes	12	18.2
Often	2	3.0
Maintain work wake/sleep cycle on days off		
Never	16	24.2
Rarely	10	15.2
Sometimes	23	34.8
Often	17	25.8

RESULTS

Participants

A total of 114 individuals completed the Web-based questionnaire, but only the data for the 66 participants who were either pilots or sensor operators was used in this study. These participants had a mean (± SD) age of 34.9 (± 8.7) yr and were involved in shift work for a mean of 12.3 (± 9.0) mo with equal representation from the three shifts; 92.4% of participants were men, 60.6% were officers, and 56% were pilots. Participants reported a mean of 6.4 (± 1.4) h of sleep per day, which was rated as poor, moderate, or excellent in quality by 24%, 64%, and 12% of participants, respectively. Participant responses to select questions are summarized in **Table I**.

Efficacy of Shift Schedule Modification

The mean scores on the six fatigue scales were compared across three independent groups, defined as follows:

- NSW ("no shift work"): E-3B AWACS officer and enlisted aircrew not involved in rotational shift work (reference group);
- SW1 ("shift work 1"): Predator RPA pilots and sensor operators surveyed in 2005 who were using the legacy squadron shift work schedules (pre-intervention group); and
- SW2 ("shift work 2"): Predator RPA pilots and sensor operators surveyed in 2006 who were using the modified shift work schedule (post-intervention group).

Data for the NSW and SW1 groups was obtained from a prior survey that has been described in detail elsewhere (25). The NSW group was selected to reduce potential issues of confounding by crew composition (e.g., prevalence of enlisted crewmembers), mission length and profile, and operations tempo. No attempt was made to link participants in the SW1 and SW2 groups; this would have been impossible given the survey responses were anonymous. However, a comparison of the demographics of participants in SW1 and SW2 was accomplished. There were no differences in participants with regards to the following variables: age, gender, rank, crew position, months involved in shift work, current shift, hours slept, and sleep quality. To the best of the authors' knowledge, there were also no significant organizational or work context changes between surveys.

The data for the three groups was pooled and normal Q-Q plots examined for each fatigue scale; no significant departures from normality were detected. Raw fatigue scores were standardized to control for the effects of differences in the number of constituent items on the magnitude of the scores for each scale. This was accomplished for each fatigue scale by subtracting the mean for that scale from every participant's raw score and then dividing the difference by the standard deviation. Group-level means for each fatigue scale, shown in **Table II**, yielded results that do not support Hypothesis 1. A MANOVA was used to assess for differences in mean fatigue scores across the six fatigue scales based on group. Significant group differences were observed (Wilk's $\lambda = 0.736$, $P < 0.001$) and specific univariate effects were found for all six fatigue scales. The SW2 group had higher mean scores as compared to the reference group (NSW) on all fatigue scales. The SW1 group also had higher mean scores than the NSW group on the four fatigue scales not targeted to assessing acute mental fatigue. No significant differences were observed between the two shift work groups, SW1 and SW2.

Variables Associated with Individual Fatigue Scores

Only data from the most recent survey (i.e., group SW2) was used for the subsequent analyses. Since scores

TABLE II. COMPARISON OF STANDARDIZED FATIGUE SCORES BY GROUP AND FATIGUE SCALE.

	Univariate Tests			Group Comparisons[a]				
Fatigue Scale	**F(2,132)**	***P***	**MSE[b]**	**SW1**	***P*[c]**	**NSW**	**SW2**	***P*[c]**
Acute physical fatigue (FS-physical)	8.994	< 0.001	14.701	0.16 (0.18)	0.016	−0.49 (0.13)	0.27 (0.13)	< 0.001
Acute mental fatigue (FS-mental)	4.384	0.014	8.028	0.11 (0.19)	0.140	−0.36 (0.11)	0.19 (0.14)	0.011
Mental fatigue (CON)	4.475	0.013	4.180	0.13 (0.25)	0.113	−0.36 (0.15)	1.19 (0.10)	0.010
Chronic fatigue (FAS)	18.551	< 0.001	4.258	0.35 (0.21)	< 0.001	−0.67 (0.14)	0.31 (0.10)	< 0.001
Quality of life (QOL)	12.424	< 0.001	10.579	0.40 (0.23)	< 0.001	−0.56 (0.16)	0.22 (0.09)	< 0.001
Burnout (EE)	10.720	< 0.001	9.351	0.38 (0.17)	< 0.001	−0.53 (0.14)	0.21 (0.12)	< 0.001

[a] Group scores expressed as mean (± SD); [b] mean squared error; [c] *P*-values for differences with the NSW reference group (Tukey's test).
SW1 = shift work group 1; SW2 = shift work group 2; NSW = no shift work; FS = fatigue scale; CON = concentration subscale; FAS = fatigue assessment scale; QOL = WHO quality of life assessment energy and fatigue subscale; EE = emotional exhaustion subscale.

on all six fatigue scales in the study questionnaire were shown to be intercorrelated, the fatigue scale scores were subject to an exploratory factor analysis with varimax rotation. The factor analysis yielded a single factor with loadings ranging from 0.775 (CON) to 0.919 (FS-physical). A reliability analysis of the six fatigue scales showed good reliability with a standardized Cronbach's α of 0.908. Given these results, a weighted composite fatigue score was computed using the factor loadings, and this was used as the dependent variable for the initial regression analysis. Nonparametric correlations were used to identify variables significantly associated with composite fatigue score. These variables were then collected into a multiple linear regression model; variables subsequently found to have non-significant regression coefficients were dropped before calculating the final model. The estimates of the regression coefficients and their standard errors are shown in **Table III** (Model I). The positive association observed between both months involved in shift work and inadequate time for life activities with the dependent variable, composite fatigue score, partially supports Hypothesis 2A; the negative association between sleep quality and composite fatigue score also partially supports Hypothesis 2B.

In an alternative analytic approach involving less data reduction, stepwise linear regression models were explored for each of the six fatigue scales. With the exception of the FS-mental and EE scales, these linear regression models were similar, if less complete, than the composite fatigue score model. The FS-mental regression model (see Table III, Model II) differed in that it included the variable crew position. This was the only model to suggest the pilot position was associated with more mental fatigue than the sensor operation position. The EE regression model (see Table III, Model III) was unique, being the only model to include gender. Both of these results add additional support to Hypothesis 2A. However, in conflict with Hypothesis 2A/B, age, current shift, hours slept, and maintenance of work wake/sleep cycles on days off were not associated with any of the fatigue scores.

Predictors of Excessive On-the-Job Sleepiness

Participants had a mean (SD) ESS score of 10.7 (± 5.5), with 34 (51.5%) scoring greater than 10 out of a possible total score of 24. Since an ESS score above 10 is a concern with respect to acceptable job performance (8,9,15), a study participant with an ESS score greater than 10 was defined as a "fatigue case." A threshold of greater than 10 appeared valid in this study given the odds ratio for being classified as a fatigue case was 5.102 (95% CI 1.731–15.041) for those reporting a moderate or high chance of

TABLE III. ESTIMATES OF REGRESSION COEFFICIENTS AND STANDARD ERRORS FROM THE FINAL LINEAR REGRESSION MODELS FOR SELECT FATIGUE SCORES.

	Model I (Composite Fatigue Score)[a]		Model II (FS-Mental Fatigue Score)[b]		Model III (EE Score)[c]	
Variables	$\hat{\beta}$	SE $\hat{\beta}$	$\hat{\beta}$	SE $\hat{\beta}$	$\hat{\beta}$	SE $\hat{\beta}$
Crew position[d]			−1.67	0.83*	7.67	2.70**
Gender[e]						
Inadequate time for life activities[f]	23.32	5.56**			9.45	1.91**
Months involved in shift work	0.50	0.25*	0.14	0.05*		
Moderate sleep quality[g]	−15.19	4.91**	−3.40	−0.99**		
Excellent sleep quality[g]	−19.30	7.40*	−5.41	1.47**		

* $P \leq 0.05$, ** $P \leq 0.01$. [a] Dependent variable—weighted composite fatigue score, $F_{4,61} = 12.354$, $P < 0.001$; [b] dependent variable—FS mental fatigue score, $F_{4,61} = 8.173$, $P < 0.001$; [c] dependent variable—EE score, $F_{2,63} = 15.878$, $P < 0.001$; [d] reference category—pilot; [e] reference category—male; [f] reference category—no; [g] reference category—poor.
FS = fatigue scale; EE = emotional exhaustion subscale.

falling asleep in the GCS (cohort odds 1.897, 95% CI 1.220–2.951), as compared to those reporting a slight or less chance (cohort odds 0.372, 95 CI 0.182–0.758).

Unifactorial logistic regression models were used to identify variables significantly associated with being classified as a fatigue case. These variables were then collected and regressed in a multifactorial logistic model; variables subsequently found to have non-significant regression coefficients were dropped before calculating the final model. Since scores on all six fatigue scales were significantly associated with being classified a fatigue case in the unifactorial logistic models, the composite fatigue score was used in lieu of the individual fatigue scale scores in the multifactorial logistic regression analysis. The estimates of the odd ratios and their 95% CI for the variables in the final logistic regression model (shown in **Table IV**) yielded results that partially supported Hypothesis 3A and failed to support Hypothesis 3B. With regards to Hypothesis 3A, only months involved in shift work and composite fatigue score were positively associated with an ESS > 10. While there was also a positive association with the use of napping during duty, this was opposite of the relationship proposed in Hypothesis 3B.

Assessment of Potential Schedule Variants

Data on predicted effectiveness was obtained from FAST simulations of four shift work schedules run over 90-d periods:

- Slow rotation: 6W:3F, 3-shift, monthly, clockwise rotating schedule;
- Rapid rotation: 6W:3F, 3-shift, rapid (i.e., 2 d, 2 mid, and then 2 night shifts), clockwise rotating schedule;
- Fixed/compliant: 6W:3F, 3-shift, fixed schedule with crewmembers maintaining work/sleep times on days off;
- Fixed/noncompliant: 6W:3F, 3-shift, fixed schedule with crewmembers reverting to typical day shift sleep times on days off.

Estimates for daily wake/sleep times and sleep quality were obtained from self-reported and actigraphy data gathered in a prior study of this population (24). The daily percent work time below criterion was calculated by FAST and extracted from the tool's summary statistics table. The criterion line in FAST corresponds to a predicted effectiveness of 77.5% and is a guide for using countermeasures to enhance performance. Performance below the criterion line represents the performance of a person during the day following loss of an entire night's sleep (4).

Significant differences in the percent work time below criterion were observed across shift work schedules ($\chi^2_{2df} = 144.052$, $P < 0.001$). **Table V** lists schedule-level descriptive statistics and pairwise comparisons. The results do not support Hypothesis 4 (Part 1) since the percent work time below criterion was greater for the fast versus slow rotation schedule, which was opposite of the hypothesized difference. Hypothesis 4 (Part 2) was also not supported as there was no observed difference between the fixed/compliant and slow rotation schedules. However, Hypothesis 4 (Part 3) was supported by the results showing that the percent work time below criterion was less for either a fast or slow rotation schedule versus the fixed/noncompliant schedule.

TABLE IV. ESTIMATES OF ODDS RATIOS AND CONFIDENCE INTERVALS FROM THE FINAL LOGISTIC REGRESSION MODEL FOR EPWORTH SLEEPINESS SCALE SCORE > 10.

	Model IV (ESS > 10)[a]	
Variables	**OR**	**95% CI**
Months involved in shift work	1.09	1.01–1.19*
Sometimes to often use napping during duty[b]	9.71	1.88–50.20**
Weighted composite fatigue score	1.08	1.03–1.13**

* $P \leq 0.05$, ** $P \leq 0.01$. [a] Model classification accuracy—84.8%; [b] reference category—never to rarely.
ESS = Epworth Sleepiness Scale.

DISCUSSION

Efficacy of Shift Schedule Modification

This study sought to update the initial assessment of shift worker fatigue in MQ-1 Predator RPA crewmembers by resurveying squadron personnel 1 yr after modifying their shift scheduling practices. The a priori expectation was for decreased subjective fatigue since the pilots were transitioned from a weekly rotation schedule, which tends to perpetuate disturbed circadian rhythms, to a monthly rotation schedule. In addition, the number of consecutive days off was increased from 1–2 to 3 to provide greater opportunity for recovery sleep. However, study results differed markedly from this expectation. Mean fatigue scores were unchanged compared to 1 yr prior, and measures of mental fatigue appeared to have worsened compared to the reference group of non-shift working aircrew. Collectively, the results from the six assessment instruments in the study questionnaire were indicative of chronic fatigue. Relative to the reference group, RPA crewmembers had higher scores on the FAS, which is specifically purported to be a measure of chronic fatigue (14). Additionally, chronic fatigue is known to predispose workers to chronic job stress and burnout, most commonly manifesting as emotional exhaustion (13). This effect was observed in the RPA crewmembers as evidenced by their higher scores on the two assessments of emotional exhaustion and burnout, the QOL and 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 continued inadequate opportunity for restorative sleep.

Variables Associated with Individual Fatigue Scores

As described by Barton et al. (3) in their shift work model, the three major factors likely to cause problems in shift workers involve disturbances in circadian rhythms, sleep, and domestic relationships. Our study also identified these same factors as being associated with composite fatigue scores. In particular, the regression analysis showed that increasing duration of shift

TABLE V. COMPARISON OF PREDICTED PERCENTAGE TIME BELOW CRITERION FOR SELECT WORK SCHEDULE VARIANTS.

			Z Statistic for Pairwise Comparisons		
Rotation Schedule	**Mean (SD)**	**Median**	**Fast Rotation**	**Slow Rotation**	**Fixed/Compliant**
Fast rotation	33.65 (22.35)	30.38	—		
Slow rotation	16.58 (32.29)	0	−6.76*	—	
Fixed/compliant	9.26 (23.64)	0	−8.82*	−1.49	—
Fixed/non-compliant	46.83 (21.47)	44.38	−3.90*	−7.82*	−9.53*

* Statistically significant at $P < 0.008$ (Bonferroni correction).

work, decreasing sleep quality, and impaired domestic relationships were all associated with increased fatigue. Problems of circadian origin stem from an individual's inability to adjust their internal biological clock to the changes in daily routine required in a shift worker's schedule. As such, circadian issues would be expected to grow with increasing exposure to shift work. While sleep duration was found to be inversely associated with fatigue, this association was not significant after including the other aforementioned factors in the analysis. Thus, it may be possible that diminished quality of sleep may be more important than the quantity of sleep in explaining the excessive fatigue observed in this study. For example, Åkerstedt, Kecklund, and Knutsson (2) reported reduced stage two, rapid eye movement, and slow wave (stages 3-4) sleep in connection with morning and night shifts. However, the average 6 h of self-reported daily sleep in this study suggests the problem is a combination of both sleep quantity and quality.

Barton et al.'s shift work model also suggests there are other individual and situational differences that need to be considered when examining shift worker adaptation. We were able to elicit some of these individual and situational factors in the regression analysis of the individual fatigue scales used in the study questionnaire. In particular, pilots were found to have higher mental fatigue scores than sensor operators, suggesting a possible task-related contribution to their fatigue. This is plausible since pilots perform prolonged vigilance work and such vigilance work is known to invoke feelings of boredom and monotony and induce decreased levels of physiologic arousal (11). However, when coupled with the need to maintain high levels of alertness, vigilance tasks can be perceived as quite stressful (22) and this stress predisposes one to fatigue (19). Another individual difference observed in this study was gender; women were observed to have higher levels of emotional exhaustion as measured on the EE. This is consistent with other studies, which have found that women often need to overcome more domestic challenges, and as a consequence, appear to have more difficulty coping with shift work (6). Not surprisingly, inadequate time for life activities was also associated with emotional exhaustion in our study sample.

Predictors of Excessive On-the-Job Sleepiness

Finally, Barton et al.'s model implies that both the acute and chronic effects of shift work can adversely impact physical health and safety. While this study was not designed to address the former, the current iteration of the survey instrument did assess the latter issue. Approximately 40% of the study sample reported a moderate to high likelihood of falling asleep in the GCS while operating a weaponized, remotely piloted aircraft. This is not surprising given the mean score on the ESS was above the threshold considered concerning for acceptable job performance (8,9,15). The factors identified as predictive of a crewmember being a safety risk included duration of shift working, increasing composite fatigue score, and the use of napping during duty hours. Interestingly, napping was the strongest predictor of high ESS/safety risk and is likely a reflection of the degree of fatigue being experienced by the individual rather than an indication of a direct hazard linked to napping. Nevertheless, consideration should be given to including the duration of shift working and high composite fatigue score into squadron preflight risk assessment tools. In addition, these same safety concerns logically extend to crewmembers driving home from work, especially since nearly 70% of the study sample reported rarely or never taking a nap prior to departing from work.

Assessment of Potential Schedule Variants

Everything discussed up to this point clearly indicates problems with features of the squadron's shift system. Rather than recommending further changes and reassessing the effect, modeling and simulation was used to explore outcomes of four scheduling scenarios. Using percent work time below the criterion level of 77.5% predicted effectiveness as a metric of a schedule's merit, there did not appear to be an alternative to the present schedule that offered any significant advantage. The rapid rotation schedule was predicted to result in a greater percent work time below criterion than the current slow rotation schedule. While the slow rotation and fixed shift schedules did not differ in terms of predicted work effectiveness, the fixed shift schedule appeared to have less overall variability and fewer excursions below the model's criterion line. However, a disadvantage of the fixed shift schedule is its dependence on individuals complying with the recommendation to maintain work-related wake/sleep routines on days off (i.e., compliant), otherwise it degrades into a weekly rotating schedule with the potential for significant circadian disturbances. In our study sample, 40% of individuals reported rarely or never maintaining work-related wake/sleep routines on days off, but this factor was not found to be associated with fatigue in any of the regression models. Additionally, most night workers maintain at least a partial day orientation with resulting shift lag because early morning light often makes complete shifting of a night worker's circadian cycle impossible (1). Thus, there was no advantage in changing from a slow rotation schedule to either a fast rotation or fixed schedule; there was also a potential disadvantage going from a slow rotation to a fixed schedule if workers are noncompliant with work/sleep guidelines.

Conclusions and Recommendations

Overall, this study found no improvement in the pervasive shift work fatigue noted in a survey of the same squadron the year prior. Since shift work is known to have adverse consequences on health and safety (3,5,17), this situation can and should be viewed through the lens of human performance, and thus the model of human systems integration (23). Fatigue and stress are survivability domain issues, which when unmitigated, can spill over into the occupational health and safety domain (3). A problem with all the schedules analyzed was the number of consecutive night shifts. As a general principle, the number of consecutive night shifts should be minimized, and preferably there should only be a single night shift in a shift plan (15). Alternatives to the 6W:3F shift plan were examined (data not presented), but it was not possible to shorten the ratio of workdays to days off because of significant manpower constraints. Bottom line, there was insufficient manpower (another HSI domain) to interject more days off and opportunities for recovery into the schedules.

At present, all that can be recommended are preventive and compensatory measures. While it is desirable to minimize the number of consecutive night shifts, an alternative is to continue the present schedule with multiple night shifts in succession and provide the opportunity for exposure to bright light during the first half of the night shift (15). While this will require modification of the GCS work environment (i.e., human factors engineering and habitability domains) and may not be immediately feasible, this feature could be considered in future GCS design iterations. However, expert consultation is required to work out the right light exposure schedule to avoid undesirable shifts in the circadian rhythm, potentially making this approach impractical for some shift workers or in certain work contexts. Other recommendations include educating supervisors and crewmembers as well as their spouses (i.e., training domain) on circadian rhythms, sleep disorders, protection from morning light for day sleepers, the impact of shift work on family and social life, alertness strategies, safe driving, nutrition, physical activity, and coping with stress. Supervisors and crewmembers should avail themselves of existing shift work educational materials available from the National Institute for Occupational Safety and Health and the National Highway Traffic Safety Administration. Supporting medical personnel should ensure they have up-to-date knowledge of sleep disorders and shift maladaptive syndrome (i.e., training domain) and provide tailored medical surveillance of shift workers (i.e., occupational health domain). Supervisors should develop policies and procedures for controlled on-duty napping and implement methods to mitigate the danger of post-shift fatigue on driving safety by providing organizationally sponsored car pools and offering work locations for post-shift naps prior to driving home (i.e., safety and habitability domains) (12,15).

In summary, this paper discussed the results of a recent follow-up survey of a population of MQ-1 Predator RPA crewmembers involved in continuous teleoperations necessitating shift work. Shift work-related increases in fatigue, sleepiness, and risk for performance decrements were examined. Shift system features and individual and situational differences associated with fatigue were also explored. Finally, shift system features of several types of schedules were assessed through modeling and simulation. The use of shift work in the setting of inadequate manning levels has significant implications with regard to enhancement of the negative effects of shift work. The lessons learned in this paper reflect the inherent limitations of trying to "do more with less" when excessive fatigue is induced in the human component of the weapons system through inadequate staffing. These were the limitations that were of concern to Napoleon Bonaparte when he instructed his commanders, "You must not needlessly fatigue the troops" (to the Armée d'Italie, 1796). If implemented correctly, shift system features can minimize the harm to workers, but it is critical for organizational leadership to realize there is no optimally healthy or safe night schedule given basic human physiology. The only approach that truly eliminates the problem is to transfer aircraft control serially to crews living and working in two or three different time zones, such that all crewmembers would be working during their local day shift.

Study Limitations

Conclusions drawn from this study must consider the limitations of the analysis. First, this study used a cross-sectional design, which is a fairly quick and easy method for measuring the current health status of populations, but has the disadvantage of being unable to assess temporal relationships, thereby limiting the ability to infer cause-and-effect relationships. Additionally, a limitation of all fatigue studies is the general lack of a standard way to assess fatigue (13). This study assessed subjective fatigue, including asking participants to report the duration and quality of their sleep. Subjective estimates of sleep have been shown to perform similarly to actigraphy, although both suffer from a wide variation in accuracy between individuals (i.e., random error) when compared with polysomnography (20). However, others have found that any one assessment of sleep propensity is not always an accurate predictor of another, even in the same individual (10). While there are relatively detailed shift work-specific assessment tools (3), the survey instrument used in this study was limited to a few relatively short fatigue scales because of the need to limit the impact on participants' time. Finally, the small group sample sizes increased the risk for false-negative errors, which should be a consideration in drawing major conclusions from this study.

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