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15. Supplementary Notes

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16. Abstract (MAXIMUM 200 WORDS)

The goals of the USCG Exemplar project includes the exploration of the potential use of reduced crew complements aboard high endurance cutters. One major concern is that crew reductions may exacerbate crew fatigue and ultimately compromise safety. The central objective of this study was to determine whether crew members are experiencing unacceptable fatigue levels while sailing under Exemplar crew reductions. This study was conducted aboard the CG Cutter MUNRO (WHEC-378 foot) during a patrol from Tokyo, Japan to Pearl Harbor, Hawaii. Daily evaluations of alertness (maintenance of wakefulness) and of the stability of the sleep/wake cycle (variability of sleep duration and timing) were used to characterize fatigue levels throughout 30 consecutive days on patrol. Fourteen crew members participated in wakefulness maintenance tests consisting of the observation of the latency to sleep onset (as indicated by brain wave activity) while volunteers attempted to maintain wakefulness. Nine out of 14 participants failed to maintain wakefulness in 57 to 100 percent of the tests. Forty-three volunteers participated in daily sleep evaluations by wearing wrist-worn activity monitors 24 hours per day. Activity monitor data were used to document daily sleep onset times, wake-up times, and the stability of the sleep/wake cycle throughout the 30-day evaluation. Over sixty percent of all scored sleep profiles exhibited severe disruptions of sleep patterns. Correlation analysis confirmed that participants experiencing frequent disruptions of the sleep/wake cycle also suffered reductions of sleep below six hours and a high incidence of failure to maintain wakefulness above six minutes, signifying reduced alertness. Watch schedules requiring frequent rotations from daytime to nighttime (0000-0400) and early morning (0400-0800) duty hours contributed to the consistent disruption of sleep/wake cycles. The combination of current watch schedules, reduced personnel, and high operational tempo are expected to exacerbate the fatigue symptoms documented in this patrol. To minimize sleep/wake cycle disruptions, it is recommended that the frequency of rotation from daytime to night and early morning duty hours be reduced.

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EXECUTIVE SUMMARY

United States Coast Guard (USCG) missions often require rapid response, sustained operations, rapid transitions from daytime to nighttime duty hours, extended duty hours, and the implementation of rotating work schedules. The interaction of operational tempo, extreme weather conditions, sea states, crew experience, and work schedules can combine to reduce crew endurance, performance, and safety. Crew endurance depends on the ability to optimize crew rest, and on the prevention of shiftwork maladaptation (or Shift-Lag). Shift-Lag and lack of sufficient energy-restorative sleep induce fatigue (sleepiness, low energy, and lack of motivation), performance degradation during duty hours, and ultimately reduced safety.

Two experimental Coast Guard (CG) programs, namely Paragon (Atlantic Area 210 ft WMEC operations) and Exemplar (Pacific Area 378 ft WHEC operations) are exploring the potential use of reduced crew complements aboard cutters. One major concern is that crew reductions may exacerbate crew fatigue, and ultimately, compromise safety. Here, we present the results of the Exemplar fatigue evaluation study conducted aboard the USCGC MUNRO (WHEC 724) during a patrol from Tokyo, Japan to Pearl Harbor, Hawaii. The central objective of this evaluation was to determine whether crew members experienced fatigue levels that may result in reduced safety.

Volunteers were solicited from crew stations affected by reductions prescribed in the Exemplar program. All experimental procedures were reviewed and approved by a certified Investigations Research Review Board. A total of forty-five crew members volunteered to participate in the crew fatigue evaluation. All volunteers were in good physical condition, with no history of chronic health problems. All information collected was kept confidential. Volunteers were informed that they could withdraw from the study at any time without consequences of any type.

METHODS

Alertness Tests

We used electroencephalography (EEG) techniques to measure individual alertness. Fourteen of the original 45 volunteers participated in this alertness evaluation. Tests were conducted every three to five days (as permitted by duty cycles) within three hours of wake-up time from normal sleep. Prior to these tests, participants were first instrumented with electrodes, connected to a portable EEG system, and asked to rest on a comfortable bed in a dark room. They were instructed to close their eyes and maintain wakefulness by mentally fighting the tendency to fall asleep.

In clinical and experimental sleep laboratories a similar test (the Maintenance of Wakefulness Test or MWT) is used to document reduced alertness (Campbell and Dawson, 1997) and the effects of sleep disorders on daytime sleepiness (Carskadon, Dement, Mitler, and Roth, 1986). Healthy individuals, who sleep soundly and without disruption seven or more hours per night, maintain wakefulness for at least 15 minutes. Individuals suffering from severe sleep disorders or sleep deprivation cannot maintain wakefulness beyond 10 minutes. Significantly reduced alertness has been demonstrated in association with wakefulness latencies at or below 8.2 minutes (Campbell and Dawson, 1997), while pathological sleepiness has been correlated with latencies below five minutes (Carskadon et al., 1986).

Twenty-four Hour Sleep/Wake Cycles

Wrist worn activity monitors (the size of an oversize wristwatch) were used to document daily sleep/wake cycles. These devices were worn throughout the day, during work and sleep periods. Sleep/wake cycle data were collected from all 45 volunteers throughout 30 consecutive days. These data provide a daily history of activity and rest that facilitated the assessment of sleep disruptions as a function of exposure to variable duty cycles and watch schedules.

RESULTS

Analysis of sleep/wake cycles revealed a high incidence of sleep/wake cycle disruption (61.5 percent). Frequent changes in wake-up times and sleep disruption occurred in association with sleep duration below six hours and with alertness degradation. Sixty-four percent of participants taking MWTs consistently exhibited sleep latencies indicating reduced alertness (less than 8.2 minutes) or pathological sleepiness (less than five minutes).

Participants working under non-rotating, stable watch schedules (e.g., permanent 0400-0800 watch) exhibited consistent patterns of sleep and wake-up times with sleep duration rarely below six hours. In contrast, participants exposed to frequently rotating schedules showed disrupted and fragmented sleep associated with the 0000-0400 and 0400-0800 watch schedules. These work schedules disrupted the organization of 24-hour or circadian sleep/wake cycles and resulted in sleep loss and alertness degradation (Shift-Lag symptoms). Recovery from this condition takes a minimum of three to four days of consistent wake-up times, daylight exposure, work schedules and sleep per night (preferably seven consolidated hours),. However, symptoms of fatigue (e.g., drowsiness during work hours) may be experienced for several days after the realignment of sleep and work schedules.

Examination of environmental conditions in sleeping quarters revealed the need to improve ventilation and personal space in enlisted quarters. Also, noise level measurements revealed a constant noise source of 80 dB(A) SPL in one berthing area originating from the ship's gyrocompass room. EPA hearing conservation guidelines recommend minimizing exposure to noise levels above 75 dB(A) (Environmental Protection Agency, 1978).

CONCLUSIONS AND RECOMMENDATIONS

Unremarkable weather conditions and low operational tempo characterized this patrol. However, evidence of fatigue, as depicted by high failure scores in the alertness tests and frequent disruption of sleep/wake cycles, was frequently detected. Based on this evidence, crew endurance levels during this low tempo patrol were considered less than optimal**.**

Operational situations involving increased tempo, deteriorating weather conditions, and reduced crewing are certain to exacerbate fatigue symptoms. The following recommendations are offered to improve endurance levels:

1) implement an endurance education program in the form of training on how to optimize sleep quality and prevent Shift-Lag;

2) design watch schedules that minimize sleep/wake cycle disruptions;

3) develop a system to optimize the number of watch qualified personnel underway to reduce the frequency of rotations into the 0000-0400 or 0400-0800 watch schedules;

4) implement physical improvements to sleeping areas to improve sleep quality.