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Crew Fatigue During Simulated, Long Duration B-1B Bomber Missions

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Crew fatigue associated with successive and unaugmented 36 h missions was evaluated in B-1B simulators. Data were obtained from 32 operationally qualified crewmembers. All crewmembers completed three consecutive, long duration missions, each preceded by 33 to 35 h of crew rest. Oral temperature, salivary melatonin and cortisol, as well as actigraph and subjective measures, were collected during all missions. Temperature and melatonin data indicate that crews maintained their local home base circadian cycles. Elevated cortisol and subjective fatigue during the first mission indicate that it was the most difficult of the three. Furthermore, quality and duration of sleep were lowest during the first mission. These findings emphasize the need for realistic training in long duration fatigue management to improve the safety and effectiveness of the first and subsequent missions.

CONSTANT EVOLUTION in aircraft design has contributed to continuous improvement in their efficiency and endurance. The long range strategic bomber is perhaps the best example of the development in long duration capability. With the advent of aerial refueling, U.S. Air Force (USAF) bomber crews have accumulated many of the non-stop, long range flight endurance records. For example, in 1949, the first non-stop around-the-world flight was flown by a B-50 bomber in just over 94 h, requiring four aerial refuelings (2). In 1957, three B-52 bombers flew the first non-stop jet aircraft flight around the world in 45 h with four aerial refuelings. The B-52 holds other dramatic records for long duration operational flights as well. For example, during Operation Linebacker II, B-52's based in Guam routinely flew 14–15 h roundtrip combat missions over North Vietnam (7). In 1981, to support Operation Bright Star, eight B-52's flew over 7,500 mi from Minot AFB, ND, and Grand Forks AFB, ND, to targets in Egypt in just over 15 h (3). The longest air combat mission in history, lasting 36 h, was recently flown by seven B-52's launched from Barksdale AFB, LA, to attack targets in Iraq (4). This mission required four aerial refuelings and was timed to coincide with the opening moments of the air war in the Gulf. The difficulties faced by the crews on these long range missions has never been systematically studied.

The great range available to the strategic bomber has made it a potent weapons platform. Launched from bases in the United States, today's long range bombers can strike targets anywhere in the world with short notice and return without compromising the airfields of friendly nations. Current military goals described in the "Bomber Roadmap" include the ability to neutralize as many as 1,250 time-critical targets within the first 120 h of a conflict by a conventional strategic air campaign launched from the continental U.S. (CONUS) (1). Such a formidable threat would unquestionably serve the United States as a deterrent to potential aggressors. However, because of cutbacks in military expenditure and the associated drawdown of military forces, fewer aircrews will be available to fly the increased number of future missions. Longer and more frequent missions mean aircrew fatigue will be an increasingly significant threat to mission success (5). In addition, chronic fatigue may develop and exacerbate the human cost associated with long endurance missions.

In flying the long distances associated with bomber missions, crews must confront fatigue related to transmeridian travel and to maintaining vigilance during their circadian performance trough. The deterioration in physical and mental performance associated with circadian desynchronosis is well documented in aviation human factors research (6,8,11,15). Since the bomber incurs less risk of detection when targets can be attacked at night, crews often must take off at night and experience altered light and dark cycles to achieve a night attack on targets. Since light exposure can alter normal

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circadian cycles (10), recovery from mission-induced fatigue may take longer for bomber crews exposed to unusual light cycles.

In support of the USAF vision of Global Reach/Global Power, Air Combat Command (ACC) has prepared contingencies for bomber crews to fly multiple, successive, long duration missions. Since sustained, long duration air combat missions are now an important part of operational responsiveness, ACC tasked the Sustained Operations Branch of the USAF Armstrong Laboratory (AL/CFTO) to assess the impairment that might be experienced during successive long duration missions. The scenario for the study developed by ACC required crews to launch from bases in the CONUS, attack targets 18 h to the east and return to bases in the CONUS. In order to maintain the advantage of darkness over target, the missions had a required launch time of 2000 hours EST. This gave the crews the additional advantage of flying over the target during their own circadian performance peak (about 1600 home base time) which was, at the same time, the defender's circadian trough (about 0200 local target time). The levels of fatigue associated with the three consecutive missions and crew rests were evaluated. Also, neuroendocrine and temperature levels were assessed to determine if the advantage of maintaining local home base circadian time could be maintained.

MATERIALS AND METHODS

The data were collected from 32 operationally qualified crewmembers. All crews consisted of the aircraft commander, co-pilot, Offensive Systems Officer (OSO) and Defensive Systems Officer (DSO). Crews were evaluated in high fidelity Weapons Systems Trainers (WST) over the course of the 5-month study. Full WST motion and graphics capabilities were used during critical events including takeoffs, landings, and low-level bomb runs. Hypothetical intelligence briefings were prepared and discussed with the crews prior to take-off.

The crews were only allowed food that they would ordinarily have available to them on missions of this sort such as MRE's and meals provided by the flight kitchen. A sound-level meter and a light dosimeter were used to sample ambient sound and light levels, respectively, during an actual B-1B sortie. Sound levels were maintained that were comparable to that experienced in the B-1B during flight. This ranged from 85.3 to 106 decibels (dB) and averaged 89.4 dB. Light levels in the WST could only be approximated due to equipment limitations. Light levels ranged from 0.1 footcandles (fc) facing the windshield from the pilot seat with the console lights up during the night phases of the missions to 26.3 fc in the back of the simulator with the internal lights on during the day phases of the mission. Light and dark levels for the pilots were adjusted to simulate what would be experienced during an eastbound flight. In actual flight, the weapon systems officers are ordinarily not exposed to as much ambient light as the pilots; therefore, no attempt was made to regulate their light exposure in the WST. Crewmembers could leave the simulator to use the toilet but were encouraged to do so quickly.

TABLE I. THE 7-POINT FATIGUE SCALE PROVIDED ON THE ACTIVITY LOG FOR EACH SUBJECT.

Subjective Fatigue
Write the number of the statement which describes how you feel RIGHT NOW:
1 = Fully alert, wide awake, very peppy
2 = Very lively, responsive, not at peak
3 = Okay, somewhat fresh
4 = A little tired, less than fresh
5 = Moderately let down
6 = Extremely tired
7 = Completely exhausted, unable to function

All data were evaluated using a Within-Subjects Analysis of Variance design ($p < 0.05$). Significant main effects were further evaluated using Tukey's pairwise comparison test. During each mission, an experimental test session occurred about every 3 h, for a total of 11 sessions. The one exception occurred between 1700 and 2200 hours when crews prepared for the bomb run. Each session consisted of a cognitive performance test battery, a 2-min electrophysiological measure, a 30-s voice record, and an update of the activity logs which the crews were asked to maintain. The activity log represented a catalog of 4 d for each subject. The crews were asked to record their oral temperature about every 3 h. They then selected their fatigue score from a 7-point scale on the bottom middle of the log and indicated that on the log above the temperature value. The range for this scale is shown in Table I. All crews wore activity monitors (actigraphs) during the 12 d they participated in the study. The actigraph is a wrist-worn device, about the size of a watch, that measures the amount of activity the wearer experiences. It is useful to indicate sleep-wake cycles. A computer program, the General Activity Program (GAAP)* was used to score the amount of actigraph-indicated sleep and the duration.

At selected times during the missions, the crews also completed a Profile of Mood Survey (POMS), a Body Pain survey, and provided a 3-cc saliva sample for neuroendocrine assays. The POMS and Body Pain surveys were obtained at 0330, 1630, and at 0400 hours the following day during each mission. These times were selected to correspond to low (0330 and 0400) and high (1630) points of the cognitive performance circadian cycles. Salivary levels of melatonin were measured to assess, along with temperature, whether local home base circadian time was maintained during the missions. Melatonin has proven to be a reliable marker of circadian patterns (12). Samples were taken at a time when melatonin levels would be highest, at about 2230, 0130, and 0330 during both nights of a mission. Salivary cortisol was also measured to determine the level of stress experienced during the missions. Saliva samples were centrifuged at about 3000 rpm for 5–15 min. The sample supernatant was removed and frozen for later assay. Salivary levels of these hormones have been shown to be consistent with serum levels (13,14). Details of the

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*GAAP was developed by Dr. T. Elsmore from the Office of Military Performance Assessment Technology (OMPAT) at Walter Reed Army Institute Research, Washington DC 20307-5100 assays are provided elsewhere (10). Details from the cognitive performance tests, body pain, and the electrophysiological tests will be reported in a separate paper.

Each crew arrived approximately 78 h before their first mission, as shown in Table II. They were completely briefed on the background of the study and their responsibilities. The 2 d prior to the first mission were spent familiarizing the crews with the data recording procedures. The crews were instructed not to leave base unnecessarily and to treat their crew rest period as if they were on alert. Crew billeting facilities were isolated from other patrons. No infractions of crew rest or restrictions during the missions were noted and all crews cooperated fully with the investigators and the demands of the study.

Unnecessary communication with the crew was kept to a minimum during the testing sessions. One investigator sat at a workbench between the WST's. Two other investigators were in the WST's to ensure the data were collected in a timely manner and to observe crew compliance. Pilots and Weapon Systems Officers (WSO's) were allowed to alternate naps during the missions in sleeping bags on the floor of the WST. At least one pilot and, in most cases, one WSO were always alert at their stations. Naps at specific times of the day produce a more efficient sleep (5,9) so naps at these times during the mission were encouraged. The crews were advised to nap during their home base night (2000–0600) when mission demands permitted. Typically, crews slept starting about 6 h after takeoff and usually right after the performance test battery ended. Most crew were able to get approximately 2 h sleep, 3–4 times during the 36 h missions.

RESULTS

The Profile of Mood Survey (POMS) data revealed that subjective fatigue, anger, confusion, depression and tension were significantly greater during mission 1. Fatigue levels during missions 2 and 3 were not statistically different. Vigor, however, did not coincide with the common trend of these dimensions and was lowest during mission 3. The 7-point fatigue scale data, which were recorded on the activity logs, similarly demonstrated that mission 1 was associated with significantly greater fatigue than missions 2 or 3. These scores were obtained more frequently than POMS scores and thereby provided additional information on circadian variability, as shown in Fig. 1a. The oral temperature values shown in Fig. 1b demonstrate cyclicity similar to that of the 7-point fatigue scale. The consistency in the peaks and troughs of the temperature curve between missions demonstrate that local home base circadian cycles were maintained.

The actigraph data indicate that the crews were getting significantly less sleep prior to and during mission 1. The amount of sleep, as scored by the Walter Reed algorithm available on GAAP, is shown in Fig. 2a. Overall, the crews were getting more rest prior to missions 2 and 3 and seemed to have recovered their normal sleep duration within 48 h after mission 3. The actigraph findings also revealed how active the crews were during the actigraphically scored sleep mission and sleep periods as shown in Fig. 2b. Low activity during sleep is usually considered to indicate a more restful sleep. The data in Fig. 2b reveal that the least restful sleep occurred during mission 1.

The pineal hormone melatonin levels did not change between missions, as shown in Fig. 3a, but were significantly lower during the 2200 sample compared to any other time. This finding is consistent with the normal rise in nocturnal melatonin cyclicity around 2200. Overall, the melatonin results demonstrate that local home base circadian cycles were maintained by the crews during the missions. Levels of the adrenal corticosteroid cortisol were significantly greater during mission 1 as shown in Fig. 3b. All levels of cortisol were low, as would be expected given the time the samples were taken.

TABLE II. SCHEDULE OF TRAINING, MISSIONS AND RECOVERY FOR CREWS.

Day 1	1200: Crews arrive quarters (BOQ) 1400: Crews briefed
Day 2	Continue training on cognitive tests
Day 3	1200: Crew rest for mission 1
Day 4	1800: Start mission 1
Day 6	0800: End mission 1 1200: Crew rest mission 2
Day 7	1900: Start mission 2
Day 9	0800: End mission 2 1200: Crew rest mission 3
Day 10	1900: Start mission 3
Day 12	0800: End mission 3; debrief 1200: Start recovery
Day 14	1000: Crews released

DISCUSSION

It was generally accepted that a well-rested crew was capable of successfully completing a single 36-h mission. However, most crews in this study had more difficulty with the first mission than with subsequent missions. For example, their subjective fatigue and their cortisol levels were higher. This may have been related to the relatively low amount and quality of sleep during mission 1 as was revealed by the actigraph data. Prior to mission 1, crews were advised on fatigue management techniques. This may have contributed to the maintenance of synchronized circadian cycles throughout the study. That crews did not suffer from circadian dysrhythmia is evidenced by the stability of temperature and melatonin cycles across missions.

Common complaints included difficulty with premission crew rest, and the inability to optimally manage pre-mission preparations. Most of the data indicate that crews used experience gained on each mission to better cope with fatigue on subsequent missions. Crews who might otherwise have difficulty in managing one or two missions may be capable of three or four such missions with training. If repeated, long-range, conventional bombing missions are to remain part of the concept of operations for war, preparations must include training to lower the risk and improve the chances for successfully completing these long duration missions. The study plan could not assess the effect of fatigue on the behavior of the crew in emergency situations, whether

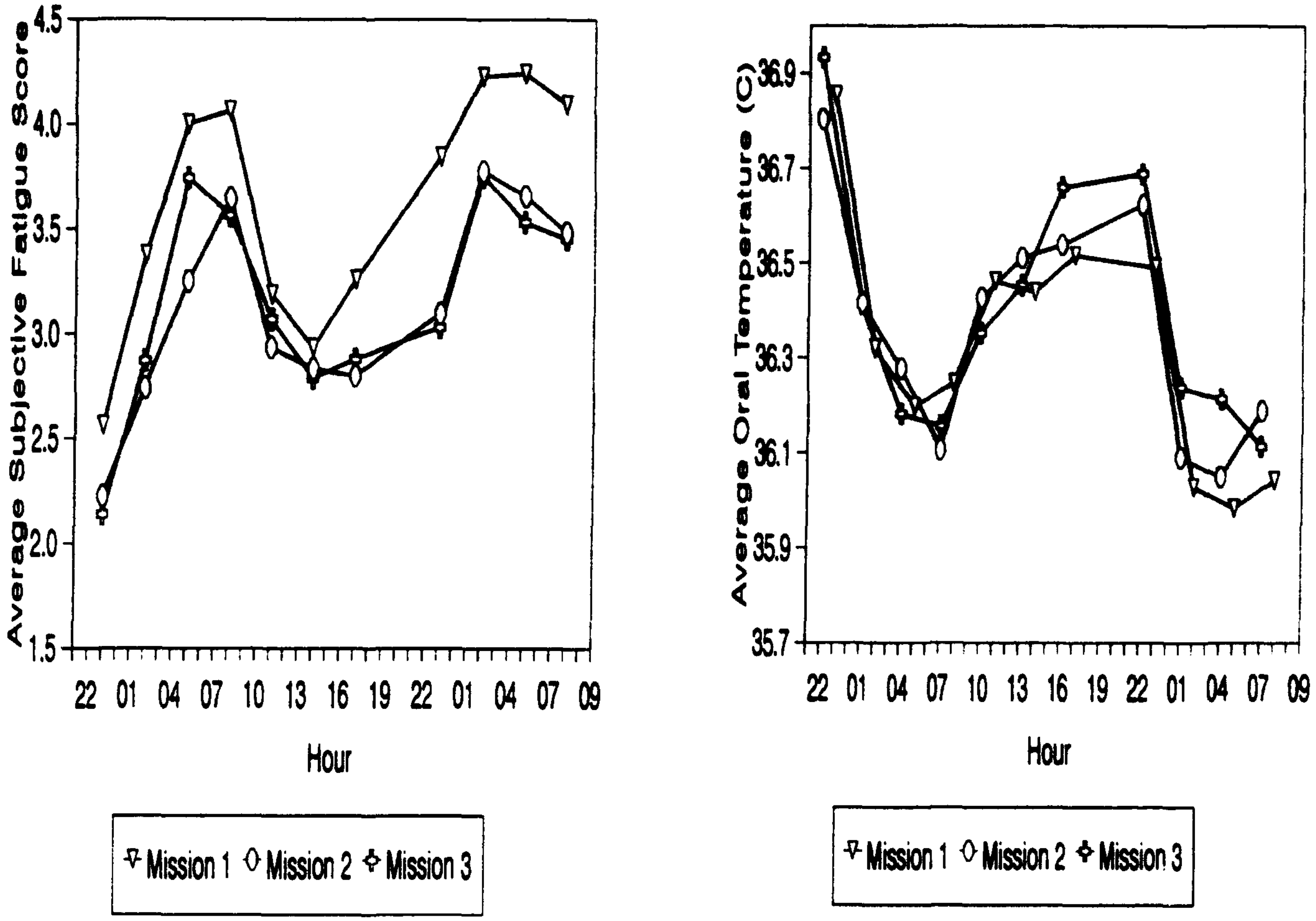

Fig. 1. A (left). Subjective 7-point fatigue rating across each mission. B (right). Oral temperature across each mission.

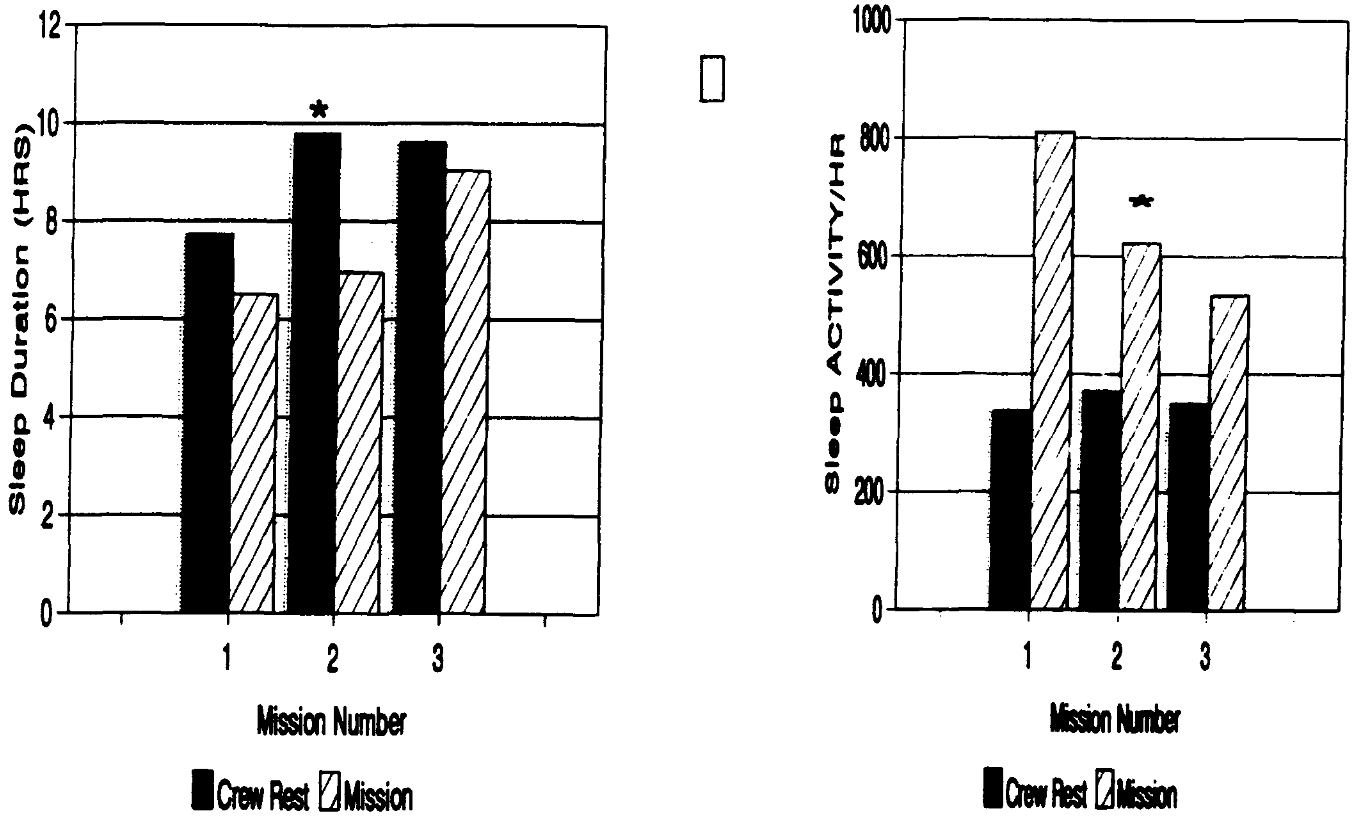

Fig. 2. A (left). Actigraph-scored sleep duration during each mission and crew rest. Note: Sleep duration in mission 2 was significantly greater than in mission 1. B (right). Actigraph-scored sleep activity during each mission and crew rest. Note: Sleep activity in mission 2 was significantly lower than in mission 1. $^*p < 0.01$.

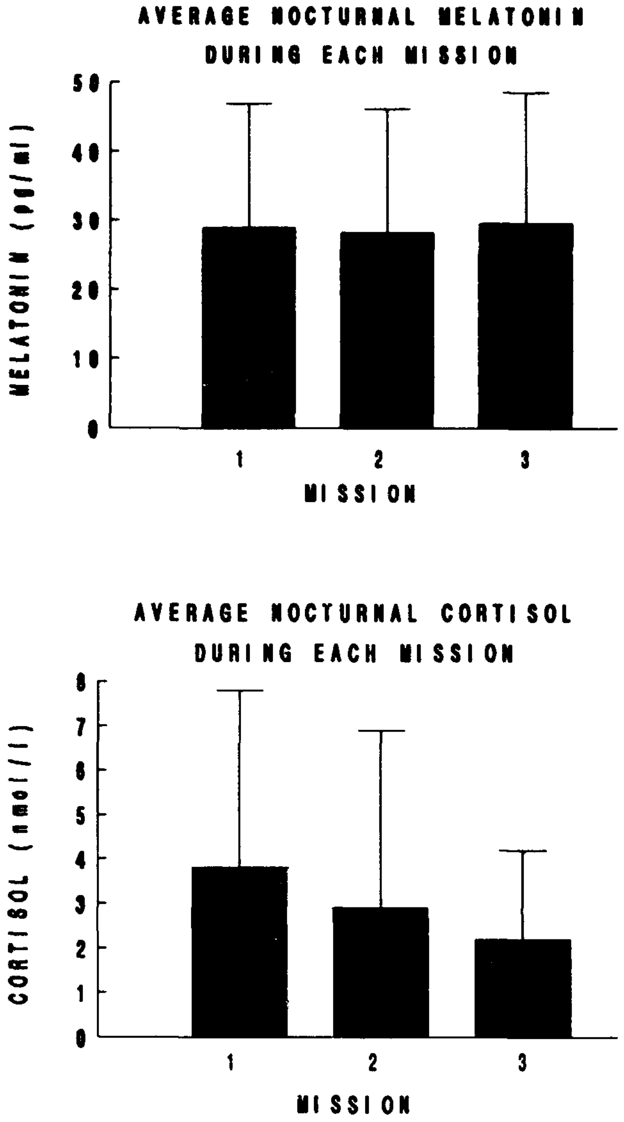

Fig. 3. A (upper). Average (and SD) nighttime melatonin levels across all missions. No changes in melatonin were found between missions. B (lower). Average (and SD) cortisol level during each mission. Cortisol levels were greater during mission 1 than missions 2 or 3.

they involve serious battle damage, or simply the strain of the missions on the airframe. Emergency situations could severely curtail the ability to follow inflight sleeping recommendations. They might also occur during the circadian troughs or other inopportune times when crews may be less capable of responding than when they are fresh and alert. There is an insidious nature to fatigue that may contribute greatly to the sequence of seemingly insignificant or unrecognized errors that suddenly culminate in an accident. The greater risk associated with flying the first long duration mission can be reduced by training aircrew in the techniques of fatigue management, sleep hygiene and, if necessary, the application of biochemical interventions to enhance alertness.

The POMS data indicate that after mission 1, the subjective stress has lessened, perhaps signaling that the crews had become more comfortable with the long duration missions. They also may indicate that mission 1 had the most associated risk. On the other hand, the POMS vigor data suggest that, over all missions, subjective vigor was declining. This finding indicates that fatigue is not simply the reverse of vigor.

The crews were possibly more comfortable sleeping in the WST; the bunk space was not quite as confining as it is on the aircraft. With a little renovation, however, sleeping arrangements on the aircraft could be modified to accommodate two sleeping crewmembers. In addition, many simple and inexpensive techniques can assist with proper sleep hygiene techniques. For example, cloth eye covers during sleep reduce the negative effects of bright light on restorative sleep. Ear plugs are more comfortable than helmets or headsets for sleeping crewmembers. Sleeping bags and mattresses on the floor of the aircraft would also improve the quality of sleep. It needs to be emphasized that restorative sleep could be vital to the mission's success. If a revitalizing, quality sleep can be provided on the airplane during the mission, every means should be taken to do so. Carefully timed administration of light and dark can help crews manage their circadian cycles. However, this protection could be enhanced on board the aircraft by increasing ambient light (with cockpit lighting) at key times and utilizing dark glasses to protect from light at other times. The use of a dedicated crew rest facility completely protected from disturbances to sleep is also extremely important.

Recent missions have demonstrated the ability of the B-1B to fly greater than 20-h sorties. If the experience with these missions permit, two or three well-planned and studied missions of 30–36 h should be flown to validate the human factors concepts developed in the WST. As the frequency and length of long duration missions increase, cockpit designs should be human engineered to help the crew meet the new demands placed on them. For example, inadequate waste management facilities contribute to unhealthy practices such as restricting fluid intake, and, in general, would add to the stress already inherent in long duration missions. A galley that offered cold storage and a means to safely heat appropriately packaged food would increase morale (crews in this study frequently commented on the revitalization they felt after a warm meal) and encourage the consumption of nutritious meals. Also, more nutritious and varied meals, both inflight and on the ground during crew rest, may make a difference in the vitality of the crew, hence the outcome of the mission. Reducing stress and fatigue by increasing the comfort of these missions could make the difference in enabling the crews to return home safely, again and again.

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