NAVAL HEALTH RESEARCH CENTER

LIGHT LEVELS ABOARD A SUBMARINE: RESULTS OF A SURVEY WITH A DISCUSSION OF THE IMPLICATIONS FOR CIRCADIAN RHYTHMS

P. D. Hunt

T. L. Kelly

Technical Document 95-1A

NAVAL HEALTH RESEARCH CENTER
P. O. BOX 85122
SAN DIEGO, CALIFORNIA 92186 – 5122

NAVAL MEDICAL RESEARCH AND DEVELOPMENT COMMAND
BETHESDA, MARYLAND

LIGHT LEVELS ABOARD A SUBMARINE: RESULTS OF A SURVEY WITH A DISCUSSION OF THE IMPLICATIONS FOR CIRCADIAN RHYTHMS

[a]Phillip D. Hunt
[b]Tamsin Lisa Kelly

[a]COMSUB DEV Group 1
San Diego, CA 92186-5122

[b]Naval Health Research Center
P.O. Box 85122
San Diego, CA 92186-5122

Technical Document No. 95-1A, supported by the Department of the Navy, Naval Medical Research and Development Command, Bethesda, Maryland, under Work Unit #61153N MR04101.003-6410. The opinions expressed in this paper are those of the authors and do not necessarily reflect the official policy or position of the Navy, the Department of Defense, nor the U.S. Government. Approved for release, distribution unlimited.

Summary

Problem

Navy operational requirements sometimes demand the use of work schedules requiring personnel to work out of synchrony with their internal circadian rhythms, the daily fluctuations in physiological and behavioral functions. The 6-on/12-off schedule, which is necessitated by the intrinsic limitations in the number of personnel available aboard submarines, requires personnel to live by a non-24-hr daily cycle. The combination of this schedule with the lack of any sunlight exposure may cause individuals to show circadian rhythms cycling at the period of their own circadian clock (about 24.5 hr, but unique to each individual), rather than remaining synchronized with the 24-hr day. This is called "free-running." If this is the case, times when there is a high risk of impaired alertness and performance would be unpredictable. The lack of synchronization with any aspect of life also might contribute to the difficulty of adapting to the schedule. Lack of bright light exposure also could predisposed to Seasonal Affective Disorder. A mood disorder which could contribute to impaired mood and performance. Bright light is the strongest synchronizer of the internal circadian clock. Timed exposure to bright light might be able to keep crewmembers synchronized to the 24-hr day. The effects of bright light on the clock are altered depending on the intensity of background lighting experienced at other times.

Objective

The objective of this study was to record background light intensities in different areas on board a U. S. Nuclear submarine. This information is needed to evaluate the likelihood that submarine personnel on the 6-on 12-off schedule actually free run and to determine how effective bright light interventions on board submarines might be.

Approach

Multiple measurements were made in different areas of various ship compartments of the USS Asheville (SSN 758) using a Simpson, Model 408 illuminance level meter (Simpson Electric Company, Elgin IL).

Results

Light levels throughout the USS Asheville were well below those thought to have effects on the human circadian clock.

Conclusion

Because light levels are low and personnel are living by a non-24-hr daily cycle, free-running is likely to occur. SAD may also occur. The low levels of background lighting should increase the effectiveness of bright light interventions during deployment.

Introduction

Circadian rhythms are daily fluctuations in physiological and behavioral functions generated by an internal pacemaker (Kelly, Smith, & Naitoh, 1989). Mismatch between the endogenous circadian rhythms and imposed activity schedules (circadian desynchrony) can be associated with decreased alertness and performance. The U.S. Congress has designated the effects of circadian rhythms on shift workers as an area needing further investigation (U.S. Congress, Office of Technology Assessment, 1991). Navy operational requirements sometimes demand the use of work schedules requiring personnel to work out of synchrony with their internal rhythms. The 6-on/12-off schedule, which is necessitated by the intrinsic limitations in the number of personnel available aboard submarines, is an extreme example of this. On this schedule, workers not only are frequently required to work during their circadian low period, they also must live by a non-24-hr daily cycle. It is common knowledge that this is a difficult schedule to work under, and interventions to promote adaptation to this schedule could be valuable.

The combination of the 6-on/12-off schedule with the unique submarine environment (an environment protected from all bright light exposure) comes remarkably close to duplicating a complex laboratory protocol known as "forced desynchrony." Forced desynchrony is used to uncover the intrinsic period of the endogenous circadian pacemaker ("tau") (Czeisler, Allan, & Kronauer, 1990). Curiously, the intrinsic period of the human biological clock is usually longer than 24 hr (about 24.5 hr). The light dark cycle is the single most powerful stimulus synchronizing the period of the biological pacemaker to the 24-hr day (Kelly, Smith, & Naitoh, 1989). When subjects live on a schedule very different from a 24-hr one and are shielded from stimuli, such as bright light (where "bright" means around 2000 lux, or more) which can reset the circadian clock, the rhythms of biological functions, alertness, and performance will cycle at the rate of the endogenous clock rather than at the rate of the environmental schedule. This is called "free-running." Some preliminary evidence suggests that such free-running may occur among submariners (Naitoh, Beare, Biersner, & Englund, 1981); however, this has not been clearly documented.

If submarine personnel living on the 6-on/12-off schedule actually are free-running, their total lack of synchronization with any aspect of life, even the fixed meal times, might contribute to their difficulty in adapting to that schedule. Not only would work and sleep periods constantly shift in the 24-hr cycle, but periods when an individual had difficulty remaining alert on shift or difficulty sleeping when off-duty would not even show a consistent association with a given shift. Timed exposure to bright light could be used to keep crewmembers synchronized to the 24-hr day. In addition to perhaps improving individual adaptation to the schedule, the predictability of the periods when lower alertness was likely (i.e., the external night shift would always correspond to nighttime by each individual's internal clock) would allow this to be planned and compensated for by supervisors.

This survey was conducted in response to a request from the submarine community to evaluate current submarine light levels. It provides an idea of how much change would be necessary to achieve biologically active levels of light. Background lighting level is also important because the effects of bright light exposure as a circadian phase shifter can be altered by the intensity of the light an individual is exposed to at other times of the day (Czeisler, Kronauer, Allan, Duffy, Jewett, Brown, & Ronda, 1989). The purpose of this report is to present the results of the survey, to discuss the implications for crewmember circadian rhythms, and to suggest possible interventions to adjust those rhythms.

Methods

Light measurements were made at sea aboard the USS Asheville (SSN 758). The ship had been completely relamped approximately six months before, prior to an extended deployment. The fluorescent bulbs used in lighting compartments such as the engineroom would have been changed as needed since that relamping. Those bulbs generally last three months or less before replacement because they remain on continuously. The light measurements were made using a Simpson, Model 408 illuminance level meter (Simpson Electric Company, Elgin IL). This device employs a photocell that matches the sensitivity of the human eye. Readings were taken at eye level standing, unless otherwise noted. In each location, two readings were taken: one with the sensor pointed in a horizontal plane of gaze, and one with the sensor pointed directly at the light source from normal eye level. The work and rest areas most frequented by crewmembers were chosen for study, and attention was given to obtaining average readings that correspond to the light exposure of crew present in each area.

Results and Discussion

The light measurement results are presented in Table 1. Considerable variation was present between light levels at different locations in a given space, partly as a result of equipment placement and partly due to the nature of the lighting fixtures and zones of light delivered. Submarine supply departments receive bulbs from multiple manufacturers and there is an easily discernible variation in light intensity from the same type of bulbs supplied by different manufacturers. Additionally, the two general types of bulbs ("daylight white" and "soft white") are used interchangeably, sometimes with both types in a single fixture. These bulb types have been previously reported to provide light of significantly different intensities (Elliott & Kobus, 1992). Thus, there will be no uniform lighting pattern between individual submarines, and the lighting in a given submarine will vary, depending on the manufacturer, the type, and the age (newer bulbs provide more intense light) of the bulbs in place at anytime. Within these limitations, the light levels recorded on the USS Asheville (SSN 758) should provide a reasonable estimate of light intensities aboard U.S. nuclear submarines.

The recorded light levels are well below the levels thought to have significant circadian effects in human beings (Lewy, Wehr, Goodwin, Newsome, & Markey, 1980). Readings with the meter pointed directly at the light fixture provide an upper limit to maximum possible light exposure. In one area, the officer's pantry with the meter pointed directly up at the light, light levels approached those that might have biological effects in humans. However, this upper limit is unrealistic since nobody is going to spend a significant amount of time staring at the ceiling in the pantry. Some areas (notably sonar, areas of the control room, torpedo room, and some engineroom locations) have extremely low light levels, necessitated by operational factors. The fact that background lighting is low to very low could be helpful. Bright light stimuli to these watchstanders may be more effective when light exposure in duty spaces is dimmer (Arendt & Broadway, 1987).

Data from the bunk lights are of particular interest. The bunk lights have a single 8-watt fluorescent tube mounted in a fixture that directs light toward the foot of the bunk and the normal position of reading

TABLE 1: LIGHT LEVELS ON THE USS ASHEVILLE (LUX)

COMPARTMENT	LEVEL	LOCATION	HORIZONTAL	VERTICAL
ENGINEROOM	Upper	Aft of evaporator	130	232
		Reduction gears midships	76	454
		Reduction gears port side	76	238
		Turbine generator, midships	216	335
		Electrical panel, aft trunk	65	119
		Manuvering	216	540
		Manuvering, 2nd location	292	432
		Reactor tunnel	162	270
	Middle	Hydrolic pumps port side	130	346
		Shaft alley, far aft	76	216
		Hipacs, midships	108	432
		Forward pump, electric control panel	162	486
	Lower	Main sea water valve space	32	108
OPERATIONS	Upper	Control room, navigation table	86	216
		Control room, planes and BCP station	5	81
		Control room, periscope	11	151
		Sonar room[1], at console	0	5
		Sonar room[2], at desk	11	151
		CO stateroom, standing	43	194
		CO stateroom, sitting at desk	108	173

COMPARTMENT	LEVEL	LOCATION	HORIZONTAL	VERTICAL
OPERATIONS	Middle	Crews mess	184	324
		Crews mess, 2nd location	108	270
		Crews mess, forward passageway	97	205
		Galley, midships	130	211
		Galley, starboard	162	347
		Medical space	54	140
		Officer's stateroom, standing	81	108
		Officer's stateroom, sitting at desk	108	432
		Officer's stateroom, passageway	194	270
		Officer's head at sink	140	248
	Middle	Officer's head, at toilet	162	378
		Officer's pantry, at sink	108	432
		Officer's pantry, standing under light	324	1188
		Officer's wardroom, at table	184	346
		Bunkroom, standing	65	486
		Bunk with lamp shade in place	54	248
		Bunk with lamp shade rotated back	119	227
	Lower	Torpedo room, central panel, midships	80	151
		Torpedo room, central panel, starboard	22	43
		Vertical launch system space	108	864
		Machine room, standing	86	184
		Machine room, work bench, port side	248	648
		Machine room, diesel	86	248

material, partially shading it from the supine crewmember's face. We have no previous reports of illumination levels from such fixtures. Modification of the bunk light is possible by loosening two screws that hold the shade plate in place and rotating this plate behind the fixture. This modification increased the light at eye level by 100% (from 54 to 119 lux). Measurements directly under the light, comparable to what might be achievable by moving the fixture closer to the head of the bed along with rotating the shade plate, show a light level higher than almost all the readings taken in other areas of the ship with the sensor in the horizontal position. Bunk light readings were taken with an 8.5 X 11 inch sheet of paper held at reading position (approximately 13 inches from eye position). This surface reflected some light. The addition of a more effective reflector on the light that directed light at the eyes would further increase light levels.

The bunk light situation is somewhat analogous to light visors, devices that seek to cause biological effects with a small light by putting the light very close to the eye. The bunk light would need to be adapted to provide somewhat brighter light to have significant effects on the biological circadian clock. Use of a blue-green light source could provide biologically effective light at a more comfortable brightness level, since humans are more sensitive to light in this range of the spectrum (Lewy, Ahmed, Bauer, Cutler, Waldman, & Sack, 1993). The bunk curtains would allow such an intervention to be used by one individual with no effects on other personnel. The need for crewmembers to sometimes "hot bunk" and importance of not interfering with crewmember free-time would require a light exposure schedule limited to time periods immediately before or after sleep periods.

Because a free-running individual tends to have a cycle length longer than 24 hr, the purpose of a bright light intervention would be to shorten the cycle (phase advance the clock). It is established that phase advances result from administration of bright light in the hours following the low point of the circadian rhythm of body temperature. (Czeisler et al., 1986), which generally falls around 0400 or 0500 in individuals synchronized to a normal diurnal schedule. Light exposure closer to the circadian low point causes larger phase advances, but care is required because light shortly <u>before</u> the low point can cause phase delays. Large phase shifts have only been reported with light exposures lasting hours; however, simple synchronization to the 24-hr cycle should require a much less prolonged stimulus. A possible schedule would be to have personnel use the bunk light to read (or just relax in bed with eyes open), for perhaps 30 min, before or after the sleep period on those occasions when that light administration would fall in the 0600-0900 time period. This may be sufficient to synchronize individuals to the 24-hr cycle. The clock time selected for exposure is somewhat arbitrary. If the exposure window was shifted 2 or 3 hr later, personnel would still be expected to synchronize but with circadian rhythms peaking a few hours later than the usual diurnal pattern.

An additional possible benefit of such light therapy could be relief of seasonal affective disorder (SAD) symptoms. SAD is a form of depression, sometimes quite severe, which affects individuals in the wintertime, particularly in areas of the world where the period of daylight is especially short (Jacobsen, Wehr, Sack, James, & Rosenthal, 1987). The submarine environment, with light levels generally lower than those that would be experienced in the winter in a northern geographic location, is an ideal environment to produce SAD, and anecdotal reports indicate that this does sometimes happen. Depression can unquestionably impair motivation and performance, and could it contribute to problems related to circadian desynchrony. Extensive research has demonstrated that bright light exposure relieves SAD (Terman, Terman, Quitkin, McGrath, Stewart, & Rafferty, 1989).

An alternative light intervention would be to adapt the bunk light to provide a dusk-dawn transition light stimulus. There is some evidence that much dimmer light ($\leq$ 1000 lux) can alter human circadian rhythms if it is presented in a graded fashion mimicking the pattern of light onset at dawn. While such an intervention might allow the use of less bright light, modifying the bunk light to present such a stimulus would be more complex. Portable devices for presenting dusk-dawn type light are currently under development (personal communication, M. Terman).

It would be easier to assure personnel received light exposure at the proper time if the lighting in the crew's mess could be adjusted. If light levels could be increased to biologically active levels during breakfast each day, all or most personnel should receive appropriately timed light a sufficient proportion of the days to assure synchronization without requiring them to pay attention to a lighting schedule or to spend time lying in bed awake. The cost and feasibility of such equipment alterations are unknown at this time.

Prior to developing and testing any light intervention, it would be necessary to establish that submariners actually are free-running. It is possible that certain consistent environmental factors, such as times of meals and some other activities, provide a sufficient cue to the circadian system to keep most individuals synchronized to the 24-hr cycle. However, this is unlikely since the inconsistency of the times of work and sleep would detract from strength of these social time cues. Previous work has provided inconsistent evidence of free-running based on body temperature measurements. Body temperature is not an ideal circadian measure because it is very susceptible to masking related to activity level (Czeisler et al., 1986). The fact that body temperature goes up whenever we are active and goes down whenever we sleep makes it difficult to detect the endogenous rhythm. In laboratory forced desynchrony studies this problem is solved by periodically putting subjects on constant routines (Czeisler et al., 1986). In a constant routine, the subject is kept awake at bed rest with small hourly feedings for 24-36 hr. This is not a possibility when your subjects are busy running a submarine. Thus, some other circadian measure should provide a more accurate determination. A study of submariner circadian rhythms using intermittent measurement of the phase of the rhythm of melatonin secretion in saliva is currently planned.

Conclusion

Light levels aboard the U.S.S. Asheville (SSN 758) were found to be generally quite low. This lack of any bright light exposure increases the likelihood that crewmembers on the 6-on/12-off schedule will show free-running circadian rhythms. It also could predispose individuals to symptoms of SAD. If crewmembers are free-running, this might contribute to the difficulties of living on the 6-on/12-off schedule. Timed bright light exposure, either in a common area, such as the crews mess, or on an individual basis using a modified bunk light, could synchronize crewmembers to the 24-hr day. Such synchronization would stablize the times when decreased alertness should be expected and compensated for, and it could increase adaptation to the 6-on/12-off schedule. Bright light might also decrease occurrence of SAD.

References

Arendt, J., & Broadway, J. (1987). Light and melatonin as zeitgebers in man. Chronobiology International, 4, 273-282.

Czeisler, C. A., Allan, J. S., & Kronauer, R. E. (1990). A method for assaying the effects of therapeutic agents on the period of the endogenous circadian pacemaker in man. In J. Montplaisir, and J. Godbout (Eds.), Sleep and Biological Rhythms, 5 (pp. 87-98). New York: Oxford University Press.

Czeisler, C. A., Allan, J. S., Strogatz, S. H., Ronda, J. M., Sánchez, R., Ríos, C. D., Freitag, W. O., Richardson, G. S., & Kronauer, R. E. (1986). Bright light resets the human circadian pacemaker independent of the timing of the sleep-wake cycle. Science, 223, 667-671.

Czeisler, C. A., Kronauer, R. E., Allan, J. S., Duffy, J. F., Jewett, M. E., Brown, E. N., & Ronda, J. M. (1989). Bright light induction of strong (Type 0) resetting of the human circadian pacemaker. Science, 244, 1328-1333.

Elliott, F. S., & Kobus, D. A. (1992). Standardizing shipboard lighting: light fixtures and light bulbs on U.S. Navy ships (Tech. Report No. 92-22). San Diego, CA: Naval Health Research Center.

Jacobsen, F. M., Wehr, T. A., Sack, D. A., James, S. P., & Rosenthal, N. E. (1987). Seasonal affective disorder: A review of the syndrome and its public health implications. American Journal of Public Health, 77, 57-60.

Kelly, T. L., Smith, D., & Naitoh, P. (1989). Melatonin, light and circadian cycles (Tech. Report No. 89-38). San Diego, CA: Naval Health Research Center.

Lewy, A., Ahmed, S., Bauer, V., Cutler, N., Waldman, M., & Sack, R. (1993, June). Circadian phase-shifting effects of "dim" green light [Abstract]. Presentation at The Fifth Annual Meeting on Light Treatment and Biological Rhythms, San Diego, CA.

Lewy, A. J., Wehr, T. A., Goodwin, F. K., Newsome, D. A., & Markey, S. P. (1980). Light suppresses melatonin secretion in humans. Science, 210, 1267-1269.

Naitoh, P., Beare, A. N., Biersner, R. J. & Englund, C. E. (1981). Altered circadian periodicities in oral temperature and mood in men on an 18-hour work-rest cycle during a nuclear submarine patrol (Tech. Report No. 81-8). San Diego, CA: Naval Health Research Center.

Terman, M., Schlager, D., Fairhurst, S., & Perlman, B. (1989). Dawn and dusk simulation as a therapeutic intervention. Biological Psychiatry, 25, 966-970.

Terman, M., Terman, J. S., Quitkin, F. M., McGrath, P. J., Stewart, J. W., & Rafferty, B. (1989). Light therapy for seasonal affective disorder. A review of efficacy. Neuropsychopharmacology, 2,1-22.

U.S. Congress, Office of Technology Assessment. (1991). Biological Rhythms: Implications for the Worker (OTA-BA-463). Washington, DC: U.S. Government Printing Office.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATE COVERED
	Feb 95	Interim, 1 OCT 94 - 28 FEB 94

4. TITLE AND SUBTITLE
Light levels aboard a submarine: results of a survey with a discussion of the implcations for circadian rhythms

5. FUNDING NUMBERS
Program Element: 61153N
Work Unit Number:
MR04101.003-6410

6. AUTHOR(S)
P. D. Hunt, T. L. Kelly

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Health Research Center
P. O. Box 85122
San Diego, CA 92186-5122

8. PERFORMING ORGANIZATION
Technical Document 95-1A

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Naval Medical Research and Development Command
National Naval Medical Center
Building 1, Tower 2
Bethesda, MD 20889-5044

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

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

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The 6-on/12-off schedule, necessitated by the intrinsic limitations in the number of personnel available aboard submarines, requires personnel to live by a non-24-hr daily cycle. The combination of this schedule with lack of sunlight exposure may cause circadian rhythms to "free run" at the period length of each individual's circadian clock (about 24.5 hr), rather than remaining synchronized with the 24-hr day. This would make times of increased risk of impaired alertness and performance unpredictable and might contribute to the difficulty of adapting to the schedule. Bright light, the strongest synchronizer of the circadian clock, might be able to keep crewmembers synchronized to the 24-hr day, but the effects of bright light on the clock are altered depending on the intensity of background lighting experienced at other times. Measurement of light intensity in multiple areas of the USS Asheville (SSN 758) showed light levels to be those known to affect the circadian clock in humans. This suggests that free running may occur and that bright light should be an effective intervention to prevent this.

14. SUBJECT TERMS
Circadian rhythms, bright light, submarine, work schedules

15. NUMBER OF PAGES
9

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited