Exploring Sleep-related Habitability Issues in Berthing Spaces on U.S. Navy Ships

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Sleep problems are prevalent in the naval operational environment. Crewmembers attribute some of these problems to habitability-related issues in their berthing compartments. This study has two goals: first, to assess the provisions in current habitability standards used in ship design; and second, to assess the extent to which habitability factors in berthing compartments affect the sleep of crewmembers in United States Navy (USN) ships. Results from eight field studies show that environmental conditions (e.g., temperature, noise, light, air quality) affect sleep quality in berthing spaces. Despite the provisions in current standards, sleep-related habitability issues remain a concern for crewmembers in the USN. Our findings suggest that living conditions may be improved in berthing compartments by revising current standards. We have identified three areas for improvement: noise (both continuous and intermittent), temperature within the compartment, and designing berthing compartments according to the organizational structure of the ship.

INTRODUCTION

Habitability describes all the factors which collectively make up the environment in which the ship's company is required to live and work efficiently (NATO, 1991). According to the American Society of Testing and Materials (ASTM), habitability in the naval environment is concerned with the ship characteristics, its facilities, personal services, and living and working conditions that result in high levels of crew morale, quality of life, safety, health, and comfort (ASTM, 2015).

Habitability is one of the domains of the human systems integration process and is an important factor for optimizing human performance and improving system performance (ASTM, 2015). Historically, better habitability has been associated with enhanced crew morale, increased personnel retention, and improved ship's company effectiveness (OPNAV, 2012; Stein, Benel, & Malone, 1983; Wilcove & Schwerin, 2008).

From a design perspective, ship designers have conflicting demands. Given that warships are built for combat, one end of the spectrum focuses on the demands of wartime conditions. In contrast, ships are also built to accommodate peacetime operations. Therefore, "the objective should be to give the maximum comfort to the crew in peacetime without impeding the primary task of fighting" (NATO, 1991, p.1-7). The need to have optimally designed spaces for sleep, however, spans both peacetime and wartime needs, for sleep is a biological imperative for humans. Research conducted at the Naval Postgraduate School over the past two decades has demonstrated that sleep problems are prevalent in the military operational environment, and that crewmembers on Navy ships are chronically sleep-deprived (Miller, Matsangas, & Kenney, 2012). Many of them have insufficient opportunities to sleep due to long work hours and operational commitments. In addition, because of the 24/7 nature of the military mission, opportunities for sleep often occur during circadian-misaligned time periods. The problem of chronic sleep debt may be further exacerbated because military sleeping conditions are less than ideal.

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With these concerns in mind, this study has two goals focused on habitability issues in berthing compartments on surface ships. First, it seeks to assess the provisions in current standards associated with habitability in areas where the crew sleeps. Described as berthing compartments or staterooms on Navy ships, these areas fall under the term "accommodation areas" (ABS, 2016), or "manned spaces". The latter term refers to any working or living space occupied continuously for more than 20 minutes (ABS, 2016; ASTM, 2013; DoD, 2012). The second goal is to assess the extent to which habitability factors in berthing compartments affect the sleep of crewmembers in U.S. Navy ships.

METHOD

First, we gathered all standards and regulations that would potentially fall into the topic area. The initial list included 25 publications of possible interest. Critical review of the initial publication list resulted in nine documents with provisions applicable to manned spaces (ABS, 2016; ASTM, 2013; DoD, 2012, 2015; ILO, 2006; NATO, 1990a, 1991, 1993; NAVSEA, 2016). The purpose of Military Standard 1472 (MIL-STD-1472) is to present human engineering design criteria, principles, and practices to be applied in the design of systems in the Department of Defense (DoD, 2012). More information about the indoor environment of manned spaces can be found in the Handbook for Human Engineering Design Guidelines MIL-HDBK-759C which supplements MIL-STD-1472G (DoD, 1995). The latter is also supplemented by MIL-STD-1474C in regards to noise criteria (DoD, 2015). Invoked by the shipboard habitability program policy, technical manual T9640-AC-DSP-010/HAB provides habitability design criteria and practices for the USN surface ships (NAVSEA, 2016). ANEP-24, 25 and 26 belong to the ANEP series of guidelines related to the management, personnel, planning, automation, selection and training, material design, shipboard organization and procedures of ship weapon system life cycle (NATO, 1990a, 1991, 1993). The "Guide for Crew Habitability on Ships" is published by the American Bureau of Shipping to provide habitability criteria for ships (ABS, 2016). The

American Society for Testing and Materials (ASTM) has issued the “Standard Practice for Human Engineering Design for Marine Systems, Equipment, and Facilities” to provide ergonomic design criteria from a human-machine perspective for the design and construction of maritime vessels (ASTM, 2013). Lastly, we included in our list the Maritime Labour Convention (MLC) which has provisions to ensure that seafarers have decent accommodation and recreational facilities on ships (ILO, 2006). Our review will not address whole-body vibration and dimensional attributes of berthing spaces and bunks. Readers should refer to the standards we reviewed for further information.

For the assessment of crewmembers’ opinions about habitability, we used data from crewmembers on four ships (N=395). Specifically, data were collected during underway periods from the High Speed Vessel HSV-2 (n=32) (Matsangas & Miller, 2006; McCauley, Matsangas, & Miller, 2005; Miller, McCauley, & Matsangas, 2005), the two variants of the Littoral Combat Ship (LCS, n=91), and the USS NIMITZ (n=272) (Shattuck & Matsangas, 2015; Shattuck, Matsangas, & Brown, 2015; Shattuck, Matsangas, & Powley, 2015). Data are presented by each habitability factor and after having been aggregated by groups of factors.

Instruments

Two questionnaires were used. On the USS NIMITZ, crewmembers were asked to identify which of the following factors affected their sleep while underway: noise (other people, inside the berthing compartment, outside the berthing compartment, the public announcement system –1MC), temperature (too cold, too hot), light, ship’s motion, bedding conditions (bed size, mattress, pillow, curtain), and odors.

Crewmembers on the other three ships (HSV-2, LCS-1 and LCS-2), were asked to rate which 12 factors interfered or promoted their sleep (3-level Likert scale: “interferes ,” “no effect,” “Promotes”.) The factors were: quality of sleep surface, heat, cold, random noise events, constant background noise, someone in another bunk, low humidity/dry air, high humidity, privacy, bunk size, ventilation, sheets/blankets/ pillows, and extreme smell in the compartment.

RESULTS

Standards’ provisions

When addressing habitability of manned spaces, current standards refer to a set of environmental factors recognized to affect humans. Such factors include climatic attributes (temperature, humidity, air flow/velocity, atmospheric contaminants), noise, lighting, whole-body vibration, and dimensional characteristics of berthing spaces and bunks. ANEP-24 and T9640-AC-DSP-010/HAB, however, extend the boundaries of habitability in ships to include food service, hygiene and sanitation, relaxation, religious activity and personal study, recreation, offices and work spaces, and communal services (NATO, 1991; NAVSEA, 2016). In regard to environmental conditions, ANEP-24 references ANEP-25, Table 1. Habitability provisions for berthing spaces. For the acoustical environments, ANEO-24 references NATO Standardization Agreement (STANAG) 4293 (NATO, 1990b). Some of the standards we reviewed provide information applicable explicitly to berthing spaces, and emphasize the need for special attention to sleeping conditions. ANEP-24 includes rest and sleep as one of the functions that habitability must fulfill during the design process (NATO, 1991), whereas MIL-STD-1474E notes that in berthing spaces and staterooms, comfort of personnel is the primary consideration – that is, berthing spaces are classified in noise Category B (DoD, 2015).

The standards we reviewed provide detailed criteria regarding lighting. Lighting levels, brightness ratio, dark adaptation, wall reflectance, location of lights, emergency lighting are only some of the different aspects of lighting which are discussed. The provisions for lighting, however, are predominantly focused on the adequacy of natural or artificial illumination for the performance of operation, control, training, and maintenance (DoD, 2012), or on safety and comfort (ABS, 2016).

The discussion of environmental noise ranges from signal comprehension of communications (a critical concern in a military environment) to hazardous noise, health effects, and injuries (DoD, 2012, 2015). Regarding berthing spaces, ANEP-25 explicitly states that the acoustical environment of ships should prevent interference with the crew’s sleep in accommodation spaces (NATO, 1990a). Along these lines, ANEP-24 emphasized the need to separate rest/sleep spaces from other spaces, in order to protect them from “noisy” activities. In order to maintain maximum personnel effectiveness, berthing areas should not be located near noise generating equipment (NATO, 1991). Furthermore, T9640-AC-DSP-010/HAB notes that berthing spaces shall be physically separate from passages and other spaces, and shall not be used as a pass-through for access to other spaces (NAVSEA, 2016).

Regarding air quality and contaminants, three standards note that ventilation intakes shall be located so as to minimize introduction of contaminated air (exhaust pipes) into the living spaces (ASTM, 2013; DoD, 2012; NAVSEA, 2016). Special provision was made by three military documents that air discharge must not be directed on personnel (DoD, 2012; NATO, 1990a), or towards a berth (NAVSEA, 2016).

With respect to the grouping of personnel in berthing compartments, the MLC notes that sleeping rooms of seafarers should be arranged so that watches are separated and that seafarers working during the day do not share a room with night watchstanders (ILO, 2006). This provision is not included in the other documents we reviewed. Only T9640-AC-DSP-010/HAB notes that personnel should be grouped by gender, rank, and type (for example, embarked personnel, detachments, air wing, staff, etc.) (NAVSEA, 2016).

Table 1 provides an overview of the habitability provisions in the main standards under focus. For detailed information, the reader should refer to the corresponding documents.

Factor	T9640-AC-DSP-010/HAB	MIL-STD-1472G (1474E for noise)	ASTM F1166-07	ABS (2016)	ANEP-25
Room temperature	65 °F dry bulb – 78 °F dry bulb and 65 °F wet bulb	Effective (or corrected) temperature 18 – 29.5 °C	22±1°C adjustable from 18°C to 26.5°C	20 - 25°C (winter) 23 - 28°C (summer)	Provides a diagram
Horizontal gradient [temperature differences – Δ(T)]		In berthing areas Δ(T) between the inside bulkhead surface adjacent to the berthing and the average air temperature within the space shall be <10 °C.			In living spaces Δ(T) at different places should not be more than 3K.
Vertical gradient		The temperature difference at floor and head level shall be <5.5 °C with <3.0 °C preferred	The temperature difference at 100 mm and 1702 mm above the deck shall be <5.5°C with 3°C preferred	The difference in temperature at 100 mm above the deck and 1700 mm above the deck shall be maintained within 3°C	In living spaces Δ(T) at the deck and head level should not be more than 3K
Relative humidity		30% - 70% (40% - 45% preferred)	30% - 70% (40% - 45% preferred)	30% - 70%	Diagram provided
Temperature/ humidity		The design goal shall be 21 – 25 °C and 45%	The design goal should be 21°C and 45%		
Air flow		Air velocities <0.5 m/s at any measured position in the space			Diagram provided
Atmospheric contaminants	Intakes shall be located so as to minimize introduction of contaminated air	Intakes shall be located so as to minimize introduction of contaminated air	Care should be taken to provide outside air from a location away from … exhausts, etc.		
Air supply/ ventilation quantity	Outside air: Minimum 5 cubic feet per minute per person.	Minimum 0.85 m³ per minute/person if the enclosure volume is <4.25 m³ per person Approximately two-thirds shall be outdoor air For larger enclosures, airflow curves are provided.		Fresh/outdoor air >8 l/s per person. Fresh/outdoor air > 40% of the total air supplied to a specific space.	Fresh air amount shall keep gases, vapors, dust and fumes within the limits of national regulations
Maximum noise level	Refers to MIL-STD-1474	For cabins: 60 dB(A) with 50 dB(A) preferred. The steady-state limit is 65 dB(A), and 75 dB(A) for intermittent (MIL-STD-1474)	60 dB(A) with 50 dB(A) preferred	Noise criteria to facilitate crew performance, communication and sleep. Maximum noise level: 50-60 dB(A)	Refers to STANAG 4293
General lighting	Staterooms/berthing spaces: 7 footcandles (~75 Lux)	Provisions focused on workspace lighting, and on compatibility with operator/ maintainer task situation	Provisions focused on workspace lighting. For further criteria (e.g., berthing spaces), references ABS (2016)	In cabins: 150 lux (30 lux if light can enter cabins at the times when people sleep)	Berthing spaces classified as Class 1, i.e., lighting is for orientation (10 – 100 lux)

Findings from USN ships

Responses from the USS NIMITZ showed that noise was the most frequently reported factor affecting crewmembers' sleep (67% of the responses) followed by temperature (52%), background light (39%), and bedding conditions (37%). Interestingly, 40 crewmembers (15%) noted that smells in the compartments (fuel smell) disturbed their sleep. Further analysis by factor showed that noise complaints were distributed equally for noise from other crewmembers in the compartments, noise from equipment and other sources within the compartments, as well as noise from sources outside the compartment. These results are shown in Figures 1 and 2 (BC: Berthing Compartment).

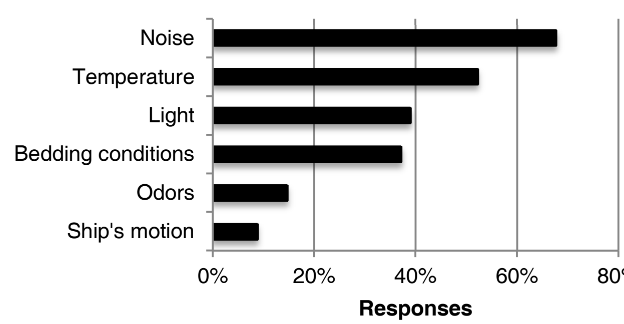

Figure 1. Groups of factors affecting sleep (USS NIMITZ)

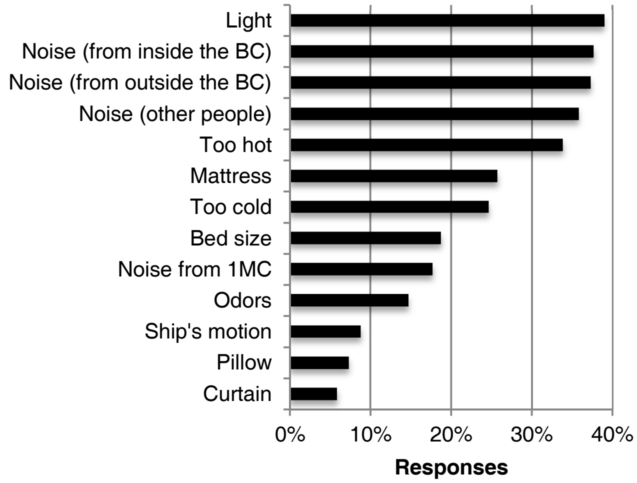

Figure 2. Factors affecting sleep (USS NIMITZ)

Next, we assessed responses from the HSV-2 and the two LCS variants. Noise from various sources was reported as the largest issue of concern (45% of the crewmembers reported that noise interfered with their sleep), followed by odors/extreme smells (33%), low or high temperature (33%), bedding conditions (31%), ventilation (26%), humidity (24%, which included either low humidity/dry air, or high humidity), and background lighting (23%). These results are shown in Figure 3.

Further analysis by factor showed two issues of concern. Random noise (intermittent noise) was reported as a problem by 62% of the respondents. In addition, odors ranked as an important issue of concern in the berthing compartments (considered the second major factor of interference). These results are shown in Figure 4.

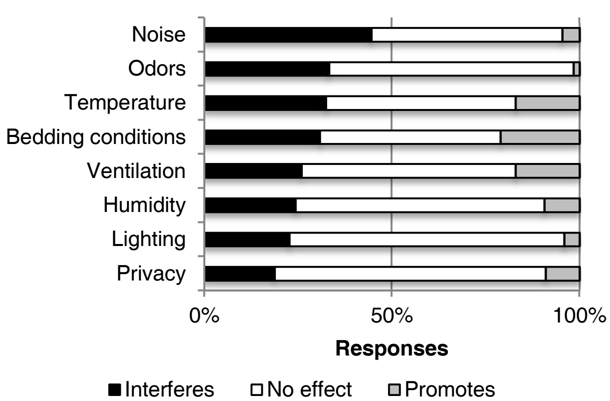

Figure 3. Groups of factors affecting sleep (HSV-2, LCS)

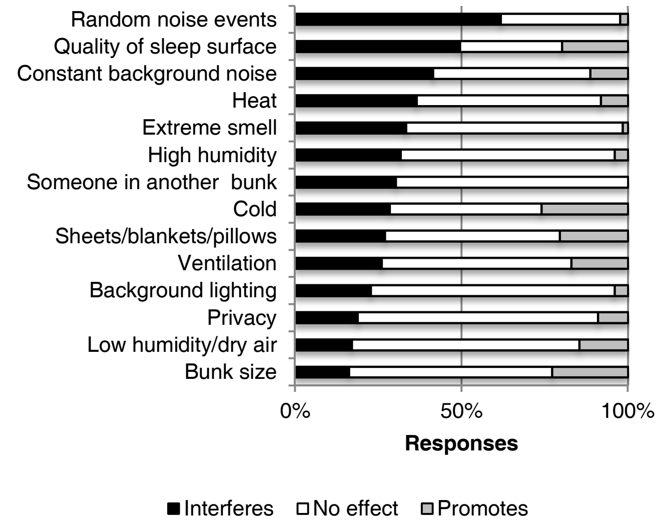

Figure 4. Factors affecting sleep (HSV-2, LCS)

DISCUSSION

Results from the studies conducted at the Naval Postgraduate School show that crewmembers have concerns about the quality of habitability in berthing compartments on United States Navy ships. Noise was consistently considered the major factor of concern. Whether originating from other crewmembers living in the compartment, from equipment and other sources within the compartment, or from sources outside the compartment, noise deleteriously affects sleep quality. Specifically, random noise events (intermittent noise) were reported as the number one problem. Research has shown that environmental noise affects sleep quality. For example, in a study conducted aboard ships of the Norwegian Navy, noise levels and the number of noise events per hour were associated with increased mobility during sleep and with decreased sleep efficiency (Sunde, Bråtveit, Pallesen, & Moen, 2016). These changes in sleep attributes are associated with elevated daytime sleepiness, mood changes, and decreased performance (Halperin, 2014). Crewmembers also raised concerns about low or high temperature in berthing spaces. Research has shown that non-optimal temperature while asleep (either low or high) affects sleep stages (Haskell, Palca, Walker, Berger, & Heller, 1981).

Furthermore, we postulate that lighting in berthing spaces, and noise originating from other crewmembers are problems that are associated with one another. Given that crewmembers are shiftworkers working on a variety of different schedules, crewmembers enter and leave the space while other crewmembers are sleeping. Berthing compartments, therefore, are never quiet for extended periods of time. This problem may be ameliorated if we consider the MLC provision about the grouping of personnel in berthing compartments: "*sleeping rooms of seafarers should be so arranged that watches are separated and that no seafarers working during the day share a room with watchstanders*" (ILO, 2006). Hence, berthing arrangements when new ship designs are developed should take into account the organizational structure of the ship. Even though this provision may be difficult to be implemented completely in existing ships, partial implementation may improve sleep-related habitability.

Lastly, we note that extreme smell from fumes was considered an issue for the smaller ships that we studied. Even though T9640-AC-DSP-010/HAB and ASTM F1166-07 propose that ventilation intakes shall be located so as to minimize introduction of contaminated air, our findings suggest that better design may be needed, especially for ships of smaller size.

In conclusion, our results suggest that some aspects of habitability conditions in berthing compartments should be reconsidered. Even though current standards address multiple facets of habitability on ships, there is room for improvement in berthing compartments. From a system design perspective, it is interesting that the pattern of major factors affecting sleep (noise and temperature) did not differ substantively between the older USS NIMITZ (commissioned in the ’70s), and the two newer ship designs (HSV-2 and LCS).

We have identified three areas in which habitability could be improved: noise (both continuous and intermittent), temperature within the compartment, and taking into account the ship’s organizational structure when considering berthing assignments. Some of these issues of concern on navy ships may be ameliorated if the US Navy uses provisions in current civilian standards and regulations. We would like to close this study with the words of a USN officer written in the early 1950s. Based on his experience from WWII, he commented on the importance of habitability on navy ships.

> Rear Admiral F.I. Entwistle, USN: “*We were not demanding luxuries or comfort. If a man is subjected to excessive temperatures, excessive noises, poor food services, no restful place to sleep, poor lighting, personal efficiency can do only one thing--decrease; and the product, or better, integration of engines, radar, guns and all the mechanical equipment is directly and similarly reduced*” (Berres, 1955, p. 556)

Disclaimer

The views expressed in this study are those of the authors and do not necessarily reflect the official policy or position of the Department of the Navy, Department of Defense, or the U.S. Government.

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