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Looking for light in the din: An examination of the circadian-disrupting properties of a medical intensive care unit

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ABSTRACT

Objective: Critically ill patients exhibit profound disturbances of circadian rhythmicity, most commonly in the form of a phase delay. We investigated the specific zeitgeber properties of a medical intensive care unit to develop a model that explained these abnormalities.
Research methodology: Prospective, observational study conducted during 2013–2014. Twenty-four-hour ambient light (lux, 672 hours) and sound pressure levels (dBA, 504 hours) were measured in patient rooms. Patients and families were surveyed regarding their perceptions of the environment.
Setting: University-based adult medical intensive care unit.
Main outcome measures: The timing and intensity of the ambient light-dark cycle and sound environment and the relationship of these measurements to patient/family perceptions.
Results: Twenty-four-hour light-dark cycles were extremely weak and phase delayed relative to the solar cycle. Morning light averaged 12.1 (4.8, 37.2) lux, when only 24.9% ± 10.9% of available light was utilised; yet patients and families did not identify low daytime light levels as problematic. Median noise levels were invariably excessive (nighttime 47.9 [45.0, 51.3] dBA) with minimal variation, consistent with the absence of a defined rest period.
Conclusion: The intensive care unit functions as a near-constant routine protocol disconnected from solar time. Behavioural interventions to promote entrainment should be supported by objective measurements of light and sound.

Implications for clinical practice

- The lighting environment of a typical intensive care unit is fully capable of engendering circadian non-entrainment and progressive phase delays, similar to the effects of blindness. Despite this, patients are largely uncritical of the lighting environment when surveyed.
- Excessive noise may exacerbate circadian disruption by increasing daytime sleep pressure, thereby reducing retinal light exposure.
- Behavioural interventions to improve the environment for sleep and wakefulness should be supported by objective measurements of light and sound.

Introduction

Sleep is an organised, multidimensional physiologic process that plays a vital restorative role in both health and disease (Crenshaw and Edinger, 1999; Ferrie et al., 2011; Goel et al., 2009; Kreutzmann et al., 2015; Meerlo et al., 2008; Mullington et al., 2009; Zagaar et al., 2012). Unfortunately, the sleep of critically ill patients is highly fragmented and devoid of rapid eye movement and slow wave sleep (Elliott et al., 2013, Freedman et al., 2001; Pisani et al., 2015; Tembo et al., 2013). Abnormalities in circadian rhythmicity are also common and may contribute to sleep disruption (Frisk et al., 2004; Gazendam et al., 2013; Mundigler et al., 2002; Olofsson et al., 2004; Paul and Lemmer, 2007; Shilo et al., 1999). Animal and human studies performed in other contexts suggest these circadian

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"dysrhythmias" are likely to be harmful (Archer et al., 2014; Evans and Davidson, 2013), with emerging evidence also linking such dysrhythmias to delirium (Fitzgerald et al., 2013; Kamdar et al., 2013; Dessap et al., 2015). Efforts to normalise the timing and amplitude of circadian rhythms of critically ill patients may be rewarded by improved sleep quality and clinical outcomes. To accomplish this, however, a better understanding of the determinants of circadian disruption in these patients is required.

Light is the most important environmental cue (zeitgeber, or "time-giver") for synchronising ("entraining") humans' central clock to solar time (Albrecht, 2012). Daytime light exposure strengthens and regulates circadian rhythmicity, facilitates daytime wakefulness and alertness (Sahin et al., 2014) and promotes sleep at night. Early morning light exposure phase advances the central clock (Albrecht, 2012), preparing the body for an earlier day. Conversely, exposure to light immediately before habitual bedtime acutely suppresses melatonin production (Gooley et al., 2011), interfering with sleep, while also inducing a phase delay (Zeitzer et al., 2000).

Exposure to weak or mistimed light-dark (LD) cycles results in circadian disruption and sleep-wake dysregulation. Most non-sighted individuals have circadian rhythms that are free-running (e.g. non–24 hour sleep wake rhythm disorder), even while living in normal society and exposed to nonphotic time cues (Auger RR et al., 2015; Sack et al., 1992). This phenomenon can be reproduced in sighted individuals when exposed to constant dim light (8 lux) (Middleton et al., 1996). In both of the aforementioned studies (Middleton et al., 1996; Sack et al., 1992) the period length (*tau*) of the circadian rhythm was longer than the average *tau* (24.2 hours) as determined by a forced dyssynchrony protocol (Czeisler et al., 1999), likely aggravating the tendency to a phase delay. This difference may reflect nonuniform distribution of non-photic time cues when subjects' self-select their rest-activity rhythms (Czeisler et al., 1999), a nonuniformity to which critically ill patients are also susceptible. Patients suffering from non–24 hour sleep wake rhythm disorder experience insomnia and daytime sleepiness as their central clock periodically becomes misaligned with their rest-activity cycle (Auger et al., 2015).

Patients receiving mechanical ventilation and continuous intravenous sedation exhibit a phase delay in the melatonin-based rhythm and significant inter-individual variability in circadian timing (Gehlbach et al., 2012). These findings suggest that their circadian rhythms may be "free-running". Such dysrhythmias are *not* explained simply by nocturnal sleep disruption from noise and patient care activities, problems that have been well documented in the published literature (Pisani et al., 2015). For the intensive care unit (ICU) environment to generate such dysrhythmias, the environment for *wakefulness*, including the timing and intensity of light exposure, must be equally poor. However, the specific properties of the ICU as zeitgeber have not been characterised previously. It is also not known how patient and nursing perceptions of the ICU environment for light and sound relate to objective measurements of these stimuli. This knowledge gap may frustrate efforts to create a more therapeutic ICU If patients and nursing staff do not reliably detect the circadian-disrupting aspects of their environment.

We hypothesise a model whereby critically ill patients fail to entrain to solar time mostly because of weak or mistimed LD cycles, consistent with the known biology of entrainment. In this model, entrainment is further constrained by environmental stimuli such as nursing assessments, baths, and excessive noise (Busch-Vishniac et al., 2005; Darbyshire and Young, 2013; Konkani and Oakley, 2012), that disrupt sleep at night, generating increased sleep pressure during the day and further reducing daytime light exposure. To provide support for this model, we first analysed 24-hour temporal variations in patient light exposure and related these measurements to the biology of entrainment, hypothesizing that LD cycles would be both weak and delayed relative to the solar cycle. Next, we measured twenty-four-hour sound pressure levels (SPL) to determine our patients' risk of noise-related sleep disturbances and to assess compliance with World Health Organization (WHO) guidelines (Berglund et al., 1999). Finally, we examined how patient and nursing perceptions of the ICU environment for light and sound related to objective measurements of these variables.

Methods

We conducted a prospective, observational study in the medical ICU (MICU) at the University of X Hospitals and Clinics. This study was reviewed by the Institutional Review Board and considered exempt. This report adheres to the Standards for QUality Improvement Reporting Excellence (SQUIRE) guidelines (Ogrinc et al., 2016).

Light and sound measurements

The MICU is a 26-bed unit with 22 routinely used single-occupancy rooms arranged in four pods, with each pod containing a central nursing station. All rooms have windows; however, some have large windows in the patient's direct line of sight, while other rooms have small windows located in nooks. Each room also has a door between it and the hallway.

Light measurements were obtained on multiple days in the 22 main rooms between the hours of 9:00 am and 11:00 am during February and March of 2013 and again from August to October 2013 (Supplemental Material 1). A handheld light meter (Extech HD450, Extech Instruments, Nashua, NH, USA) was used to measure light intensity (lux) under two conditions: (1) immediately upon entering each room with the lighting environment being left "as is" (AS IS); and (2) in a state of "maximum available brightness" (MAX BRIGHTNESS) after turning on all lights and opening window blinds.

Twenty-four-hour variations in ambient light levels were recorded in a subset of rooms using a small, portable light meter (Actiwatch 2, Phillips Respironics, Andover, MA, USA). At the end of each day of measurements, one device was placed in the room with the highest value for MAX BRIGHTNESS (BRIGHT ROOM) and another in the room with the lowest value for MAX BRIGHTNESS (DIM ROOM).

Sound data were collected between January 31, 2014 and March 4, 2014. Two handheld sound meters (SLM, SDL 600, Extech Instruments, Nashua, NH, USA) set to A-weighting, fast response (e.g. 125 millisecond time constant), were placed in each MICU pod, one each in the rooms nearest and farthest from the adjoining nursing station. The meters were secured above the bed, approximately one to 1.2 meters from the patient's head and set to sample sound pressure levels (SPL) at a rate of once every second for 72 hours. We also measured SPL for five to 10 minutes before and after closing the door to these rooms. Empty patient rooms served as control rooms. Sound meters were also placed inconspicuously at each nursing station to log measurements for 72 hours.

To analyse the origin of MICU noise, we performed broadband analyses (focusing on the A weighted sound spectrum, but also collecting C weighted peak values) at two nursing stations, each on a single day during July 2014 from 9:00 am to 11:00 (Brüel & Kjær Type 2270 sound meter, Nærum, Denmark.) Logging period was set for one second and broadband statistics were determined from 100 millisecond samples. Similar measurements were made in the Respiratory Specialty Care Unit, a step-down unit in the same hospital.

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