



THE AUSTRALIAN NATIONAL UNIVERSITY

**An Investigation of Sleep Monitoring Techniques and the
Impact of the Clinical Environment on Intensive Care
Patients' Sleep**

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A thesis submitted to the College of Health and Medicine, Australian National University
in fulfilment of the requirements for the degree of
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Symbols and Nomenclature

AASM: American Academy of Sleep Medicine

ACT: Australian Capital Territory

ACTH-HREC: Australian Capital Territory Health Human Research Ethics Committee

ACTRN: Australian Clinical Trial Registry Number

Actigraphy (ACTG): a non-invasive monitoring technique that monitors rest and activity cycles

ANU-HREC: Australian National University Human Research Ethics Committee

ANZICS: Australian New Zealand Intensive Care Society

APACHE II: Acute Physiology and Chronic Health Evaluation II

AUD: Australian dollars

BIS: bispectral index

BMAL1: brain and muscle ARNT-like 1

BMI: body mass index

CAM: Confusion Assessment Method

CLOCK: circadian locomotor output cycles kaput

CNS: central nervous system

COPD: chronic obstructive airways disease

CORE: Centre for Outcome and Resource Evaluation

CRRT: continuous renal replacement therapy

dB (decibels): a logarithmic measure used to quantify sound levels

dB(A): a scale of sound measure that attenuates the sounds heard by the human ear

EEG: electroencephalogram—records the electrical activity within the brain

EMG: electromyography—monitors skeletal muscle electrical activity

EOG: electro-oculography—measures the corneo-retinal electrical activity

Epoche: a period of time

GABA: Gamma-aminobutyric acid—inhibitory neurotransmitter

HDU: high dependency unit

HPA: hypothalamus–pituitary–adrenal [axis]

Hz: Hertz—unit of frequency.

IABP: intra-aortic balloon pump

ICDSC: Intensive Care Delirium Screening Checklist

ICU: intensive care unit

IL: interleukin

KSS: Karolinska Sleepiness Scale

$L_{A \text{ max}}$: maximum recorded sound level in the A-weighted scale.

$L_{A \text{ min}}$: minimum recorded sound level in the A-weighted scale.

L_{eq} : average level of noise over the monitoring period.

LOS: length of stay

LSQ: Little Sleep Questionnaire

Lux: unit of illuminance and luminous

MIP: maximal inspiratory pressure

N1: non-rapid eye movement sleep stage 1

N2: non-rapid eye movement sleep stage 2

N3: non-rapid eye movement sleep stage 3

NK: natural killer [cells]

NREM: non-rapid eye movement—sleep stages N1, N2 and N3

NSW: New South Wales

Polysomnography (PSG): a biophysiological method of assessing sleep

PSQI: Pittsburg Sleep Quality Index

RASS: Richmond Agitation Sedation Scale

RCSQ: Richards–Campbell Sleep Questionnaire

REM: rapid eye movement – conjugate rapid eye movements

SCN: suprachiasmatic nucleus

SOFA: sequential organ failure assessment

SWS: slow wave sleep

TBI: traumatic brain injury

TNF: tumour necrosis factor

TST: total sleep time

VLPO: ventrolateral preoptic nucleus

VSH: Verran and Snyder-Halpern

WHO: World Health Organization

Zeitgeber: an external or environmental cue that entrains the circadian rhythm

Thesis Overview

Background

Sleep is an essential biological function necessary for survival and plays a critical role in hormonal regulation and maintenance of physiological homeostasis (Alvarez & Ayas, 2004; Brummel & Girard, 2013; Friese et al., 2009; Knutson et al., 2007). Sleep dysregulation can produce a vast array of adverse physiological and psychological effects in individuals. Patients admitted to the intensive care unit (ICU) are susceptible to extensive sleep disturbance in the form of sleep deprivation, sleep fragmentation or circadian dysrhythmia (Elliott et al., 2013; Friese et al., 2007). Despite these issues and their implications, monitoring sleep within this patient cohort remains problematic and challenging because of the limited sleep monitoring techniques available to clinicians and the acceptability of these to patients.

Aims and Objectives

This thesis aims to explore the sleep characteristics of patients admitted to an ICU and patients' experience of sleep, and to explore the feasibility of sleep monitoring techniques that may be incorporated as a standard component of clinical care in the intensive care setting to assist clinicians in understanding of sleep disturbance and the effectiveness of sleep promoting interventions.

This thesis also integrates an environmental assessment of the clinical environment to explore the impact of external factors such as noise, light and clinical interactions as a potential contribution to sleep disturbance in this cohort. These stressors are commonly reported by patients and staff as factors that impede sleep; investigating the patient perspective offers valuable insights into the patient experience to aid clinicians' awareness of the activities that contribute to poor quality of sleep. These insights can provide a basis on which staff can intervene and consider strategies that could ameliorate their impact.

Significance

Sleep disturbance is a significant stressor associated with an ICU admission, and up to 50% of patients report disturbed sleep, with 30% continuing to experience sleep disturbance post ICU discharge (Beltrami et al., 2015). Despite its vast physiological and psychological impacts on patients, sleep remains deprioritised within this clinical context. Inadvertently, a lack of attention to the important role sleep plays in a patient's overall recovery may be exposing them to adverse health consequences and increasing their propensity for an increased length of hospital stay and development of delirium (Flannery et al., 2016; Pisani et al., 2015). For sleep to become an integrated component of overall patient assessment and clinical care, there is a need to identify an objective and feasible sleep monitoring method that can provide clinical data on the sleep profile of patients admitted to the ICU. This research builds upon the contemporary knowledge and understanding of sleep architecture and sleep disturbing factors, while attempting to address the deficiency in sleep monitoring within the ICU setting. The findings of this research may provide important insights related to the effective integration of sleep monitoring within the ICU and identify contributing factors that adversely affect sleep.

Thesis Structure

This thesis is presented as a thesis by compilation and contains published manuscripts within the fields of critical care, nursing, and healthcare. The reproduction of these published materials has been approved by the respective publishers (Appendix A). The published manuscripts have not been amended from their original acceptance, other than for formatting; therefore, the referencing applied may reflect the prescribed requirements of the journal, such as American English and referencing techniques, which may vary from Australian English and American Psychological Association (APA) referencing techniques.

Chapter One provides the background of sleep issues experienced within the hospital setting, including challenges encountered in the clinical environment. This chapter provides the prelude to the subsequent research by identifying the sleep disturbance encountered by patients cared for in the hospital environment and the unique impact of the intensive care environment. The findings of this preliminary research provided the impetus to explore the impact and novel approaches to monitoring sleep as a component of holistic and humanistic approaches to patient care within the clinical setting. This foundational research identified the complex issues linked to patient sleep. Published manuscripts included in this chapter are as follows:

- **Delaney, L. J.,** Currie, M. J., Huang, H.-C. C., Lopez, V., & Van Haren, F. (2018). “They can rest at home”: An observational study of patients’ quality of sleep in an Australian hospital. *BMC Health Services Research*, 18, Article 524.
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Chapter Two explores the biological need for sleep and how sleep disturbance adversely affects both the physiological and psychological functioning of individuals. There exists an inordinate number of negative effects linked to sleep disturbance and disruption of physiological homeostasis. The implications of these for ICU patients are potentially significant given the potential bidirectional relationship between sleep disturbance and delirium, and implications for health outcomes for patients who develop delirium. The development of delirium is prognostically significant and is attributed to prolonged hospital length of stay and long-term disability; however, the measured impacts of sleep disturbance

on patient outcomes are not explicitly clear. This chapter includes the following published manuscripts:

- **Delaney, L. J.,** Van Haren, F., & Lopez, V. (2015). Sleeping on a problem: The impact of sleep disturbance on intensive care patients—A clinical review. *Annals of Intensive Care*, 5, Article 3.
- **Delaney, L. J.,** Litton, E., & Van Haren, F. (2021). The nexus between sleep disturbance and delirium among intensive care patients. *Critical Care Nursing Clinics*, 33(2), 155–171.

Chapter Three discusses the challenges encountered associated with sleep monitoring within this clinical context. To facilitate the recognition and understanding of the extent to which sleep disturbance is experienced, sleep monitoring techniques need to be available to accurately assess patient sleep. The current literature highlights the challenges faced when assessing sleep among ICU patients. This chapter includes the following published manuscript:

- **Delaney, L. J.,** Van Haren, F. V., Currie, M., Huang, H.-C. C., & Lopez, V. (2015). Sleep monitoring techniques within intensive care. *International Journal of Nursing & Clinical Practices*, 2, Article 2.

Chapter Four provides the details of the research protocol, outlining the research design, planned analysis and outcome measures to address the research aims and objectives. This chapter includes the published study protocol:

- **Delaney, L. J.,** Currie, M. J., Huang, H.-C. C., Litton, E., Wibrow, B., Lopez, V., & Van Haren, F. (2018). Investigating the application of motion accelerometers as a sleep monitoring technique and the clinical burden of the intensive care environment on sleep quality: Study protocol for a prospective observational study in Australia. *BMJ Open*, 8(1), Article e019704.

Identifying feasible and accurate sleep assessment methods for implementation is critical to garner biophysiological information around sleep behaviours, to evaluate the extent of the problem encountered and the effectiveness of sleep promoting interventions. **Chapter Five** presents the findings related to the sleep architecture of ICU patients and the clinical feasibility of motion accelerometer monitoring as a proxy assessment of sleep compared to the gold standard, polysomnography. This chapter includes the following published manuscript:

- **Delaney, L. J.**, Litton, E., Melehan, K. L., Huang, H.-C. C., Lopez, V., & Van Haren, F. (2021). The feasibility and reliability of actigraphy to monitor sleep in intensive care patients: An observational study. *Critical Care*, 25, Article 42.

Chapter Six investigates the sleep experiences of conscious ICU patients, inclusive of a comparison of sleep monitoring techniques to determine the potential clinical application of sleep monitoring in the context of this cohort of ICU patients. Given that more than 60% of patients admitted to the ICU do not require mechanical ventilation, attention is needed in relation to the sleep quality of patients given its diverse impacts on both physiological and psychological functioning. This chapter includes the following published manuscript:

- **Delaney, L. J.**, Litton, E., Huang, H.-C. C., Lopez, V., & van Haren, F. (2022). The accuracy of simple, feasible alternatives to polysomnography for assessing sleep in intensive care: An observational study. *Australian Critical Care*. Advance online publication. <https://doi.org/10.1016/j.aucc.2022.02.004>

Chapter Seven discusses the sleep disturbing factors and self-reported sleep quality of ICU patients. The findings of this sub-study provide insights into the stressors that patients experience in the clinical setting that affect sleep and suggest that many of these are modifiable with a more focused assessment of patient sleep, and considerations of workflow and behavioural modification. This chapter includes the following manuscript:

- **Delaney, L. J.**, Litton, E., Huang, H.-C. C., Lopez, V., & Van Haren, F. (2022).

Intensive care patient's quality of sleep and identification of sleep disturbing factors:

An observational sub-study. Manuscript submitted for publication.

Chapter Eight provides a final summary conclusion of the research undertaken.

Based on the research conducted and findings, it identifies areas for future research. This chapter includes the following published manuscript:

- **Delaney, L.**, Litton, E., & Van Haren, F. (2019). The effectiveness of noise interventions in the ICU. *Current Opinion in Anesthesiology*, 32(2), 144–149.

Chapter 1: Introduction and Background

What hath night to do with sleep (John Milton)

1.1 Introduction

Sleep is a complex yet essential biological process, of which its core function has not been fully elucidated in healthy individuals, let alone those suffering from critical illness. Sleep in the hospital setting is frequently reported as sub-optimal and subject to a vast array of disturbances attributed to the clinical environment, with noise being a primary stressor (Lei et al., 2009; Yilmaz et al., 2012). Research exploring the sleep experience of patients has been predominantly conducted within the intensive care unit (ICU) setting, whereby biophysiological monitoring conducted via polysomnography (PSG) can be more readily implemented. PSG-based studies have reported the presence of atypical sleep architecture characterised by decreased slow wave sleep (SWS) and rapid eye movement (REM) sleep, with increased fragmentation (Boyko et al., 2017; Romagnoli et al., 2020; Wilcox et al., 2018). The absence of these features contributes to substandard sleep quality, resulting in circadian disturbances leading to sleep/wake cycles that traverse the 24-hour cycle (Delaney et al., 2021; Elliott et al., 2013; Kelly & McKinley, 2010). Overall, patients cared for in the hospital environment report poor quality sleep that is not refreshing, leading to feelings of increased fatigue and altered mood (Wesselius et al., 2018). Sleep disturbance has been linked to potential adverse events among hospitalised patients; for example, Stone et al. (2008) reported that female patients with suppressed sleep duration (<7 hours) and a sleep efficiency below 70% were at a higher risk of falls incidence in the subsequent year compared with those with normal sleep. Further, impaired sleep is associated with negative impacts on immunological function in both animal studies and those involving healthy adults,

which may have significant adverse implications for hospitalised patients (Kuo & Williams, 2014).

Despite the growing recognition of the importance of sleep more broadly in society and within the context of acute illness, little has been accomplished by way of improving sleep within this patient population. Studies undertaken in the ICU suggest that upward to 50% of patient total sleep time (TST) is acquired during daylight hours (Aurell & Elmqvist, 1985; Freedman et al., 2001; Gabor et al., 2003), contributing to disjointed sleep and circadian disturbance. The implications are significant and may negatively affect patient recovery and neurocognitive performance, and have been linked to an increase in patient morbidity (Alvarez & Ayas, 2004; Ely et al., 2004; Honkus, 2003).

Sleep disturbance is reported to occur in up to 61% of patients who survive critical illness (Closs, 1988; Mathews, 2011; Tamburri et al., 2004) and is deemed to be a significant stressor associated with their ICU admission (Nelson et al., 2001; Rotondi et al., 2002). Despite the diverse physiological and psychological repercussions attributed to sleep disturbance, sleep monitoring does not form a standard component of clinical care. While many hospitals and clinicians espouse the provision of holistic care, sleep is often considered a quiescent state (Delaney et al., 2018; Medrzycka-Dabrowska et al., 2018; Yamazaki et al., 2020) with limited consideration of the physiological attributes associated with sleep, such as brain activity and bodily repair. This may be partly attributed to a lack of clinical knowledge regarding sleep and sleep physiology due to limited educational exposure within nursing programs (Gellerstedt et al., 2019; Huang et al., 2018; Radtke et al., 2014). The lack of attention paid to the importance of sleep for recovery suggests there is a significant omission in meeting the needs of patients, resulting in the cumulative effects of sleep disturbance.

Addressing sleep disturbance may have a beneficial effect on decreasing hospital length of stay by reducing complications linked to sleep disturbance, such as delirium,

memory consolidation, low mood, and fatigue (Kamdar, Needham & Collop, 2012; Weinhouse et al., 2009). However, the ability to effectively monitor sleep emerges as a challenge as few reliable resources are available to clinicians. Subjective sleep assessments readily performed by staff are prone to observer bias and are inaccurate, with staff over-estimating TST compared with PSG (Aurell & Elmqvist, 1985), as they fail to capture the extent of sleep fragmentation experienced, making them a poor proxy for sleep assessment. Further, patients' self-reported sleep quality is perceived as subjective, and lacks validity as they may be influenced by misperception of time, and fails to reflect the physiological experience (Frieze et al., 2007).

1.2 Linkage

Hospital environments are the institutions of healthcare, with healing being the core aim. Holistic care and the commentary around its associated concepts have been widely espoused; however, this approach needs to encompass health and embrace wellbeing, in which sleep is a critical component. Subsequently, hospitals need to devise strategies that deliver both aspects concurrently. Healthcare organisations have developed strategies that facilitate a wide range of healthcare and wellbeing needs, inclusive of advanced medical treatments and interventions, drug and alcohol programs, and breastfeeding and lactation support; however, they have grappled with the ability to support the primary biological need for sleep.

Although complex physiological and psychological interventions have been devised to support many aspects of health and wellbeing, the ability to address the fundamental physiological need for sleep has been a struggle in providing patients with an environment that permits sleep and methods that allow clinicians to accurately monitor sleep.

Quality of sleep is an important concept in the research of patient sleep and is primarily determined by the individual's subjective feelings of being refreshed, active and

prepared for the day ahead (Dogan et al., 2005). Sleep is critical in the recovery from acute illness, with studies indicating an increased need for sleep due to neuro-immune interactions that endeavour to optimise our immune response to illness and injury (Dunwell, 1995; Humphries, 2008; Imeri & Opp, 2009). However, the hospital environment is often unfavourable in its ability to support sleep because of a myriad of factors, including noise, clinical activity, and design characteristics, whereby patients frequently experience sleep disturbance throughout their hospital admission, which may perpetuate post-discharge (Dobing et al., 2016; Gellerstedt et al., 2014).

The research relating to sleep disturbance in the hospital setting has primarily been conducted within America and Europe, with limited studies conducted in the Australian setting to identify the factors that affect patient sleep. As a result, understanding of how the Australian healthcare context may influence patient sleep has not been fully elucidated. The publication “‘They Can Rest at Home’: An Observational Study of Patients’ Quality of Sleep in an Australian Hospital’ highlights the issues patients encounter regarding sleep in an Australian hospital setting. Emerging from this research are a number of challenges that need to be addressed to support sleep and recognise its important contribution to patients’ overall recovery.

1.3 “‘They Can Rest at Home’: An Observational Study of Patients’ Quality of Sleep in an Australian Hospital’

The following presents the findings of a study conducted to explore the sleep quality of patients cared for in the Canberra Hospital, published 5 July 2018 in the journal *BMC Health Services Research* (<https://doi.org/10.1186/s12913-018-3201-z>), including text, tables and references.

RESEARCH ARTICLE

Open Access



"They can rest at home": an observational study of patients' quality of sleep in an Australian hospital

Lori J. Delaney^{1,2,6*} , Marian J. Currie^{1,2}, Hsin-Chia Carol Huang³, Violeta Lopez⁴ and Frank Van Haren^{2,5}

Abstract

Background: Poor sleep is known to adversely affect hospital patients' recovery and rehabilitation. The aim of the study was to investigate the perceived duration and quality of patient sleep and identify any environmental factors associated with patient-reported poor sleep in hospital.

Method: A cross-sectional study was conducted involving 15 clinical units within a 672-bed tertiary-referral hospital in Australia. Semi-structured interviews to determine perceptions of sleep quantity and quality and factors that disturb nocturnal sleep were conducted with patients and nursing staff. Environmental noise, light and temperature were monitored overnight, with concurrent logging of noise sources by observers.

Results: Patients reported a mean reduction in hospital sleep duration, compared to home, of 1.8 h (5.3 vs. 7.1 h; $p < 0.001$). The proportions of patients reporting their sleep quality to be poor/very poor, fair and of good quality were 41.6, 34.2 and 24.2% respectively. Patients reported poorer sleep quality than nurses ($p < 0.05$). Patients, nurses and observers all reported the main factors associated with poor sleep as clinical care interventions (34.3%) and environmental noise (32.1%). Noise levels in all 15 clinical areas exceeded WHO recommended levels of < 30 dB [A] by 36.7 to 82.6%, with peak noise levels of 51.3 to 103.3 dB (A).

Conclusion: Hospital in-patients are exposed to factors which reduce the duration and quality of their sleep. These extrinsic factors are potentially modifiable through behaviour change and reconfiguration of the clinical environment. The findings from this study provided the foundation for a quality improvement project currently underway to improve patients' sleep.

Keywords: Clinical care, Environmental stressor, Hospital, Medical, Noise, Nursing, Sleep, Sleep disturbance

Background

There is evidence that poor sleep in hospital jeopardises patients' recovery. The ability to sleep is important for somatic and cognitive processing, and physiological recovery. Sleep disturbance has deleterious effects on immunological function, [1, 2] the hypothalamic-pituitary-adrenocortical and somatotrophic systems, [3–7] and can decrease responsiveness to hypoxic states and inspiratory muscle strength [8, 9]. Neurobehavioural alterations such as confusion, delirium and a decline in working memory have also been attributed to sleep disturbance [10–13]. These effects have

been reported to persist even after recovery sleep has been obtained, [11] negating the idea that the effects of sleep disturbance can be overcome once patients are discharged from hospital or high acuity areas.

Sleep disturbance in the clinical environment has been attributed to several extrinsic factors such as ambient noise, exposure to artificial lighting and clinical interactions [13–17]. Noise has been the most studied sleep disturbing factor with reported noise levels frequently exceeding the World Health Organization (WHO) recommended nocturnal noise levels of less than 30 dB (A) in the clinical environment [18]. Studies report ambient noise levels ranging from 50 to 60 dB(A) in intensive care, [13, 15, 19] and 40 to 55 dB(A) in the general ward environment [20].

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The clinical environment may also influence the circadian rhythm of sleep as artificial lighting can suppress melatonin production. Melatonin plays an important regulatory role in sleep–wake patterns, and exposure to artificial light during the sleep phase can adversely affect patients' perceptions of the quality of their sleep [21–23]. Environmental temperature has also been identified as a factor that can induce misalignment of sleep–wake cycles, which can affect the restorative sleep phases of slow wave and rapid eye movement sleep [24–26].

Patients sleep in hospital has not been fully elucidated or explored in the Australian context. This study sought to determine the need for interventions to improve patients' sleep in a large tertiary referral hospital in Australia, by determining sleep duration and identifying and quantifying the factors that adversely affect patient sleep in this setting.

Methods

A prospective cross-sectional study was conducted over a six-month period (May to October 2013) in 15 clinical areas: six acute medical and six surgical wards, an intensive and high dependency care unit, and one aged care and one rehabilitation ward. These clinical areas were considered representative of services provided in this 672-bed tertiary referral teaching hospital in Australia. The study involved technical monitoring and concurrent direct observation of the nocturnal environment, patient interviews and nursing reports for each clinical unit for two consecutive nights between 22:00 and 07:00 h.

Participants

Patients and nursing staff were recruited for this study. Non-probability convenience sampling was used to recruit patients to participate in a semi-structured interview to provide their individual perspective on sleep in the clinical setting. Patients admitted to any one of the 15 clinical wards on the two consecutive nights were eligible to participate in the interviews, unless they were intubated; were receiving end-of-life care; had a medical diagnosis of florid psychosis, dementia, confusion or expressive disorder; or the medical or nursing staff considered them clinically unsuitable.

Nursing staff working the night shift during the monitoring period were invited to complete a survey regarding their perceptions of the quality of their patients' sleep and what they considered to be sleep-disturbing factors. Nursing staff were not required to provide direct patient care to the patients who participated in the semi-structured interview. Rather, nursing staff provided an overview of the clinical environment at the time of monitoring.

Data collection

Data were collected using three methods: subjective data were obtained from nursing staff and patients, objective

clinical data were derived from environmental monitoring and observational data were documented by the study research assistants. These data were concurrently obtained over two consecutive nights on each ward. The data collection tools were adapted, with approval, from documents designed by the Imperial College Healthcare (United Kingdom National Health Service) to more accurately reflect the Australian hospital's clinical environment in terms of service delivery and design.

The researchers made no attempt to blind clinical staff or patients to the study purpose. Staff were informed that technical and observational information were being collected about the clinical environment in general, and not specifically about them or the patients. No alterations were made to the clinical environment, such as reminding staff to turn off lights or alerting them to alarms.

Outcome measures

Four instruments were used to measure the study outcomes which had been developed by researchers at the Imperial College Healthcare (UK) based on existing sleep questionnaires and review of the literature: the Patient Sleep Interview Form [27], the Nurses' Self-report Form [27], the Environmental Sleep Observation Form and environmental monitoring devices [27].

Patient sleep interview form

The patient interviews comprised open-ended questions concerning the patients' perceptions of their sleep experience in the hospital. The interview questions addressed sleep quality; sleep hygiene behaviours at home and if and how their sleep differed in the hospital; and which factors they believed inhibited, prohibited or aided their sleep in the hospital. The patients were interviewed once the environmental monitoring of the clinical ward was completed, and their responses were recorded verbatim in writing by the research assistant conducting the interview.

Nurses' self-report form

This questionnaire elicited nurses' perceptions of their patients' quality of sleep in the clinical ward, including the factors that they perceived inhibited the patients' ability to sleep inclusive of the clinical environment. Nurses' suggestions on how to improve patients' sleep were also requested. Comments provided by clinical staff pertained generally to their clinical environment and were not matched to the patients who participated in the semi-structured interviews.

Environmental sleep observation form

The Environmental Sleep Observational Form was used to log the frequency of predetermined categorised noise sources which had the potential to inhibit or disturb

patients' sleep, such as conversations, alarms, telephone calls and patient buzzers. The documentation of observational data was completed by two research assistants (who were not registered nurses) during each night of clinical monitoring for one hour at four time points: 23:00, 02:00, 04:00 and 06:00 h. These timeframes were selected to reflect the spread of activity throughout the night in the clinical setting.

Environmental monitoring

Environmental monitoring devices were positioned in the clinical environment to monitor noise, luminance and temperature. A total of 12 noise, light and temperature monitors were positioned in a range of clinical areas in each ward, including the nursing station, corridors, and single and shared patient rooms in order to capture the activity in the clinical areas. The devices were positioned directly behind the patients' beds, permitting the monitoring of stimuli from the patients' perspective, while minimising their effect on the work of the clinical staff. In clinical areas, such as nursing stations and corridors, sound monitoring devices were mounted on the wall in the centre of the room. This occurred concurrently with the patient interviews and nursing surveys.

Noise and luminance monitoring Noise and luminance levels were recorded using Extech sound level meters (Model SDL600, frequency range 31.5 Hz to 8 KHz) and Extech light meters (Model SDL400), which both conformed to American National Standards Institute and International Electro-technical Commission Standards.

Noise levels were recorded in A-weighted decibels (dB), with a fast response time (125 ms) to permit the capture of peak noises (within a decibel Min-Max from 30 to 180 dB), and noises that occurred rapidly. The A-weighted filter was used because it attenuates the curve that describes loudness frequency for the human ear. Whilst luminance levels were recorded in Lux, with a recording Min-Max of 0 to 1999 Lux accuracy: $\pm 4\% + 2$ disability glare threshold.

Noise and light meters were located within close proximity to each other and were programmed to log data at five-second epochs, and were calibrated, as per the manufacturer's recommendations, before each recording. All logged data from the sound and luminance meters were saved to a secure digital 2 GB memory card in a spreadsheet format.

Temperature and humidity monitoring Temperature and humidity were recorded at 30-s epochs using ThermoLoggers (Thermodata Pty Ltd) (accuracy $\pm 1^\circ\text{C}$ and $\pm 0.6\%$ humidity, range temperature -40°C to $+85^\circ\text{C}$), as temperature and humidity is less variable than the other environmental measures. These devices were

calibrated prior to being positioned within the clinical environment as per manufacturers' recommendation and were positioned within close proximity to the sound and luminance monitors. Data was then downloaded directly from the thermologgers into Excel (Microsoft 2010) spreadsheets.

Data analysis

All data were collated, coded and entered into the Statistical Packages for Social Science (IBM SPSS, version 20) for quantitative analysis. Descriptive statistics of mean and standard deviation (SD) were applied. The chi-square statistic was used to determine any differences in sleep quality reported by patients and staff. Missing data related to environmental monitoring (noise, light, temperature and humidity) was managed via a data reduction method which deleted cases which involved missing data. To replace missing data an additional night (9 h) of environmental monitoring was undertaken to replace missing data. This method was applied in three cases. The interview responses from the patients and nurses were transcribed from the interview form, and underwent content analysis using NVivo (10 QSR). The coding of the responses was continuous and iterative, with responses coded to emerging themes that were then synthesised into smaller theme matrices. The codes identified were descriptive (rather than interpretative) of the responses in an effort to reduce researcher bias.

Results

Demographic profiles

A total of 144 patients (4–10 per clinical unit) (53.5% female) were interviewed across the 15 clinical units, with a mean age of 64.2 years (SD 17, Min-Max, 18 to 90 years). The mean duration of patient hospital admission at the time of the interview was 15.5 days (SD 34.8, Min-Max, 1 to 275 days). The Nurses' Self-report Form was completed by 81 nursing staff (response rate 52%); 88% were registered nurses and 12% were enrolled nurses (nursing staff without tertiary qualifications), which reflected the usual staffing for night duty in this hospital.

Sleep duration and quality

The patients reported a significant reduction in mean sleep duration (5.3 h, SD 2.33 h, Min-Max, 0 to 10 h,) compared to mean sleep duration at home (7.1 h, SD 1.78 h, Min-Max, 3 to 15 h; $p < 0.01$). A mean decrease in nocturnal sleep duration of 1.8 h was reported by patients during the hospital admission.

The quality of patient sleep reported by patients and perceived by nursing staff differed significantly (Fig. 1). More patients reported their sleep quality to be poor to very poor (41.6%, $p < 0.005$) compared to nursing staff, with 34.2% of patients compared to 61.1% of nursing

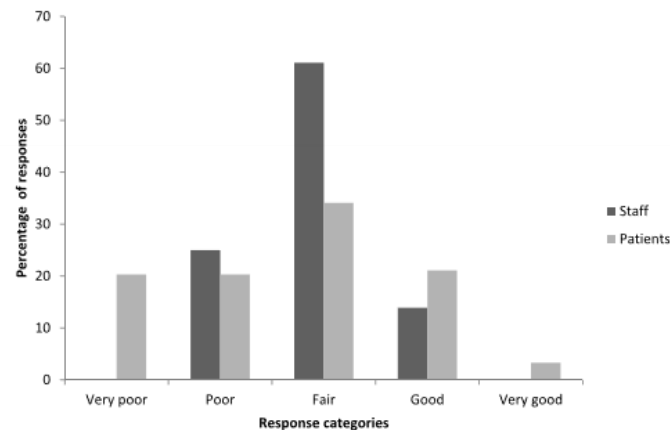


Fig. 1 Comparison of Nursing Staff and Patients' self-reported sleep quality in Hospital. Legend: Nursing staff observational assessment of patient sleep quality did not reflect patients self-reported sleep quality, indicating considerable discordance and as a surrogate assessment may not be reflective of the patients experience

staff rating their sleep as fair and 24.2% of patients versus 13.9% of nursing reporting quality sleep as being good. Comparatively, nursing staff were more likely to assess patient sleep as being fair ($p < 0.3$).

Sleep disturbing factors

The information derived from the patient interviews identified four primary sleep-disturbing factors with clinical care and environmental noise the major sources of sleep disturbance (Fig. 1). Patients reported staff as the primary source of noise, with the main foci for noise being the nursing stations in the clinical environment. Although the interviewees identified the noise made by nursing staff as a contributing factor to sleep disturbance, patients' responses suggest there was some expectation that their sleep would be negatively affected in hospital. Patients' comments included: 'Can't be helped.' (P10); 'Not sure if anything can be done.' (P21); 'Not really, the nurses need to do stuff.' (P95).

While the nursing staff acknowledged that noise in the clinical environment adversely affected patients' quality of sleep, they perceived that the main source of noise in the clinical environment was 'other patients' (Fig. 2). Like the patients, the nursing staff reported that nocturnal noise was an expected and accepted aspect of hospitals. Qualitative responses included: 'Noise is part of the ward/hospital.' (N16); 'Cannot be helped, I tell my patients they can rest at home when they are well.' (N19); 'Unable to make anything quieter (N12); and 'A lot, but some noises are not practical to minimise in this context' (N46).

Some nursing staff respondents acknowledged the impact of noise on patients: 'Noise is very disturbing for patients, most patients complain' (N81). Responses alluded to the impact clinical staff and colleagues behaviours had on the

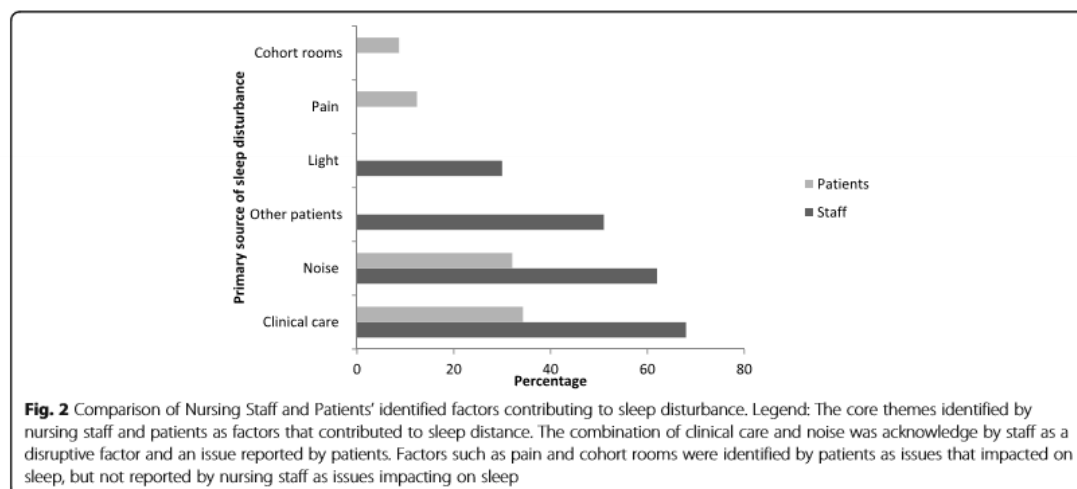
nocturnal environment of wards within the study: *Staff changing from days to night need to remember it is night and make less noise (N18); Try to keep noise down but difficult. I ask wardsmen to try and keep noise down (N 24); Noise can be controlled if everyone co-operates (N54); and Some avoidable with staff attitude change. (N58).*

In addition, nursing staff (65%) reported the exogenous factors of exposure to artificial lighting as the primary cause for patients' poor quality sleep, compared with 22% reporting offensive odours and 18% reporting a cold clinical environment as the perceived primary sleep disturbing factors for patients.

Environmental monitoring

Noise levels were found to be elevated in all clinical areas. The intensive care unit was found to have the highest mean noise level of 53.22 dB(A) (SD 5.72), with the nursing stations in all clinical areas demonstrating the highest percentage (18.7%) of protracted elevations in noise levels greater than 60 dB(A) (Fig. 3). Noise ascensions greater than 70 dB(A) occurred between one and 45 times per hour during the monitoring period. The nursing station and corridors in all clinical wards registered the highest noise levels. Different noise levels were recorded at the four measurement time points with a reduction in noise ranging from 3 to 6 dB between the hours of 01:00 and 05:00, but levels all still exceeding WHO recommendations. Noise was highest in the clinical areas between 22:00 and 24:00 and 05:00 to 07:00 with the highest noise levels recorded in the intensive care unit (98.3 dB[A]), surgical ward (103.3 dB[A]) and medical ward (102 dB[A]).

Observers reported that the four most frequent nocturnal noise sources as staff, with a mean noise occurrence of 34.99 (SD 25.16) times per hour; alarm noise



(M 13.81, SD 30.19); doors (M 7.95, SD 8.02) and miscellaneous machine noises (M 6.69, SD 13.43). Noise generated specifically by patients was identified as the fifth most common event, with snoring reported as the major patient-generated noise source (M 5.47, SD 8.97/ per hour). The surgical assessment and planning unit (SAPU) had the lowest occupancy rate of all wards at the time of monitoring, which may account for the low noise levels recorded in patient care areas.

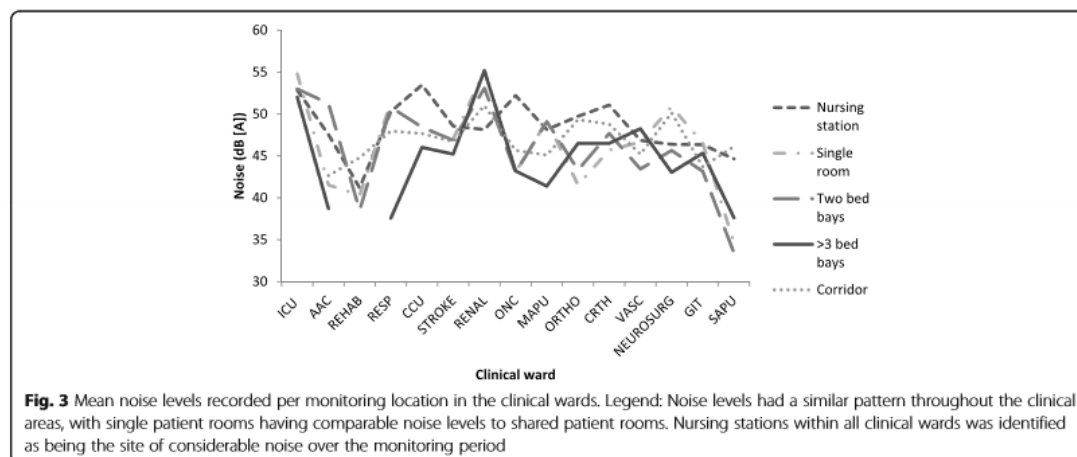
Light

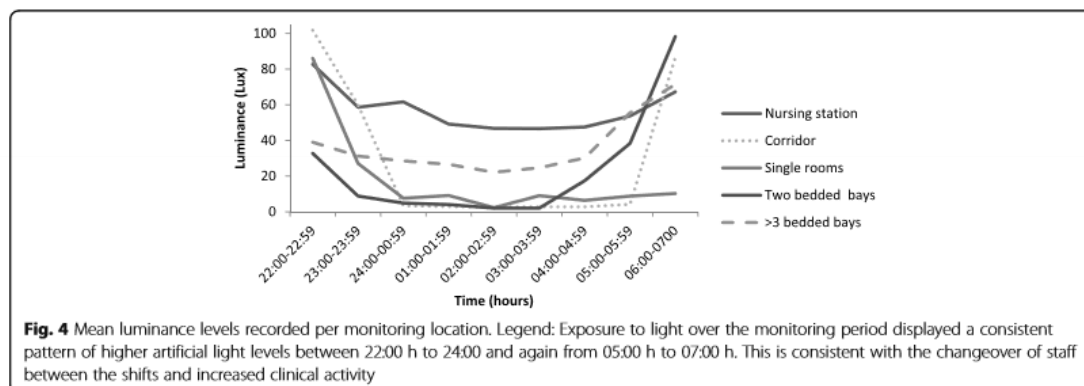
Luminance levels overnight were found to be low (< 100 Lux) throughout the clinical areas and in patient rooms. The highest level of nocturnal illuminance was recorded at the nursing station for all clinical wards, with a minimum luminance of 37.18Lux and a maximum exposure

of 150.50 Lux. The luminance patterns overnight mirrored the pattern of measured nocturnal noise, with the lowest light levels recorded between 01:00 and 05:00 h, and the highest levels recorded between 22:00 and 24:00 h, and after 05:00 h (Fig. 4).

Temperature

Recorded temperature varied little overnight across the clinical wards and locations (22.64 to 22.27 °C). Humidity levels remained higher than environmental temperature until the early hours of the morning (02:00 h), before declining by 1.5% and becoming lower than the environmental temperatures. Environmental temperature was reported by 40% of nursing staff as being too cold, although only 18% considered the environmental temperature to be a factor that contributed to





patient sleep disturbance. However, only 5% of responding clinical staff reported providing a warm blanket as a sleep promoting strategy. Comparatively, only 4% of patients commented on the environmental temperature as a factor that they perceived disrupted their sleep.

Discussion

The findings of this study confirm that patients' sleep duration and quality are compromised during hospital admissions. However, comments provided by patients reveal that they expect to experience sleep disruption in hospital, and view this as an acceptable aspect of healthcare. Given the negative effects of sleep deprivation on patients, this is cause for concern. It could be argued that hospital staff fail in their duty of care as there is increasing evidence that the dangers posed by reduced sleep duration and poorer quality of sleep are as great as those posed by clinical events such as falls, infections and medication errors.

Sleep duration and quality could be considered to be another vital sign worthy of monitoring. In our study, the assessment of sleep quality differed significantly between patients' self-reports and the perceived quality by nursing staff working in the clinical environment, with staff overestimating patients' quantity and quality of sleep. Although our findings were not derived from linked assessment, it affirms the findings of other studies where staff reports, using validated instruments such as the Richard-Campbell Sleep Questionnaire (RCSQ), overestimate the quantity and quality of patients' sleep when compared to patients' reports and biophysiological measures such as polysomnography [28–31]. Implementing patient self-reporting monitoring of sleep via validated sleep assessment tools such as the RCSQ and motion accelerometer monitoring such as actigraphy, may provide clinicians with greater insight regarding patients' sleep duration and quality.

The two main factors associated with sleep disturbance in this study were the need to provide clinical care and noise, primarily generated by nursing staff. The latter was

consistently reported by patients and nursing staff, and supported by objective environmental monitoring. The ambient noise levels recorded in the clinical environments consistently exceeded the 30 dB(A) WHO recommendation by as much as 82.6%, and were characterised by sporadic noise ascensions in all clinical areas [18]. Previous polysomnographic studies reported that noise levels between 40 and 45 dB(A) are associated with a 10 to 20% probability of awakening, with noise sources over 50 dB(A) producing electroencephalographic changes that indicate arousal [32]. Such noise levels mean that patients are unlikely to achieve the critical sleep stages (slow wave sleep and rapid eye movement) that are important for physiological healing and psychological wellbeing.

Noise in all clinical wards in this study was primarily attributed to staff and in particular to activities at the nursing station. The most disruptive noises reported by patients were directly or indirectly controllable by humans such as conversation levels and television volumes. This is consistent with previous studies suggesting that over 50% of the noise in the environment was generated by humans [33]. Clinical staff undertaking routine activities appear to be unaware of, or underestimate their effect on patients. This lack of awareness may account for nursing staff overestimating patients' sleep quality.

The noise patterns generated in this study indicated similarities across all clinical areas, independent of clinical acuity, suggesting that traditional ward designs are a factor in noise generation and dispersion. Centrally located nursing stations frequently act as a hub for clinical activity and socialising and this results in greater dispersion of noise throughout the ward. To reduce noise in the clinical environment, both human behaviour and ward design need to be considered.

The two main sleep disrupting factors of clinical care provision and noise are amenable to behavioural modification [34, 35]. Studies reveal that patients can experience a significant number of clinical interactions overnight with

Tamburri et al. reporting a mean of 42.7 nocturnal clinical interactions with patients [36]. The ability and need to cluster clinical activities is imperative in order to facilitate patients ability to sleep, however this may necessitate the reconfiguration of care activities and procedures such as daily radiological and pathological investigations. Ensuring an allocation of time whereby minimal to no clinical interactions and procedures are scheduled has been reported as being beneficial in providing patients with a planned period to rest and sleep [37]. Reassuring patients that sleep is important to recovery and supporting clinical staff in rationalising and the scheduling of clinical activities to permit sleep may contribute beneficially to patients overall well-being. Studies of the effect of behaviour modification strategies have demonstrated reductions in noise levels of 6 to 20% [19]. Reported interventions include staff education about the importance of sleep and the use of noise monitoring equipment to alert staff to increases in noise volume [35]. Kol et al. demonstrated a significant reduction in environmental noise levels in an intensive care environment after the introduction of staff education and a rearrangement of the ward environment (67.6 dB[A] pre versus 56 dB[A] post, $p < 0.05$) [38]. In contrast, Nannapaneni et al. reported that a multipronged noise intervention inclusive of education and noise monitoring had a minimal effect on ambient noise levels, but did result in a reduction in the number of noise ascensions [39]. Although further research into behaviour modification approaches to noise reduction is needed, it appears that behavioural modification alone may not be successful in reducing noise levels [40]. Subsequently, a multifaceted approach—including clinical support and changes to care provision, clinical equipment and ward layout and design may be required to provide a nocturnal environment that supports patient sleep while ensuring safe clinical care. Even simple interventions such as providing patients with masks and ear plugs may enhance patient sleep.

Light and temperature were not identified as major impediments to patient sleep quality in this study. While light exposure has been shown to suppress the regulatory hormone responsible for sleep–wake patterns, the extent to which this may be affected in general clinical environments has not been extensively researched. Current research indicates that low-level light intensity of less than 500 Lux for as few as 20 min is sufficient to suppress melatonin secretion [20, 21, 41]. Therefore its potential physiological effects need to be minimised, by ensuring efforts are undertaken to increase bright light exposure during the day, and limit unwanted light during the night—particularly lights generating blue (white light) wavelengths—through the use of dimmers and alternative lighting strategies [42]. Similarly, it is important to ensure that thermoregulatory efficiency is maintained to limit the deleterious effects of temperature on sleep architecture –

in particular slow wave sleep and rapid eye movement sleep. The environmental monitoring of the clinical areas in this study showed that mean environmental temperatures were slightly higher than the optimal temperatures (15 to 20 °C) to support sleep [43]. While, patients did not report this as a sleep impeding factor, clinical staff reported the environmental temperature as cold. This may have been reflective of the physiological effects of fatigue associated with night duty.

Limitations

While the multiple methods of data collection and inclusion of 15 clinical areas are strengths of this study, the results may not be generalisable to all hospitals or all ward areas. Although unlikely, the factors associated with sleep disturbance may be intrinsic to this hospital and patient cohort experience. Factors such as building construction, changes in the acuity of patients and staffing numbers, and the time of year during which environmental monitoring is undertaken can all affect sleep. As the clinical environments in this study were monitored for only two nights and the environmental data were not continuously recorded the findings may not accurately reflect the diversity in clinical activity that occurs over time. Further, the qualitative information derived from patients and clinical staff were not case matched, but rather provided a personal experience and general perception of the nocturnal clinical environment. The fact that monitoring equipment was positioned to minimise its effects on patients and nurses, rather than to maximise its ability to capture peak noise levels may have affected the results.

It also needs to be acknowledged that while most healthy individuals sleep primarily or exclusively at night, it is important to consider that patients requiring hospitalization will likely require some daytime nap periods. This study looks at sleep only in the night-time period 22:00–07:00 h, without the context of daytime sleep considered.

The researchers made no attempt to deceive clinical staff regarding the nature of the study so the influence of the Hawthorne Effect should be considered. The presence of the observer and environmental monitoring equipment in the clinical environment could have altered behaviour among patients and nursing staff seeking to conform to the presumed research objectives. As a result, the findings reported may be an underestimation of the magnitude of the issues that affect sleep.

Conclusions

This hospital wide study employed patient, nursing staff and environmental monitoring data to explore the sleep experiences of patients admitted to an Australian hospital and determined that sleep quantity and quality are reduced for the majority of patients. As it is well known

that sleep is needed for physiological and psychological health, these findings should be of concern to hospital staff and patients. The fact that patients and nursing staff expect, and accept, poorer quality sleep in hospital demonstrates the lack of knowledge about the many and serious adverse effects of sleep reduction and fragmentation.

The primary factors interrupting patients' sleep were the need for clinical care and noise. Several strategies to reduce the impact of these sleep limiting factors are available, although evidence for their efficacy is equivocal and more research is needed. Clustering care and tailoring care for patients have both demonstrated some positive effects on sleep quality and quantity. This study also found that noise exceeded WHO recommendations regarding ambient and peak noise with staff, other patients and equipment identified as the main sources of noise. Behaviour modification and critical appraisal of equipment and reconfiguration of the clinical environment may reduce the burden of noise. The perceptions by both nurses' and patients' that lost sleep can be recouped when they get home is of particular concern and demonstrates the poverty of understanding about the therapeutic value of sleep indicating that both clinicians and patients require education about the importance of sleep.

The findings of this study provided the impetus for the development of clinical guidelines and education to enhance awareness of sleep physiology among our clinical staff and the evaluation and appraisal of equipment, ward design and clinical practice in order to promote sleep as an important facet to recovery.

Abbreviations

°C: Celsius; ACT: Australian Capital Territory; dB: Decibels; dB(A): Decibels in the A weighted scale; GB: Gigabyte; Hz: Hertz; IBM: International Business Machines; kHz: Kilohertz; Lux: Illuminance; M: Mean; ms: Milliseconds; N: Nurse (N18 - nurse number 18); P: Patient (P10 - patient number 10); QSR: QSR International; RCSQ: Richards-Campbell Sleep Questionnaire; SAPU: Surgical Assessment and Planning Unit; SD: Standard deviation; SDL: Sound detection limit; SPSS: Statistical Packages for Social Sciences; UK: United Kingdom; WHO: World Health Organisation

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Availability of data and materials

The dataset supporting the conclusions of this article may be available upon request from the lead author to ensure any changes to the project do not invalidate the project's ethical approval in accordance with the ACT Health Human Research Ethics Committee approval letter.

Authors' contributions

LJD: research, data analysis, manuscript development, editing and approval of final manuscript. CH: research supervision, research development, editing and approval of final manuscript. MC: research supervision, data analysis, editing and approval of final manuscript. VL: research supervision, research development, editing and approval of final manuscript. FVH: research supervision and, editing and approval of final manuscript.

Ethics approval and consent to participate

The study was approved by the institution's Human Research Ethics Committee (ETHLR12.253) and conducted in accordance with the principles outlined in the Declaration of Helsinki. The HREC approved the consent procedures for participation in the study which included; verbal consent sought from patients prior to the interviews, and implied consent related to the completion and return of the Nurses' Self-report Form undertaken by nursing staff.

Competing interests

The authors declare that they have no competing interests.

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1.4 Transition

Patients' reported sleep experience in the hospital setting is poor, and the contributing factors to poor quality of sleep are primarily related to noise generated by human activities. Noise is perceived as an unwanted acoustic phenomenon whose characteristics may adversely affect individuals both physiologically and psychologically (Seidman & Standring, 2010). Functionally, the noise levels reported are reflective of those generated by normal conversation (50–60 dB) and are sufficient to produce noise annoyance and stress (Short et al., 2011). Although the World Health Organization (WHO) provides recommendations pertaining to noise levels in the hospital setting, these are infrequently implemented and have not been reported to be achieved in contemporary research.

Noise levels in the clinical setting have been reported to be consistently increasing since the 1960s at an average of 0.38 (dB A) over the daytime per year and 0.42 (dB A) overnight per year, with limited assertive action to curtail their impact (Busch-Vishniac et al., 2005). This is significant in the context of sleep, as each 10 dB elevation in recorded sound produces an approximate doubling of perceived sound (Grumet, 1993). In addition, the capacity to tolerate noise levels is deemed to be reduced in a person who is suffering illness compared with that of a healthy individual (Hilton, 1985) and may negatively affect their ability to sleep and remain asleep, and their quality of sleep. There is a lack of awareness among clinical staff regarding the significant impact that their routine behaviours and activities have in the soundscape of the clinical setting, and as a result, much of the research targeting noise levels has focused on behavioural modifications to abate environmental noise.

Patients frequently report noise levels as a sleep disturbing factor; however, staff responsiveness to this, and perceptions around the importance of the role of sleep as a component of recovery, appear mixed. This may be related to limited knowledge and awareness regarding the important role sleep plays in supporting both physiological and

psychological recovery (Alkadhi et al., 2013; Gellerstedt et al., 2019; McIntosh & MacMillan, 2009). Education relating to sleep in healthcare is infrequently and inadequately addressed in both undergraduate and postgraduate curricula (Gellerstedt et al., 2019; Meaklim et al., 2020). In a recent Australian and New Zealand study, the extent to which sleep education was integrated into medical education was reported to be approximately 2.5 hours across 4 years of education (Meaklim et al., 2020). In the absence of adequate clinical knowledge and the ability to effectively monitor sleep, sleep is easily overlooked and deprioritised as an essential aspect in the patient's overall care. Sleep is readily jeopardised in preference for clinical activities, with several researchers alluding to the adverse impact of clinical cultures that value frequent clinical interactions delivered at the expense of sleep as a proxy indicator of high-quality nursing care (Goodemote, 1985; Haddock, 1994; Webster & Thompson, 1986). In the absence of a shift in awareness of the important physiological processes that occur during sleep, changes to the clinical environment may be challenging to instigate because of entrenched cultures.

Emerging from this study are the unique challenges that are encountered within the intensive care setting and the need to balance the frequency of observations and interventions with a need for sleep to aid recovery. These appear to be different to those experienced by patients cared for in the general ward environment because of the degree of monitoring, clinical interaction, severity of illness and pharmacological agents administered to patients. Clinical practices and the environment obfuscates the traditional day/night environment and the clinicians ability to distinguish sleep from a wakeful state. Sleep disturbance among ICU patients is reported to be linked to a variety of adverse effects that may hamper recovery and increase hospital length of stay, with delirium being a primary concern (Beltrami et al., 2015; Salas & Gamaldo, 2008; Sato et al., 2017; Shi et al., 2012). The disruptive nature of the ICU environment is not conducive to sleep, and is exacerbated by the concurrent limitation in

recognition of the psycho-physiological importance of sleep in the context of patient recovery.

As a vulnerable patient population, who lack autonomy and control over their environment, they are exponentially exposed to high levels of noise within the ICU environment with restricted diurnal variation. Identified within the study were the high levels of noise generated within the ICU, which exceed the recommendations provided by the WHO, with noise being a primary factor in the sleep disturbance experienced by patients. This provided the impetus to further explore the soundscape of the ICU and to identify the sound characteristics of an Australian ICU. In this study, noise levels within the ICU were compared to the recommendations provided by the WHO; further expanding of previous research reporting the soundscape of the ICU, this study reported on the variability of noise levels and the extent to which sound pressures were increased within the clinical environment. Limited research has been conducted within the Australian context reporting on noise levels within the ICU, and this study contributed to the body of knowledge domestically and internationally pertaining to the noise levels generated within this clinical context.

1.5 ‘The Nocturnal Acoustical Intensity of the Intensive Care

Environment: An Observational Study’

The following presents the research findings related to the soundscape of the intensive care environment, published 11 July 2017 in the *Journal of Intensive Care* (<https://doi.org/10.1186/s40560-017-0237-9>). The presented content includes text, tables and references.

RESEARCH

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The nocturnal acoustical intensity of the intensive care environment: an observational study

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Abstract

Background: The intensive care unit (ICU) environment exposes patients to noise levels that may result in substantial sleep disruption. There is a need to accurately describe the intensity pattern and source of noise in the ICU in order to develop effective sound abatement strategies. The objectives of this study were to determine nocturnal noise levels and their variability and the related sources of noise within an Australian tertiary ICU.

Methods: An observational cross-sectional study was conducted in a 24-bed open-plan ICU. Sound levels were recorded overnight during three nights at 5-s epochs using Extech (SDL 600) sound monitors. Noise sources were concurrently logged by two research assistants.

Results: The mean recorded ambient noise level in the ICU was 52.85 decibels (dB) (standard deviation (SD) 5.89), with a maximum noise recording at 98.3 dB (A). All recorded measurements exceeded the WHO recommendations. Noise variability per minute ranged from 9.9 to 44 dB (A), with peak noise levels >70 dB (A) occurring 10 times/hour (SD 11.4). Staff were identified as the most common source accounting for 35% of all noise. Mean noise levels in single-patient rooms compared with open-bed areas were 53.5 vs 53 dB ($p = 0.37$), respectively.

Conclusion: Mean noise levels exceeded those recommended by the WHO resulting in an acoustical intensity of 193 times greater than the recommended and demonstrated a high degree of unpredictable variability, with the primary noise sources coming from staff conversations. The lack of protective effects of single rooms and the contributing effects that staffs have on noise levels are important factors when considering sound abatement strategies.

Keyword: Critical care, Disturbance, Intensive care, Noise, Sleep disturbance, Staff

Background

Both sleep deprivation and fragmentation have been associated with a variety of adverse somatic, cognitive, and physiological effects. Patients are subjected to a cacophony of disruptive sounds in the intensive care unit (ICU) environment, and numerous studies have found an association between noise and the sleep disturbance experienced by patients [1–8]. Objective and subjective studies show that even small changes in noise levels can adversely impact

sleep [1–4, 9]. For example, a 10 dB (A) (refer to list of abbreviations) increase in noise is perceived as a doubling of noise levels, while sound intensity is doubled for each 3 dB (A) increase [10]. Altered sleep architecture and circadian disturbances have been attributed to poorer patient outcomes and is potentially a precipitating cause for the onset of delirium [11–15].

There exists a number of official recommendations regarding noise levels within the hospital environment. The World Health Organization (WHO), the Environmental Protection Agency, and the International Noise Council all recommend that to reduce sleep disturbance, noise levels within hospital wards should not exceed 30 dB(A) at night [16]. However, none of these recommendations

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are specific to the ICU environment, but rather, they are generalised to the hospital environment [17].

Noises that may be disruptive to the ICU environment include conversations, monitor alarms, phone calls, doorbells, and door closures. Compared with lower acuity hospital areas, these are purported to be more frequent and intense in the ICU and result in elevated noise levels [17]. In addition to mean noise level, noise variability may also contribute to sleep disruption. Variations in noise levels may heighten the sympathetic nervous system response, increasing cortisol release, and increase sleep latency [6, 18]. Current research debates the impact of noise on the patients with polysomnography studies reporting that noise levels contributed to 15 to 20% of patient sleep disturbances [3, 4], in contrast to subjective studies which reported that noise is a significant stressor for patients [1, 5, 6, 11]. The effectiveness of interventions to reduce noise levels have been questioned with results revealing transient reductions in ambient noise levels, with limited reductions in the quantity of peak noise levels [1]. Emerging research suggests that the sound quality and the unpredictable variable changes in noise levels may be the major factor-associated adverse effects within the ICU environment which requires intervention [19, 20].

The primary aim of this study was to investigate the intensity and pattern of nocturnal noise levels such as variability and their sources within an Australian ICU compared with the recommendations stipulated by the World Health Organization (WHO). The secondary aim was to investigate whether single-patient rooms provided a significant reduction in ambient noise levels compared with open-bed areas.

Methods

Setting

This observational study was conducted in a 24-bed, open-plan designed, Australian tertiary referral ICU. The unit provides both ICU and high dependency care, including medical and surgical services, trauma and neurosurgical care and post-operative cardiothoracic care. The ICU design is characteristic of a second-generation ICU and includes two centralised open nursing stations, four isolation rooms, three two-bedded bays and four four-bedded bays, with all beds in shared bays separated by linen curtains and rooms separated by semi-partitioned walls (Fig. 1).

Data collection procedures

Noise monitoring

Six sound monitors (Extech Model SDL 600) were positioned throughout the unit: at the nursing station and in the patients' clinical environment. The placement of the sound meters was determined via cluster randomisation

and involved only the occupied patient care spaces, with sites categorised as nursing stations, single-patient rooms, two-bedded and four-bedded bays. Sound monitors were mounted adjacent to the head of patients' beds at a height of 155 cm. This position was chosen to reflect the experience of patients, minimise disruption to clinical care and reduce interference with other monitoring equipment. Noise levels were monitored for 9 h (2200–0700 h) over three weekday nights—two consecutive and one non-consecutive based on a predetermined hospital wide monitoring roster.

Sound levels were recorded in A-weighted decibels at 5-s epochs using an Extech Sound Level Monitor (Model SDL 600, frequency range 31.5 Hz–8 KHz, 30–180 dB (A)) which complied with the International Electrotechnical Commission Standards. The A-weighted filter was used as it attenuates the curve that describes loudness frequency for the human ear. All logged data were saved onto a secured digital 2-GB memory card in a spreadsheet format for subsequent analysis.

Logging of noise sources

Two research assistants completed the logging of noise sources in the ICU into predetermined categories: staff, alarms, doors, phones, wash basins, trolleys and pumps, including an 'Other' category to accommodate unexpected noise sources. To reflect the nocturnal activity in the clinical setting, the research assistants logged noise sources at four different time points: 2300 to 2400, 0200 to 0300, 0400 to 0500 and 0600 to 0700 h.

Data analysis

Data derived from the sound monitors (Extech Model SDL 600) were downloaded and exported to Microsoft Excel (2010). Descriptive statistical analysis (means and standard deviations) was undertaken using IBM SPSS software (version 20) to describe the noise levels recorded. The variability of noise levels within the ICU were calculated by determining the difference between the mean and maximum noise levels within 5-min intervals over the 9 h recording period. The noise sources logged by the research assistants for each hour were collated and reported via descriptive statistics. An analysis of variance (ANOVA) was performed to identify differences between noise levels recorded over each of the three nights and to determine if single-patient rooms were significantly quieter than shared patient spaces.

The perceived loudness of noise is a logarithmic measure and subsequently does not exhibit a linear relationship to changes in noise levels. In order to quantify the impact of the recorded noise levels, psychoacoustical analysis was undertaken in order to describe the increases in volume and the acoustical intensity that these produce (Additional file 1: Table S1) [18]. Identification

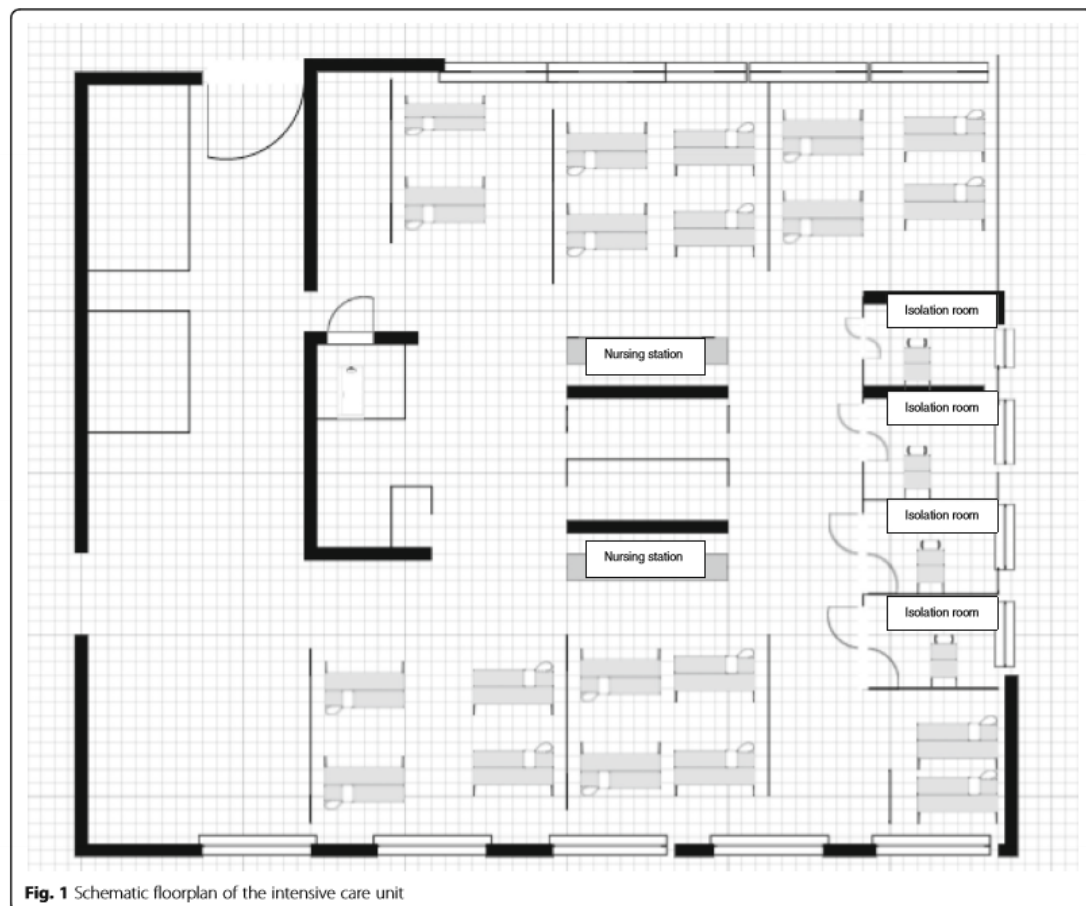


Fig. 1 Schematic floorplan of the intensive care unit

of these measures provides details of sound levels produced in the environment, whilst acoustical intensity reports a linear relationship of how many times greater the noise levels are compared to the recommended levels (30 dB A).

Ethics

The Australian Capital Territory Health Human Research Ethics Committee (ETHLR.12.253) approved the study; the need for informed consent was waived. The study was conducted in accordance with the principles outlined in the Declaration of Helsinki.

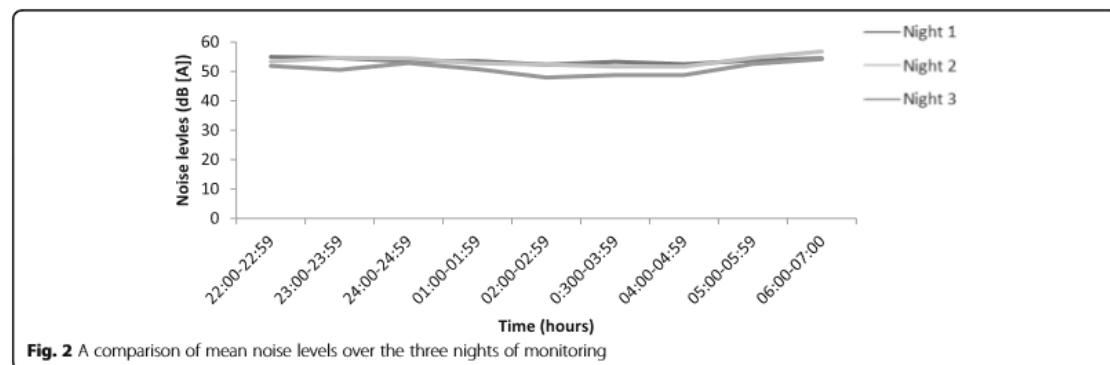
Results

A total of 18 clinical spaces, which included 16 patient care spaces and two nursing stations between June and September 2013 were monitored for nocturnal noise levels. Each bed space was occupied for the entire

monitoring period. The ambient noise levels recorded over the three nights were similar with a variance of 2.86 dB (A) (night 1 $L_A \text{ mean} = 53.71 \pm 4.69$ dB (A), night 2 $L_A \text{ mean} = 53.15 \pm 6.21$ dB (A) and night 3 $L_A \text{ mean} = 50.85 \pm 6.18$ dB (A)) (Fig. 2). The overall ambient nocturnal noise level for the monitoring period in the ICU was 52.85 dB (A) (SD 5.89) and exceeded the WHO recommendations by 22.85 dB (A), which produces an increase in both noise volume (4.8 times greater) and acoustical intensity (192.8 times greater) than recommended.

The peak noise levels ranged from 85.5 to 98.3 dB (A). Noise levels within single-room and open-bed areas were similar to noise levels in two-bedded bays ($p = 0.37$) and four-bedded bays ($p = 0.06$) (Table 1). The primary sources of environmental noise were staff conversations and monitor alarms, which accounted for 35.4 and 34.1% of noises per hour respectively (Table 2).

The variability in ambient noise levels in the ICU is shown in Fig. 3, with frequent undulations in noise levels



ranging from 9.9 to 44 dB (A) above ambient noise levels. Peak noise levels >70 dB (A) were found to occur 10 times/hour (SD 11.4).

Discussion

Noise

We found that nocturnal noise exceeded the international recommendations throughout the entire monitoring period. The noise levels were of similar intensity to heavy traffic. Our results are consistent with other studies reporting noise levels in an ICU [1, 4, 6, 21–24]. The elevated ambient noise levels and the high degree of variability, in combination with the frequency of peak noises identified, are likely to contribute to sleep disruption [1–3, 21–23]. At the reported noise levels, the ICU environment is perceived to be 4.8 times louder, producing an acoustical intensity 193 times greater than the WHO recommendations. Our ICU can be classified as moderately noisy (50–60 dB (A)) to very noisy (60–70 dB (A)) according to the hospital noise levels described by Pereira et al. [24] and may have adverse implications for patients in the ICU.

Sleep disturbances associated with waking, arousal and sleep-to-wake transitions are purported to occur with sound intensities ranging between 50 and 60 dB [25, 26], with spikes in noise levels identified by Gabor et al. [4] as a contributing factor to sleep disruption. Stanchina and colleagues demonstrated that noise variability between ambient noise levels and peak noises determined

the number of arousals for individuals exposed to ICU noise [19]. This indicates that noise disturbance is not only attributed to peak noises, but is also associated with frequency and unpredictability [27]. Subsequently, the capacity for patients to acclimatise to noise levels is unlikely to occur when the noise levels generated demonstrate frequent undulations and elevations in noise levels. The variability in noise levels within the ICU is likely to preclude patients' ability to acclimatise to noise within the environment and adversely impact on sleep continuity, contributing to additional physical and psychological stress. This is supported by patient reports, whereby unfamiliar and loud noises were a major causative factor in preventing their ability to sleep whilst in the ICU [28].

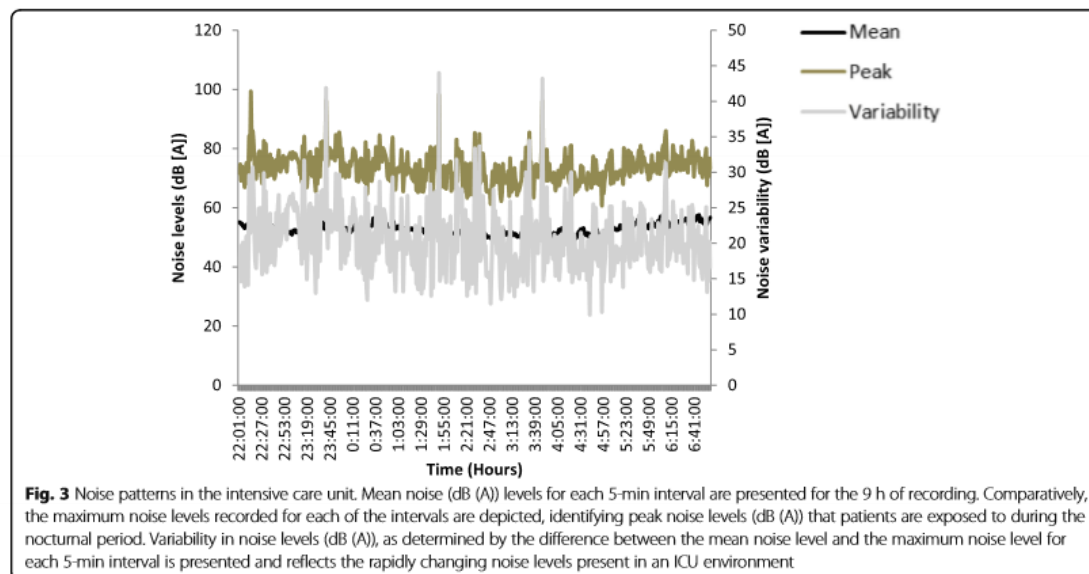
The resultant unpredictability of the environment has been associated with a heightened stress response secondary to autonomic stimulation and enhanced sympathetic activity, which adversely affects sleep latency. As a result, increased cortisol release inhibits melatonin secretion and thereby disrupts circadian rhythm regulation [29]. Exposure to noise sources greater than 50 dB (A) have been shown to produce cardiovascular changes such as increased heart rate variability, [30–32] along with electroencephalographic changes suggestive of

Table 2 Sources of nocturnal noise in occurrences per hour in the ICU

Source	Mean occurrences per hour mean (SD)	Proportion of total occurrences per hour (%)
Staff	84.38 (32.77)	35.5
Alarms	81.06 (43.95)	34.1
Other	35.81 (19.96)	15.1
Doors	12.88 (12.37)	5.4
Pumps	7.19 (12.55)	3.0
Equipment	6.06 (4.64)	2.6
Trolleys	5.94 (7.19)	2.5
Wash basins	4.13 (2.55)	1.7

Table 1 Nocturnal noise levels within the ICU

Location	Mean (dB (A))(SD)	Min (dB (A))	Peak (dB (A))
Intensive care unit (overall)	52.9 (5.9)	40.2	98.3
Nursing station	54.8 (5.8)	42	98.3
Isolation rooms	53.5 (4.1)	47.7	96.3
Two-bedded bay	53 (6.8)	41.6	86.1
Four-bedded bay	52 (6.1)	40.2	85.5



arousal and lightening of sleep [33]. The association between heart rate and acoustics was reported by Hagerman et al. who identified an increase in pulse rate occurring with higher acoustical exposure, resulting in an increased incidence of readmission in a coronary care unit [34]. The variable and unpredictable changes in noise levels within the ICU are likely to impede on sleep quality and continuity, which may have further implications on cognitive function and the development of delirium.

Further, clinicians working within the environment are also susceptible to noise-induced stress, which can lead to exhaustion and irritability [35]. The emerging research on 'alarm fatigue' suggests that 72 to 99% of clinical alarms are false alarms. This contributes to staff desensitisation to alarms and has even been associated with patient deaths [36]. Further, evidence suggests that noise can impinge on concentration and clinical decision-making [36].

The use of single-patient bed spaces as a means to reduce patients' exposure to elevated and disruptive noise levels is not supported by the findings of this study, with four-bedded bays having the lowest ambient noise levels. Previous findings reported by Tegnstedt et al. further support this finding, whereby single-patient rooms were not found to have lower noise levels than shared patient spaces [37]. The reported noise levels in the single-patient rooms in this study may be reflective of the acuity of patients cared for in these rooms. Higher acuity patients require greater clinical interventions resulting in more noise being generated, whilst four-bedded bays may be more likely to be co-habited by less acute patients. In addition, behavioural modifications, such as

regulatory processes that staff engage in, in shared care spaces may contribute to a more conscientious approach to the noise generated in order to reduce its burden and impact on multiple individuals. Further, the clinical design of the single-patient rooms may also be a contributing factor, whereby alarm volumes may need to be increased in order to assure staff's ability to hear them when outside of the room or in the anteroom. In addition, the lack of noise-absorbing features may be a critical consideration that results in greater noise reverberation.

Sources of noise

The frequent ascension of noise levels in this study was observed to be associated with frequent monitor alarms, to which staff did not always respond. The impact of this on environmental noise was compounded by the ability for staff to communicate intelligibly to safeguard clinical decision-making and interventions, whereby speech needs to be 15 dB greater than the ambient noise to ensure clarity of communication. This in turn contributes to a further escalation in noise levels, known as the Lombard effect [38]. Noises produced at these levels are unlikely to provide patients with a nocturnal environment to support sleep and is problematic for clinical staff to ensure that communication is intelligible to mitigate the risk of error. This may account for the high rate of noise attributed to staff behaviour and suggests that moderating behaviour and alarm settings may have a beneficial effect on reducing nocturnal noise levels. The reported noise levels and the identified sources of noise in this study may adversely affect both patient and

clinicians, and thus, there is a need for strategies to be devised and implemented to reduce the disruptions and stressors imposed by constant noise exposure.

Possible interventions

The possibility of curbing noise levels in the ICU environment by employing behaviour modification approaches to ameliorate the noise generated by staff and alarms has been previously identified. Such initiatives have included modifying alarms (tailoring parameters to patients and adjusting the volume at night) [1, 39] staff education regarding the physiological aspects of sleep and its role in recovery [39, 40] and behaviour-regulating interventions such as the use of 'yacker trackers' to identify noise increases [41]. While many of these studies report an initial successful reduction in subjective noise levels, few have demonstrated measurable or sustained reductions [1, 38, 41–44]. These studies suggest that strategies need to consider a range of approaches including sound elimination such as providing patients with ear-plugs and re-designing the environment rather than focusing solely on behaviour modification [29, 41, 44].

Research regarding environmental design indicates that it has the capacity to influence psychology, physiology and social behaviours, which may contribute to a reduction in noise [45]. A landmark report published by Ulrich and colleagues [29] identified 600 studies which linked the clinical environment to positive or negative outcomes for patients and staff in four main areas: patient safety; staff stress and fatigue; increased effectiveness in care delivery; and improved overall healthcare quality. Specifically, these authors found that design features such as single-patient rooms, noise-absorbing materials and exposure to natural light to be useful in promoting appropriate circadian rhythms and reducing noise to facilitate sleep. Other authors have found that these design features were associated with a reduction in noise and improved sleep [4, 46–48], a reduction in medication errors [49, 50], improved communication [51] and reduced length of hospital stay [51–53]. However, despite the reported benefits, fiscal restraints imposed on healthcare organisations have resulted in selective implementation of recommendations [41].

Limitations

The findings of this study cannot be generalised to all ICU environments, as the study was conducted in a single Australian ICU, which may be unique in design and location. The noise levels recorded were recorded at night and are likely to be lower than the noise levels during the day. Further, the study did not undertake direct patient assessment regarding the impact of noise on ICU patients, and as a result, the impact of noise can only be postulated based on the current findings and

previous research. The presence of the observer and environmental-monitoring equipment in the clinical environment could have contributed to alterations in behaviour in order to conform to the presumed research objectives. If anything, this is likely to underestimate true noise levels. Despite these limitations, the study included the measurement of noise from multiple locations within the ICU, across three separate nights, and the identification of noise variability which may be an independent risk factor for noise-induced harm. The concurrent logging of noise sources during the monitoring period permitted the identification of primary noise sources rather than speculating on the primary contributing factors.

Conclusion

The occurrence of high mean noise levels in combination with the variability in noise levels and the frequency of peak noises may contribute to sleep disruption. Mean nocturnal noises in the ICU significantly exceeded those recommended by the WHO and demonstrated significant variability which is likely to result in substantial sleep disruption. The primary sources of noise were identified as staff conversations and monitor alarms. Single rooms had similar noise levels to those of two- and four-bedded bays. Further research into strategies to reduce noise, the physiological responses (e.g. heart rate, cortisol levels) and evaluation of interventions is required to enhance the therapeutic environment and understand their implications on patients. Providing patients with both relief from persistent exposure to noise and diurnal variation in noise levels have the potential to aid in their physiological and psychological recovery.

Additional file

Additional file 1: Table S1. Sound level change and loudness ratio. (DOCX 15 kb)

Abbreviations

ANOVA: Analysis of variance; dB (A): Decibels in A-weighted scale; ICU: Intensive care unit; $L_{A\text{ mean}}$: Mean ambient noise; SD: Standard Deviation; SPSS: Statistical Package for Social Science; WHO: World Health Organization

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Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Authors' contributions

LJD, MC, CH, VL, EL, and FvH did the literature review, data analysis and the development of the manuscript and its editing. All authors read and approved the final manuscript.

Ethics approval and consent to participate

The Australian Capital Territory Health Human Research Ethics Committee (ETHLR12253) approved the study; the need for informed consent was waived.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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1.6 Chapter Summary

The findings presented in Chapter 1 highlight the challenges encountered by patients admitted to general wards and the ICU, more specifically in attempting to sleep. The reported findings suggest an incongruence between clinical staff perceptions of sleep and the psychopathophysiological benefits of sleep for patients. Omissions in knowledge pertaining to the important physiological processes that occur during sleep have been previously reported within the research (Gellerstedt et al., 2019; Huang et al., 2018; Radtke et al., 2014).

Subsequently, enhancing clinical knowledge and empowering nursing staff to champion sleep-promoting activities within the clinical environment are critical in promoting sleep as a priority component in the overall care of patients. As the healthcare professionals who are closest in the proximity of patient care, nurses can be potentially instrumental in addressing sleep disturbance within the clinical environment and promote interventions that provide an advantageous environment for sleep.

The perception that there is little that can be undertaken to improve sleep and the ability to rationalise or alter workflow to reduce sleep disturbance cannot be achieved needs to be challenged to illicit future change. Research highlights the conflict that nurses encounter when providing care between the need to monitor vital signs and waking patients and the ability to identify non-priority tasks that could be reduced overnight to improve sleep (Hope et al., 2018). The need to provide clinical care, particularly nocturnal assessment of vital signs, which frequently contributes to patient awakening, requires some judicious assessment. Stratifying patients to identify those who could have a reduction in nocturnal disturbance (e.g. nil vital signs documentation and medication administration overnight) has been found to produce a 50% reduction in the administration of sedatives among low-risk patients (Bartick et al., 2010; Tan et al., 2019). The emergence of wearable technology may also provide some clinical benefit, not only in reducing sleep disturbance associated with clinical

activities (such as vital sign monitoring) but also in facilitating the ability to monitor and evaluate sleep quality throughout a patient's admission (Delaney et al., 2021; Weenk et al., 2017).

The findings reported reiterate those of past research, which suggest that behavioural factors are a leading contributor to increased noise and are perceived by patients to be the primary stressor leading to their sleep disturbance (Kahn et al., 1998; Konkani et al., 2014; Luetz et al., 2016; Simons et al., 2018). Workflow organisation and potentially clinical design also contribute to the exacerbation of these factors. In the absence of assertive changes and amendments to the clinical environment, patients will remain vulnerable to sleep disturbance because of the dynamic state of the ICU. This cohort of patients are of particular interest as they often experience complex healthcare needs, have increased hospital lengths of stay, and are subjected to potential secondary complications related to their admission. While the environment presents as unfavourable to acquire quality sleep, the ability to accurately assess sleep is problematic and inadequately addressed. In the absence of a feasible objective method, sleep will likely remain poorly considered and inadequately addressed in the context of critical care.

The following chapter discusses the literature regarding the physiological basis for sleep and the accompanying neurobiological impact sleep disturbance potentially has on patients cared for in the ICU. Recognition of the diverse adverse consequences attributed to sleep disturbance is not commonly acknowledged. A lack of situational awareness by staff may result in omissions in the accurate identification of sleep disturbance. Presently, sleep is inconsistently and haphazardly monitored in the ICU and does not form an integral component of the clinical care of patients. Rather, clinical considerations associated with sleep disturbance frequently arise once the manifestations of sleep deprivation become clinically evident, resulting in reactive management strategies rather than preventative and a

propensity to seek pharmacological interventions (NSW Therapeutic Advisory Group Inc, 2021). Predominantly, the role of sleep in the clinical management of patients is deprioritised and viewed as a passive state that can be readily disrupted to meet clinicians' needs, rather than the patient's needs.

Chapter 2: Psychological and Physiological Repercussions of Sleep Disturbance

Sleep is the only medication that gives ease (Sophocles)

2.1 Introduction

The inability of patients to achieve quality sleep has been attributed to a multitude of psycho-physiological complications, which can adversely affect the patients' recovery. Intensive care patients are vulnerable to sleep disturbances, resulting in qualitative sleep deprivation (Freedman et al., 2001; Friese et al., 2007; Gabor et al., 2003), manifesting as a reduction in REM and SWS (Freedman et al., 2001; Richards & Bairnsfather, 1988), and contributing to a constellation of symptoms that result in difficulty with sleep initiation, fragmentation, early morning awakenings, and decreased TST (Friese et al., 2007).

Physiologically, sleep deprivation can detrimentally affect the immune response (Honkush, 2003; Vgontzas et al., 2004; Wysocki, 1996), contribute to cardio-metabolic changes (Knutson et al., 2007; Doraciak, 1990), and heighten pain sensitivity (Alvarez & Ayas, 2004). The psychological impact of sleep deprivation manifests as lethargy, irritability, confusion and delusions, along with decreased motivation and willingness to engage in activities that endeavour to expedite recovery, such as mobilisation and chest physiotherapy (Mathias & Alvaro, 2012).

A lack of nocturnal sleep contributes to daytime somnolence, which both patients and nursing staff have reported. Anecdotal reports are supported by PSG studies that indicate that between 40% and 50% of patients' sleep is acquired during daylight hours (Aurell & Elmqvist, 1985; Bihari et al., 2012; Freedman et al., 2001; Gabor et al., 2003), with sleep quality failing to improve over the course of the ICU admission. Orwelius and colleagues

(2008) reported that 38% of patients within medical–surgical ICUs experienced difficulty falling asleep, with a further 61% reporting a greater requirement for sleep secondary to illness. Biophysiological studies involving PSG monitoring report the presence of atypical sleep architecture, with a notable reduction of SWS and REM sleep, which contributes to phase-shifting in an individual’s circadian rhythm (Aurell & Elmqvist, 1985; Boyko et al., 2012; Delaney et al., 2021; Elliott et al., 2013; Freedman et al., 2001; Freedman et al., 1999; Prajapat et al., 2021; Watson et al., 2013). Management strategies typically focus on pharmacological interventions, such as administering of sedatives, anti-anxiolytics and supplementation of endogenous hormones such as melatonin. The net effect of sleep disturbance is that it contributes to increased hospital length of stay, and incidences of delirium and falls (Ely et al., 2001; Hansell, 1984; Kollef et al., 1998), with sleep disturbance being perpetuated for months after discharge from the ICU (Kelly & McKinley, 2010).

2.2 Chronobiology of Sleep

Circadian mechanisms are intrinsic rhythms that facilitate physiological, biochemical and behavioural processes, and revolve around a 24-hour period (Gumz, 2016). They are critical regulatory mechanisms for hormones such as corticosteroids and melatonin, as well as immunological function and the regulation of cytokines (Bollinger et al., 2010). Circadian patterns of patients, in particular, the sleep–wake cycle, are adversely affected by the intensive care environment because of the lack of diurnal variation and critical illness, which may have serious implications for the functional recovery outcomes of patients (Arendt, 2000; Hu et al., 2010; Olofsson et al., 2004).

Sleep disturbance is recognised as an issue in the ICU patient population, with emerging research suggesting that it may be a contributing factor in the onset of delirium (Ely et al., 2001; Van Rompaey et al., 2009; Zaal et al., 2013). The neurobiology of sleep suggests that sleep disturbance impedes the clearance of the degraded by-products of neural activity

(Xie et al., 2013) as sleep appears to be integral in synaptic and cellular homeostasis to facilitate memory consolidation and integration (Tononi & Cirelli, 2014). Physiologically, sleep disturbances adversely affect the cardio-respiratory system and the hypothalamus–pituitary–adrenal axis (Buckley & Schatzberg, 2005; Delaney et al., 2015; Kamdar et al., 2012; Matthews, 2011; Redeker et al., 2004). Sleep disturbance may have serious implications for ICU patients, such as the onset of delirium and mortality rates, with Evans and French (1995) reporting an increase among patients who experience sleep disturbance as a component of their ICU admission.

Sleep is an important component in a patient’s recovery from acute illness, and is defined as a ‘reversible behavioral state of perceptual disengagement from, and unresponsiveness to the environment’ (Kryger et al., 2005, p.13). Physiologically, it is characterised by an amalgam of physiologic and behavioural processes that are perceived as indicators of sleep, such as closed eyes, behavioural quiescence and reclined posture (Carskadon & Dement, 2011). Neurologically, sleep reduces the activity of the reticular activating system, which induces the loss of awareness and responsiveness to external environmental stimuli (Tortora & Derrickson, 2008).

2.3 Neurobiology of Sleep Regulation

The endogenous rhythm of sleep is modulated by neuroendocrine signals, which are regulated by the circadian clock (Billings & Watson., 2015). The suprachiasmatic nucleus (SCN) located within the hypothalamus acts as the regulatory mechanism of circadian patterns, promoting arousal during the day (Fisk et al., 2018). Conversely, sleep is controlled by the ventrolateral preoptic nucleus (VLPO) situated in the anterior hypothalamus (Murillo-Rodriguez et al., 2009). Nuclei located within this area have been associated with non-REM sleep, and those located dorsally and medially to the VLPO are linked to REM sleep (Lu et al., 2002; Lu et al., 2000). While the SCN plays an essential role in the timing of sleep and

wakefulness, it also contributes to the regulation of several circadian processes such as cortisol and melatonin regulation, and core body temperature (Hastings et al., 2008).

There exist 10 known circadian regulatory genes involved in the initiation and regulation of the sleep–wake cycle (Xie et al., 2019). Specifically, the *circadian locomotor output cycles kaput (CLOCK)* and the *brain muscle aryl hydrocarbon receptor nuclear translocator-like 1 (BMAL1)* are associated with the length of the circadian cycle (Chan et al., 2012). The maintenance of the oscillatory pattern occurs via a negative feedback loop and aids the SCN (master clock) in coordinating the circadian rhythms (Dijk & Archer, 2010). Sleep regulation is coordinated by two primary mechanisms involved in the sleep process—the homeostatic and circadian (Schwartz & Roth, 2008). The homeostatic mechanism regulates sleep pressure (the need for sleep) and endeavours to achieve a set duration of sleep in relation to an individual’s sleep–wake cycle (Reichert et al., 2014). Under the homeostatic mechanism, sleep deprivation contributes to a phenomenon known as sleep rebound (Vyazovskiy, 2015), which provides an adjustment to compensate for sleep loss by increasing the duration and intensity of recovery sleep, and is comprised of a greater duration of REM sleep. Disruption of the endogenous circadian control or misalignment between the circadian rhythm and the external 24-hour environment can lead to phase-shifting, which can have adverse consequences on sleep and the functional capacity of individuals (Young & Bray, 2007; Zhu & Zee, 2012). Patients cared for in the ICU environment are susceptible to altered homeostatic mechanisms due to the atypical sleep physiology and disruptive nature of the clinical environment.

The entrainment of the circadian pacemaker to the environment geophysical time is achieved via photoperiodic information regarding day and night, relayed by the optic nerve to the SCN (Lack & Wright, 2007) and zeitgebers (social cues) such as meals. Both of these regulatory mechanisms are altered in critical illness as patients cared for in the ICU have

limited exposure to natural light and, in turn, have prolonged exposure to artificial light during the day and night, while enteral nutrition is frequently provided over a 24-hour continuum (Berry, 2012). Disturbances in circadian synchrony contribute to delayed initiation of sleep, and increased sleep fragmentation and early morning arousals, which may contribute to delays in recovery and the onset of delirium (Waterhouse et al., 1993).

2.4 Linkage

Sleep disturbance contributes to a number of pervasive psycho-physiological effects that may have detrimental effects on ICU patients. The body, during sleep, undergoes an array of physiological changes that aid in maintaining homeostasis. In the ICU, physiological status can fluctuate, resulting in altered haemodynamics, modulation of the immune response and neuroendocrine function, which can be further compounded by sleep disturbance. The following publication presents an overview of sleep architecture, and the psycho-physiological impact sleep disturbance has on patients cared for in the ICU, highlighting the need to critically consider sleep a fundamental component of overall care.

2.5 ‘Sleeping on a Problem: The Impact of Sleep Disturbance on Intensive Care Patients—A Clinical Review’

The following presents a review of the research regarding the physiological and psychological implications of sleep disturbance among intensive care patients, published 26 February 2015 in the *Annals of Intensive Care* (<https://dx.doi.org/10.1186%2Fs13613-015-0043-2>), including text, tables and references.

REVIEW

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Sleeping on a problem: the impact of sleep disturbance on intensive care patients - a clinical review

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Abstract

Sleep disturbance is commonly encountered amongst intensive care patients and has significant psychophysiological effects, which protract recovery and increases mortality. Bio-physiological monitoring of intensive care patients reveal alterations in sleep architecture, with reduced sleep quality and continuity. The etiological causes of sleep disturbance are considered to be multifactorial, although environmental stressors namely, noise, light and clinical care interactions have been frequently cited in both subjective and objective studies. As a result, interventions are targeted towards modifiable factors to ameliorate their impact. This paper reviews normal sleep physiology and the impact that sleep disturbance has on patient psychophysiological recovery, and the contribution that the clinical environment has on intensive care patients' sleep.

Keywords: Clinical care; Environment; Intensive care; Light; Sleep; Sleep deprivation; Sleep fragmentation; Noise

Review

Introduction

Sleep is considered to be an essential biological function to maintain physiological and emotional wellbeing. However, sleep in the intensive care unit (ICU) has been reported by survivors of critical illness to be of a poor quality and a major stressor associated with their admission [1]. The proclivity for sleep and circadian disturbance amongst ICU patients has been attributed to the intrusive clinical care and clinical environment, with environmental factors inclusive of noise, and light as etiological causes. As a result, patients exhibit symptoms consistent with dysomnia, such as difficulty with sleep initiation and fragmentation, and early morning awakenings [2]. This paper discusses the impact of environmental factors: noise, light and clinical care interactions on patient sleep and the psychophysiological consequences of sleep disturbance.

Normal sleep architecture

Sleep involves a number of sequential stages, with two predominate phases: non-rapid eye movement (NREM)

and rapid eye movement (REM) sleep. NREM consists of three stages which constitutes between 75% to 80% of the total sleep time (TST) [3] with the first stage (N1) acting as a transition between wakefulness and deep sleep. N1 is characterised by physical drowsiness, combined with decreased ocular movements and a reduction in muscle activity [3,4]. This is followed by N2, in which the individual becomes decreasingly unaware of their surroundings, yet remains easily roused by noise [5]. As sleep progresses, N2 becomes the predominant stage making up 45% to 55% of the NREM phase.

Stage N3 consists mostly of slow wave activity and is considered to be an anabolic and physically restorative stage [6]. This stage is prominent in the first third of the night's sleep and is deemed to be the deepest and most restful stage of the sleep cycle. During slow wave sleep (SWS), metabolic activity is at its lowest leading to a reduction in oxygen consumption. Growth hormone is secreted during this stage which promotes protein synthesis, tissue healing and physical recovery [7]. In contrast, the proceeding REM phase features increased cerebral and physiological activity, whereby the brain's metabolic rate reflects that of a wakeful state with bursts of REM, coupled with skeletal muscle atonia [3,8-10]. The time spent in REM sleep increases over the length

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of the night and makes up 20% to 25% of TST [6]. Whilst REM sleep contributes to a restful night sleep, this phase has a lower threshold for awakening than SWS.

The onset of oneiric phenomena has traditionally been associated with REM sleep; however neurophysiological research indicates that dreaming occurs in both REM and NREM phases [11,12]. The occurrence of oneiric activity between the phases have some qualitative variances with dream activity during NREM sleep being associated with memory processing and recall of experiences, whilst in REM sleep it is characterised by visuohallucinatory and unusual content [13]. The role of dreaming is thought to have importance for cognition, associated with mental processing and memory consolidation.

Sleep disturbance in ICU

The sleep physiology of ICU patients indicates that whilst their TST is often normal (7 to 9 h) [2,14-17], sleep is highly fragmented with patients experiencing 6.2 awakenings per hour [2]. Sleep quality is further compromised as the majority of sleep is spent in stages N1 and N2 which is perceived to be 'light sleep' with limited restorative benefits. Subsequently, the characteristics of non-consolidated light sleep have resulted in ICU patients being sleep deprived. This has been attributed to a reduction in the duration of REM sleep and SWS, the supposition is that these phases support restorative processes and are important for recovery [16,18]. Due to a lack of quality sleep, patients experience daytime somnolence, with as much as 50% of patient TST occurring during daylight hours [15,16,19,20]. Sleep cycles which traverse both day and night perpetuate the phase shifting of circadian rhythms with sleep disturbance persisting months after discharge from ICU [21].

The impact of severity of illness on sleep architecture and sleep disturbance has been widely considered; however, there are limited studies explicitly investigating this factor. There exists some clinical indication that higher acuity scores are associated with greater sleep disturbance, specifically increased fragmentation and number of awakenings [22]. Gabor et al. [15] reported that healthy participants exposed to the ICU environment compared to ICU patients did not demonstrate the same level of sleep disturbance and reduction in SWS, suggesting that critical illness may be a contributing factor to the abnormalities seen in the sleep architecture of ICU patients. However, in this study, the healthy participants were only exposed to the noise within the environment and not to the full sensory experience of ICU such as frequent clinical interactions and invasive monitoring. Further, patients with higher acuity score also demonstrate considerable reduction in the EEG activity, which confounds the ability to accurately interpret polysomnographical data.

Problematic to the investigation of severity of illness on sleep is the numerous contributing factors such as mechanical ventilation, pain, pharmacological agents and the greater need for clinical interventions, which confound the ability to determine causality.

Physiological effects of sleep disturbance

Physiologically, sleep deprivation has a myriad of negative cognitive, autonomic [23], metabolic [24,25] and hormonal [7,26,27] effects on the body that may contribute to prolonged ICU admission and in turn may contribute to an increase in patient morbidity. Findings derived from animal-based studies reveals that sleep deprivation is associated with increased mortality; the implications of such findings within the ICU setting have the capacity to be profound as sleep disturbance is commonly experienced by this patient cohort [27,28].

Effects on the respiratory system

The chemosensitivity of the brain's respiratory centre is reduced amongst sleep-deprived patients, with White et al. [29] reporting a decrease in intrinsic ventilatory response to hypoxic and hypercapnic states. Further, studies have reiterated varying adverse effects of sleep deprivation on respiratory muscle function including Phillip et al. [30] who demonstrated a significant reduction in FEV1 (mean decline of 6%) and FVC (mean decline of 5%) in sleep-deprived patients with underlying chronic obstructive pulmonary disease (COPD) compared to non-sleep-deprived COPD patients. Furthermore, maximal inspiratory pressure (MIP) was found to decrease from 81.5 ± 8.8 cmH₂O in rested individuals to 75.9 ± 7.6 cmH₂O in those who were sleep deprived [30]. Issues associated with inspiratory muscle endurance has also been reported by Cheng and Tang [31], who found that sleep deprivation amongst healthy individuals resulted in a significant decline in respiratory muscle strength. Findings such as these suggest that sleep-deprived states may contribute to patient hypoventilation, adversely affecting pulmonary reserves and overall readiness and ability to expedite weaning from mechanical ventilation.

Effects on the cardiovascular system

The manifestation of cardiovascular effects of sleep deprivation emanates from the stimulation of the sympathetic nervous system (SNS) and the release of the catecholamines adrenaline and noradrenaline. As a result, increases in blood pressure and heart rate are reported due to changes in baroreflex sensitivity [32-34]. Ogawa et al. [33] reported that increased baroreflex results in a 12 mmHg elevation in blood pressure as a result of a single night's sleep deprivation amongst healthy individuals.

Effects on the immunological system

Neuro-immunological research asserts that there exists a bidirectional relationship between sleep deprivation and the immune system. Although the vast majority of studies conducted are animal based, the reported changes identified in the immunological system in response to sleep deprivation can have significant implications for critically ill patients.

The adaptive immune response and the functioning of the T cells have been reported to be vulnerable to sleep disturbance, as studies have identified that sleep plays an important role in the extravasation of the T cells [35,36]. The resulting increase in the propensity for sleep during illness may play an important role in promoting the function of the immune response and overall recovery. Previous animal studies have identified that interleukin (IL)-1 and tumour necrosis factor (TNF) contribute to an increase in non-REM sleep and sleep fragmentation [37]. This occurs as immunoreactive neurons of the cytokines which are located in regions of the brain that play a role in the sleep-wake cycle. Although the reported propensity for sleep during critical illness remains unknown, it is hypothesised that the role of IL-1 and its interaction with 5-hydroxytryptamine (5-HT) may proffer an explanation. The onset of fever in response to invading pathogens potentiates the immune response and promotes survival. The resulting increase in pro-inflammatory cytokines such as IL-1 impacts on the sleep architecture through increasing the NREM phase with greater fragmentation and reducing REM sleep; these effects, however, allow for an enhanced inflammatory response [38-40]. The increased NREM sleep is thought to be an important aspect that supports the onset of fever; as during this phase the brain and body temperature is reduced, along with metabolic activity [37]. These features of the NREM stage allow for enhanced heat dissipation with the corresponding increase in sleep fragmentation further facilitates heat loss [37].

Furthermore, the function of natural killer (NK) cells has been shown to be adversely effected in sleep-deprived states, although research findings have not always been consistent. Irwin et al. [41] found that the functionality of NK cells was reduced by 30% in sleep-deprived states in healthy subjects. This was further reiterated in their 1996 study which demonstrated that whilst NK cell activity initially declined, it did improve after sleep recovery. In contrast, Dinges et al. [42] reported that NK cell activity was increased in healthy adults who were sleep deprived; however, leukocyte function was suppressed. Although much of the research investigating the relationship between immune function and sleep deprivation has been conducted on healthy individuals, it is apparent that sleep provides an important role in the effective functioning of the immune system.

Effects on the metabolic system

During nocturnal sleep, downregulation occurs in the hypothalamus-pituitary-adrenal (HPA) axis and the SNS, which both have important roles in stress responses. Ensuing is a decrease in noradrenaline, adrenaline and cortisol levels which suppresses the immune systems anti-inflammatory cytokines [43]. During sleep, particularly SWS, growth hormone is released in combination with prolactin and leptin which provide pro-inflammatory signals which triggers the immune system activation [44]. The HPA axis plays an integral role in the body's response to stress, primarily via the release of cortisol. Abnormal cortisol levels in ICU patients contribute to further disturbances with circadian rhythms, as cortisol release is normally increased prior to waking to stimulate the individual into a state ready to be active. An increase in cortisol levels and suppression of melatonin produces a propensity for patients to be in a wakeful state which may further exacerbate catabolic activity and increases oxygen consumption.

Sleep disturbance adversely effects carbohydrate metabolism resulting in insulin resistance and glucose clearance. Whereby, the increase in SNS activity and the ensuing stress response suppresses the release of insulin from pancreatic beta cells [45,46]. The impact of this on healthy individuals is an increased susceptibility to chronic health conditions such as coronary artery disease and diabetes. Within the ICU patient population, this can exacerbate underlying co-morbidities, putting them at risk for additional secondary complications. For example, instability in blood glucose levels has been associated with increased patient mortality [47]. The immunological effects of sleep disturbance also have a concomitant effect on metabolic functions with pro-inflammatory cytokines increasing in activity with moderate total sleep loss, which contributes to insulin resistance [44].

Effects on the neurocognitive system

The onset of delirium amongst ICU patient ranges between 60% to 80% for mechanically ventilated patients and 20% to 50% for non-mechanically ventilated patients [48,49]. Delirium has been identified as an independent predictor for adverse patient outcomes including increased hospital length of stay, a persistent decline in cognitive status and increased patient mortality [48-50].

A number of factors have been purported to contribute to the development of delirium, with sleep deprivation thought to be a contributing factor. However, the relationship is not clearly understood in regard to whether sleep deprivation leads to delirium or if the onset of delirium contributes to sleep deprivation. Nonetheless, sleep deprivation and delirium share a number of similar features namely a decline in cognitive function inclusive of psychomotor vigilance, memory and disturbances in

language and perception which is characterised by hallucinations and delusions [51,52]. Although recommendations aimed at minimising the likely onset and complications associated with delirium include reducing sleep disturbance, one of the major challenges is associated with the pharmacological agents used to treat symptoms associated with delirium. Many of the pharmacological agents such as haloperidol and benzodiazepines used can potentially exacerbate sleep disturbance, due their inhibitory effect on SWS and REM sleep [52].

Commonly used GABA agonists such as propofol and benzodiazepines (Table 1) increase total sleep time and decrease sleep latency; however, these decrease N3 and REM sleep stages [53,54]. The pharmacokinetics of these medications suppresses cerebral function which produces changes in EEG activity such as a reduction in delta activity [55]. Similarly, commonly used opioids, morphine and fentanyl, increase total sleep time, they adversely impact N3 and inhibit REM sleep [56]. Although sedation and analgesia is commonly required to support therapies such as mechanical ventilation and promote patient comfort, understanding the cumulative effects of commonly used pharmacological agents and identifying newer emerging medications that may reduce the negative effects on sleep is an area for further research. Preliminary animal-based research regarding the effective of dexmedetomidine indicates that it increases N3 sleep, whilst ICU-based research suggests that incidences of delirium onset maybe reduced [57]. These preliminary findings suggest the dexmedetomidine may have an important role in the management of critically ill patients, which may reduce the incidences of delirium and the degree of sleep disturbance experience by patients.

The impact that traumatic brain injury (TBI) has on sleep can be profound. The prevalence of TBI ranges between 30% and 84% and makes up a large percentage of critical care admissions [58,59]. In the acute phase of presentations, the impact that pharmacological agents

combined with increased intra-cranial pressure can severely affect cerebral functioning and neurotransmitter activity resulting in decreased EEG activity. Sleep disturbance within this patient cohort may have significant implications for recovery outcomes, with previous research indicating that the presence of SWS and REM sleep, along with sleep efficiency correlated to improved cognitive outcomes [60]. The negative effects that TBI has on sleep can persist for months after ICU discharge and are predominantly associated with sleep initiation and maintenance and sleep architecture which can adversely affect cognition and behaviour [61,62].

Environmental factors impacting of ICU patients sleep

The importance of sleep in patient recovery can be deprioritized in ICU due to the need to meet increasingly complex care requirements. Sleep disturbance has emerged as an indicator for adverse clinical outcomes [52,63] and in turn should not be viewed as a passive physical state but rather acknowledged as an important bio-physiological process. The impact of the ICU environment on patient sleep has been frequently reported on and investigated as a primary etiological cause of sleep disturbance. Factors such as light, noise, clinical care-related interactions, combined with medications and acute illness have all been hypothesised as causal factors for sleep deprivation [1,2,7,15,16,19,64,65] (Table 2).

Effects of noise levels

Noise levels in ICU have been presumed to be the most disruptive environmental stressor that patients are subjected to and are a relentless feature due the cacophony of clinical activity and technological monitoring. Noise is defined in terms of mechanical energy and is commonly

Table 1 The effect of pharmacological agents on sleep

Pharmacological agent	TST	SWS	REM
Propofol	↑	↓	↓
Lorazepam	↑	↓	↓
Alprazolam	↑	↓	↓
Diazepam	↑	↓	↓
Haloperidol	↑	↑	↓
Morphine	↓	↓	↓
Fentanyl	↑	↓	↓
Midazolam	↑	↓	↓
Dexmedetomidine	↑	↑	↓

TST, total sleep time; SWS, slow wave sleep; REM, rapid eye movement; ↑, increase; ↓, decrease.

Table 2 Factors impacting on sleep architecture

Factor	Example
Environmental noise	Staff conversations and monitoring alarms
Prolonged exposure to low levels of artificial light	
Inflammatory mediators	
Pain	
Pharmacological agents	Sedative, opioids, benzodiazepines and inotropes
Mechanical ventilation	
Increased cortisol release	
Decreased endogenous melatonin levels	
Critical illness	
Clinical interactions	Vital sign monitoring, pathological investigations and medication administration

reported in the A weighted decibel (dB) scale as it most accurately attenuates the noise levels heard by the human ear [66]. The measure of decibels is logarithmic, and as a result, a 10-dB increase in noise constitutes a doubling of the noise level [67].

The World Health Organisation (WHO) recommends that noise levels within hospital wards should not exceed 30 dB(A) at night in order to reduce sleep disturbance [68]. The ability for ICUs to meet the WHO recommendations is improbable and is further reiterated within the literature whereby ICUs worldwide repeatedly cite noise levels in excess of 50 dB [2,64,65,69-71]. Moreover, noise levels in ICUs have steadily increased over the past decades, with a study conducted by Busch-Vishniac [72] quantifying this at a rate of 0.38 dB(A) per day and 0.42 dB(A) per night, per year. The evolving advances in medical care, technology and increasing patient acuity are contributing factors to the acoustical changes within the clinical environment. The noise generated from alarms associated with the intensive monitoring of patients frequently exceeds 70 dB(A), which is reflective of the noise generated by traffic [73]. Further, with the increasing ambient noise level, the impact of the Lombard effect can be compounded. This communication phenomenon results in individuals increasing their speech amplitude in order to enhance the intelligibility of their speech within noisy environments and contributes to a rapid escalation in environmental noise. This creates an environment that is detrimental to patients' sleep as noise levels frequently undulate between low levels, with frequent short, sharp and unpredictable escalations in noise [74].

Both subjective and objective studies have reported noise as a primary source of sleep disturbance, with staff being the primary source of the generated noise [15,16,75]. Subjective studies investigating the impact of noise on sleep indicate that ICU patients identify the exposure to noise and inability to sleep as a major stressor recounted by patients. Further, objective studies indicate that the noise generated within the environment is not conducive to the ability to sleep. The primary source of noise within the clinical environment has been attributed to staff behaviours, which Kahn et al. [76] reported accounted for greater than 50% of noise sources with an average noise level of 84 dB. Previous studies have suggested that the disruptive nature of staff behaviours evolve from the propensity of staff to deprioritized sleep, due to patients being intubated and sedated, and lacked knowledge regarding the psychophysiological effects of sleep deprivation [70,77]. As a result of subjective studies, behaviour modification strategies have been widely investigated as a means to curtail the impact of noise generated by staff on patient sleep and have been cited as being successful in reducing noise levels by 6% to 20% [78-80]. These behaviour modification activities

have primarily involved an educational approach to enhance staff awareness of the impact their behaviours have in contributing to noise levels and promoting reductions in alarm volume settings to promote a diurnally appropriate environment. However, these studies have employed subjective assessments of the impact of behaviour modification, such as clinical staff perception of nocturnal noise, as opposed to using an objective environmental measure of noise. This has been problematic as studies that have employed environmental noise monitoring to determine the effect of behaviour modification on noise have been unable to achieve a measurable reduction in noise levels [81]. Furthermore, achieving sustainable change in the clinical environment has not been extensively investigated as behaviour modification studies have been undertaken over short durations, with follow-up assessments conducted after the immediate intervention period.

Studies employing objective measures of sleep have reported varying results. Aaron et al. [75] investigated the impact of noise on sleep via polysomnography (PSG) and reported that noise sources exceeding 50 dB(A) resulted in electroencephalographic changes indicative of arousal in 25% of cases. However, this finding has not been consistently reported in proceeding studies; further, there is a discrepancy between self-reported sleep quality and the biophysiological data obtained regarding sleep. Studies employing time synchronised monitoring of sleep via polysomnography and environmental noise monitoring, such as Freedman et al. [16] identified that only 11.5% of arousals and 17% of awakenings could be attributed to noise. Likewise, in a similar study, Gabor et al. [15] identified that 20% of awakenings were the direct result of environmental noise. Neither study was able to account for the cause of the remaining 75% to 80% of arousals but postulated that clinical interactions may account for much of these. However, this was not supported by Gabor et al.'s [15] findings, whereby only 7% of awakenings could be associated with clinical interactions. Subsequently, the degree to which noise acts as the pathogenesis of sleep disturbance in ICU remains unclear, although it is commonly reported as an issue by survivors of critical illness.

Effects of clinical interactions

The need for clinical interventions increases exponentially in ICU as many assessments are scheduled on an hourly basis such as vital sign monitoring, fluid balance assessments and pharmacological administration. These interventions in combination with basic care needs establish an environment in which sleep is easily deprioritized and disrupted. Furthermore, the design of ICU can compound issues, as the clinical area is frequently open planned with patients segregated from each other by

curtains, which achieves little in quashing the impact of the clinical environment on patients' senses.

Early observational studies conducted by Walker [82] and Woods [83] reported that patients were disturbed between 1 and 14 times per hour, and given that a single sleep cycle requires 90 to 110 min to complete, patients cared for in the ICU have little ability to achieve quality sleep. In more contemporary studies such as Lee et al.'s [84], 50% of subjects reported being woken 2 to 5 times throughout the night, which contributed to difficulties falling back to sleep once woken. This finding has been corroborated by previous studies conducted by Redeker and Hedges [85] and Tranmer et al. [1]. In contrast, studies conducted by Tamburri et al. [86] and Celik et al. [87] report much higher patient to staff interactions with both studies reporting between 40 and 60 interactions per night. Comparatively, the frequency of disruptions for mechanically ventilated patients was found to be substantially higher, with Le et al. [88] reporting that patients experienced 20 to 60 disruptions per hour.

The intensive monitoring that patients are subjected to is detrimental to the intrinsic sleep cycle, suggesting that under these conditions ICU patients will experience sleep deprivation. Further, in an observational study by Le et al. [88], nursing staff reported that 13.9% of nocturnal interactions could be safely omitted and, in turn, reduce the disturbance to patients. This suggests that a number of nursing-based activities are performed as a routine rather than based on clinical evidence and necessity. This highlights the need for clinical staff to critically evaluate the necessity for some of the care provided and to consider making adjustments to workflow in order to promote nocturnal sleep.

Effects of light

Regulation of the circadian rhythm is influenced by so-called zeitgebers (environmental cues) to remain entrained to the typical day/night routine. Prominent zeitgebers include meal times and exposure to daylight, both of which can be suppressed amongst critically ill patients. Nutrition is frequently provided enterally on a 24-h continuum, whilst ICU design and critical illness does not permit patient exposure to adequate natural light. Subsequently, the outcome of inappropriately timed zeitgebers in combination with prolonged exposure to low levels of artificial lighting can impact on the circadian pacemaker leading to circadian disturbance.

The protracted exposure to artificial lighting obfuscates the normal circadian rhythms, with light levels within ICUs being highly variable, ranging between a mean of 5 and 1,400 Lux. Exposure to low levels of artificial light less than 500 Lux and for as little as 20 min has been identified as sufficient to suppress nocturnal

melatonin secretion [89–92]. Melatonin is an important regulator hormone of the circadian rhythm. Melatonin levels increase during the early hours of the night to facilitate the onset of sleep and decrease during the morning when cortisol levels increase. Whilst there is a focus on the potential role of melatonin in promoting sleep in this patient population, subjective studies have reported that ICU survivors perceived light exposure to be minimally disruptive to their ability to sleep [93]. Hu et al. [94] investigated the effect of non-invasive, non-pharmacological interventions of ear plugs and eye masks on ICU patients ($n = 14$) who underwent PSG sleep monitoring. The study found that these interventions resulted in an increase in recorded REM sleep, a reduction in REM latency with less arousals ($p < 0.05$) and an elevation in melatonin levels ($p = 0.002$). Suggesting that although patients may not perceive exposure to light a major cause of sleep disturbance, it appears to have a detrimental effect of sleep wake patterns, and simple interventions may be able to minimise its effects.

A considerable body of research focuses on how light exposure affects endogenous melatonin secretion and the potential efficacy of supplemental melatonin as a means to entrain the circadian rhythm and overcome the lack of light variation to maintain the external zeitgeber. Munigler [95] reported that melatonin secretion was suppressed in patient with sepsis compared to non-septic ICU patients who demonstrated normalised circadian patterns similar to healthy individuals. In a double blind placebo controlled study ($n = 8$), patients receiving supplemental melatonin demonstrated an improvement in sleep duration and sleep quality [96]. In contrast, a study conducted by Egi et al. [97] involving 32 tracheostomised ICU patients was inconclusive regarding the benefits of melatonin in promoting sleep, finding that although melatonin levels increased in the treatment group it did not result in improved observable nocturnal sleep (240 min versus 243.4 min in the placebo group). A similar study undertaken by Bourne et al. [98] also studied the effect of supplemental nocturnal (21:00 h) melatonin administration of 10 mg in 27 ICU patients who had undergone tracheotomy insertion to promote ventilator weaning. The reported outcome of this study was that sleep in the treatment group increased by 1 h (sleep efficiency index difference = 0.12, 95% CI -0.02 to 0.27, $p = 0.04$) compared to the placebo group, along with an objective improvement in sleep quality as evaluated by bispectral index (BIS).

Melatonin has emerged as a possible treatment to maintain the circadian rhythm with oral administration having good bioavailability, with minimal negative effects on respiration despite its hypnotic effects [99]. To date, the studies conducted have involved small participant numbers and variances in sleep assessment. Future studies

involving larger participant numbers and standardised sleep monitoring via PSG are required to ascertain the potential of melatonin as a standard therapy, along with the effect of concurrent interventions such as eye masks and ear plugs to negate some of the sensory experience of the ICU environment.

Sleep monitoring techniques

Sleep-related research conducted amongst ICU patients clearly identifies significant sleep disturbances, which can have deleterious implications on their psychophysiological condition which protract recovery. Despite these findings, there remains no method that is feasible for widespread implementation that accurately monitors patients' sleep within the ICU environment. Although PSG provides considerable benefits over other strategies in being able to provide details of sleep physiology, it is not a strategy that is feasible to be implemented widely as it is expensive, labour intensive and technically difficult. In comparison, simple cost-effective methods involving clinical observations are questionable regarding their accuracy as studies have indicated that these result in an overestimation of sleep time and quality [17,65,100]. This was demonstrated by Nicolas and colleagues' [8] quantitative single blinded descriptive study, investigating nursing-based assessment and patient perception of sleep which found that these correlated only 50% of the time, with nursing staff overestimating patients' quality of sleep. Adjunct methods such as actigraphy (ACTG) have been considered, although studies involving the ICU are few and participant numbers are small. There are, however, some favourable attributes associated with ACTG use in comparison to PSG in that it is cost effective, is easy to interpret and is able to collect data over an extended period. The limitations of ACTG need to be acknowledged in that it will provide no information regarding the sleep architecture of patients and may be suitable only for a limited cohort of ICU patients. However, it may be potentially useful in monitoring circadian disturbance and sleep fragmentation, both of which are major issues associated with ICU patients. Potentially, further advancements in monitoring techniques and the development of advanced monitoring algorithms may provide clinicians with a viable method.

As a result there is a need to develop accurate and effective clinical monitoring methods of sleep, to facilitate the early recognition of sleep disturbance. Interventions need to be implemented that aim to provide an environment that supports sleep and recognises its role in patient recovery (Table 3). Additional research needs to be undertaken in order to understand the physiological impact of critical illness on patient sleep, the relationship between delirium and sleep disturbance, along with how

Table 3 Interventions to reduce sleep disturbance

Intervention	Example
Establish a nocturnal environment	By reducing volumes of alarms and phones.
Enhance staff awareness of noise produced by conversations	Soundear
Employ the use of night settings in monitoring equipment with backlighting to reduce exposure to light.	
Judicious use of pharmacological agents	
Monitor, assess and treat pain	
Devise individualised sleep hygiene routines	
Employ relaxation techniques in preparation for sleep	Music therapy and massage
Decrease environmental stimulus	Via the use of eye masks and ear plugs
Reduce nocturnal clinical interactions	Cluster clinical care and scheduling of procedures
Ventilator support to promote rest overnight	
Reduce daytime napping in order to reduce circadian dys-synchrony	
Promote daytime activity	Such as sitting out of bed and mobilisation

mechanical ventilation can be utilised to facilitate nocturnal rest, and identification of pharmacological agents and regimes that do not interfere with the intrinsic sleep cycle. Further, identifying strategies that can be readily implemented that endeavour to minimise the impact of complications associated with sleep deprivation. However, research investigating sleep promotion strategies have lacked clinical efficacy [17,92,100], as PSG is not viable for widespread implementation, behavioural assessments such as ACTG have not been able to accurately assess sleep in critically ill patients, and subjective assessments such as nursing-based observation frequently overestimate sleep. Adjunct interventions such as behaviour modification of staff through education have only been subjectively evaluated and their impact on the long term is not evaluated. Emerging benefit of eye masks and ear plugs may have some benefit in quashing the effect of the ICU environment on patients but do improve the sleep architecture of patients. Similarly, melatonin administration reports some promising benefits; however, larger studies are required. A primary issue confronting clinicians regarding sleep in ICU is the development of a method that allows for sleep monitoring to be implemented as a standard of clinical care, which provides accurate information regarding the sleep of this patient cohort.

Conclusions

Despite decades of research identifying the impact of the clinical environment on ICU patients' sleep, little

has been accomplished in overcoming the factors that are purported to contribute to sleep disturbance. There exists a multitude of factors that contribute to sleep disturbance that highlights the complexities faced when attempting to manage sleep disturbance and consequences of sleep deprivation on patient recovery. This is also inclusive of the intricate impact that severity of illness has on sleep which is yet to be fully elucidated. Clinicians involved in the provision of care to patients need to be attuned and aware of the consequences of sleep disturbance and how to make modifications to their environment and care planning in order to promote sleep and aid recovery. There exists a need to undertake further clinical research to identify effective strategies to curtail the impact of the clinical environment on patients' ability to sleep and to enhance understanding between the impact of sleep deprivation and patient outcomes. Further, future research should be directed at identifying an accurate and feasible sleep monitoring method to facilitate the ability to implement strategies that endeavour to promote sleep and recovery, whilst decreasing the associated complications linked to sleep deprivation.

Abbreviations

ACTG: actigraphy; BIS: bispectral index; COPD: chronic obstructive pulmonary disease; dB: decibels; HPA: hypothalamus-pituitary-adrenal axis; ICU: intensive care unit; IL: interleukins; Lux: unit of illuminance and luminous; MIP: maximal inspiratory pressure; N1: non-rapid eye movement stage 1 sleep; N2: non-rapid eye movement stage 2 sleep; N3: non-rapid eye movement stage 3 sleep; NK: natural killer cells; NREM: non-rapid eye movement; PSG: polysomnography; REM: rapid eye movement; SWS: slow wave sleep; TBI: traumatic brain injury; TNF: tumour necrosis factor; TST: total sleep time.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

LJD is responsible for the development of the manuscript and review of the cited literature. FvH contributed to editing and drafting of the manuscript, and writing of the final paper. VL contributed to the literature search, review of the draft manuscript and writing of the final paper. All authors declare that they have no competing interests.

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2.6 Linkage

Sleep supports important neurophysiology functions essential to maintain normal physiological functioning and overall wellbeing of individuals. The research reports the constellation of adverse physiological and psychological effects linked to sleep disturbance that may contribute to increased susceptibility to complications and prolonged ICU admission and hospital length of stay. Although the extent to which sleep disturbance contributes to these complications has not been fully understood, in part because of a lack of feasible sleep monitoring methods and broader recognition of its potential adverse health consequences, sleep disturbance is thought to be a contributor to the onset of delirium. Comparatively, the impact of delirium on patient outcome is better understood and is recognised as a significant prognostic indicator of patient outcomes.

While our understanding of sleep is not fully elucidated in terms of its prognostic impact, research into delirium has garnered considerable attention and increased awareness of the impact it has on patient morbidity and mortality. Although the relationship between sleep disturbance and delirium is not fully understood, research suggests there may be an ascribed shared mechanism, on the basis of neurobiological changes that occur because of both sleep disturbance and delirium. Sleep disturbance is frequently under-reported and poorly considered in the context of patient care, while comparatively delirium has established assessment approaches and is more frequently considered in the overall context of patient care. The following publication discusses the reciprocal relationship between sleep and delirium, and addresses the neurobiological characteristics presenting the impact of delirium on patient outcomes, along with clinical care considerations that may be implemented to reduce the impacts of sleep disturbance and delirium among patients.

2.7 ‘The Nexus Between Sleep Disturbance and Delirium Among Intensive Care Patients’

The following presents a review of the research regarding the relationship between sleep and delirium from a neurobiological position and their impact on patient outcomes, published June 2021 (<http://dx.doi.org/10.1016/j.cnc2021.01.001>), including text, tables and references.

The Nexus Between Sleep Disturbance and Delirium Among Intensive Care Patients



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KEYWORDS

• Delirium • Intensive care • Light • Noise • Sleep • Sleep disturbance

KEY POINTS

- Sleep disturbance and delirium have a variety of negative sequelae having an impact on patient outcomes, inclusive of physiologic and somatic effects. It is unclear, however, if sleep disturbance leads to delirium, or if delirium is the precipitating cause of sleep disturbance among intensive care patients.
- The bidirectional relationship between sleep disturbance and delirium may be attributed to their neurobiological effects, which have an impact on the function of the prefrontal cortex.
- Neurohormonal changes exhibited in sleep disturbance and delirium are identified to affect the dopaminergic systems, leading to alterations in acetylcholine levels, which are important for attention, motor activity, and memory.
- Nonpharmacologic interventions that have endeavored to address sleep disturbance may have a concurrent positive effect on reducing incidences and duration of delirium, because they seek to normalize the sleep-wake patterns through reduced exposure to light and noise disturbance.
- Effective clinical management for both sleep disturbance and delirium may require a combination of interventions to reduce the adverse effects of the clinical environment, whereby the regulation and normalization of sleep-wake patterns may exert important clinical effects in reducing incidences of delirium.

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INTRODUCTION

Intensive care units (ICUs) provide advanced clinical care to support critically ill patients. Inherently, the ICU environment subjects patients to an inordinate amount of clinical monitoring and a panoply of stimuli that frequently are reported to be disruptive and stressful to patients. The implications of this manifests as disturbance to sleep, with research demonstrating high degrees of sleep fragmentation and atypical sleep architecture (structural organization of sleep). Intensive care-based sleep research indicates that 50% of patients report sleep disturbance, with 30% experiencing persistent sleep disturbance post-ICU discharge.¹

Sleep disturbance has been linked to a variety of negative sequelae, including decreased respiratory function, altered cardiovascular responses, impaired immunologic function, increased pain and anxiety, and decreased overall patient outcomes.¹⁻³ Factors linked to sleep disturbance within ICUs are diverse and primarily center around the environmental burden and soundscape that patients are subjected to. Research attempting to address these factors has reported varied outcomes, with few studies reporting a sustained benefit in the regulation of the environmental burden and, in turn, enhanced sleep quality.⁴⁻⁶

Emerging from current intensive care research is the impact delirium has on patient recovery, with research aimed at improving sleep quality exhibiting positive effects in reducing the incidence and duration of delirium. These findings suggest that there may exist a bidirectional relationship between sleep disturbance and delirium,^{7,8} premised on the alterations identified in cognitive function and the positive effects reported in the regulation of sleep-wake patterns.^{7,8}

Delirium is reported to complicate 25% of hospital admissions, with incidences as high as 50% among surgical patients, and is disproportionately prevalent among patients cared for in ICUs (20% to 87%).⁹⁻¹² The sequelae of delirium is prognostically significant and includes protracted hospital length of stay (up to 10 days) and long-term disability related to activities of daily living.^{13,14} Although delirium is considered an acute condition, cognitive function may not be recovered fully, with research indicating that up to 52% of patients do not return to baseline cognitive function,¹⁵ and as many as 25% have impairments comparable to mild Alzheimer disease.^{13,16} Delirium in ICU also has been associated with long-term symptoms of posttraumatic stress disorder.^{17,18} Reported risk survival analysis suggests delirium does not increase short-term mortality^{19,20}; however, the presence of delirium may have an adverse impact on long-term outcomes in which mortality rates appear to be increased. A cohort study conducted by Pisani and colleagues²¹ investigating the long-term effects of delirium reported a reduction in 1-year survival by approximately 10% per day of delirium, after adjustment for covariates, such as age, severity of illness, medication, and comorbidities. Both sleep disturbance and delirium are contemporary and challenging issues encountered within the ICU setting that adversely affect patient outcomes. This clinical review analyzes the shared characteristics between sleep disturbance and delirium, addressing pathophysiology, clinical characteristics, and interventions, whereby strategies to address sleep disturbance may exert a beneficial effect on reducing delirium.

SLEEP DISTURBANCE IN INTENSIVE CARE

Sleep is a complex and dynamic state that is essential for survival. Sleep disturbance among ICU patients is prevalent and considered a contributing factor to the development of delirium. Polysomnography studies involving ICU patients consistently identify the presence of abnormal sleep architecture and atypical electroencephalographic activity, characterized by a predominance of wakefulness and light stages of sleep

(stages N1 and N2) (Fig. 1). In contrast, the critical restorative stages of sleep; slow wave sleep (SWS) and rapid eye movement (REM) sleep, which are important for mental well-being and physiologic health, are reported to be severely restricted and at times absent.^{8,22–25} The acquired total sleep time reported among ICU patients is variable, ranging between 2.1 hours and 8.8 hours, and is highly fragmented, traversing day and night, with circadian dysrhythmia an elevated risk.^{22–25} In older adults (aged >60 years), sleep duration normally is reduced and becomes more fragmented, with increased duration of stage N1 (transition stage from wake to sleep) and stage N2 (light sleep) and an accompanying reduction in SWS and REM sleep. These physiologic changes to sleep architecture increase with age and are important to consider in the context of an ICU admission and, in turn, heighten the susceptibility for sleep fragmentation and may exacerbate the propensity to develop delirium. The impact of the interaction between sleep disturbance and delirium remains unclear, although they appear to share similar physiologic features. Fitzgerald and colleagues²⁶ suggest that significant sleep disturbance is attributed to active delirium, with studies identifying sleep disturbance being a characteristic present in 73% to 99% of patients with delirium.^{27,28} The ability to monitor sleep in the ICU remains clinically challenging due to limited feasible options and the gold standard of sleep monitoring, polysomnography, being costly, highly technical, and impractical for widespread implementation. Staff-based observations, although easily implemented,

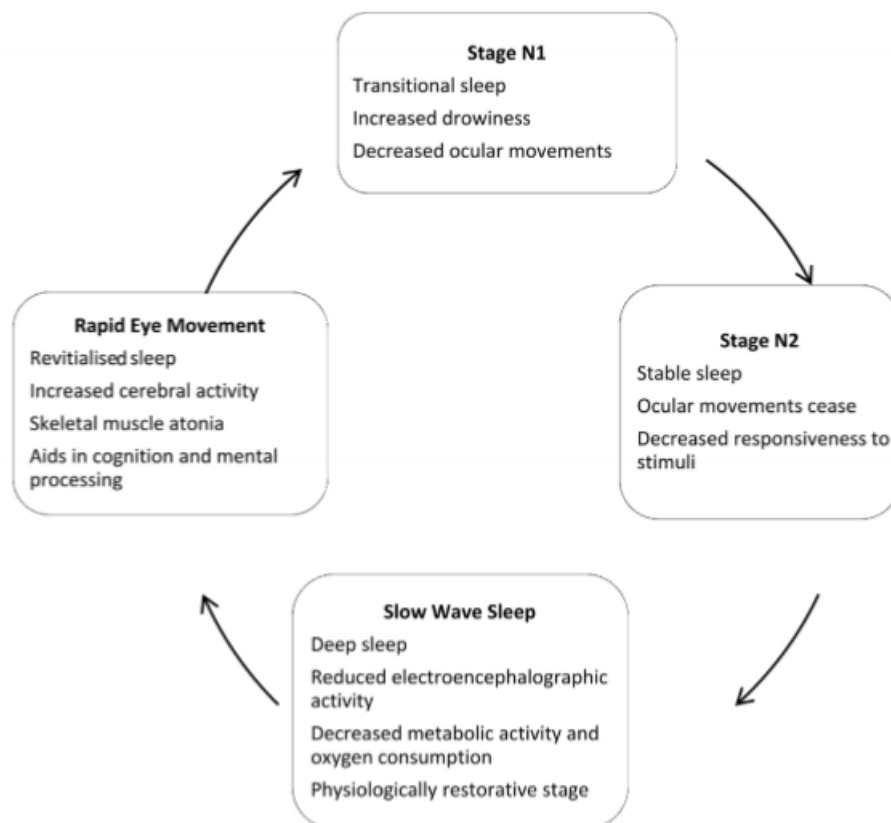


Fig. 1. Physiologic characteristics of the sleep cycle.

nonintrusive, and cost-effective, are deemed subjective and inaccurate to inform clinical decision making, with research indicating that staff overestimate the duration of sleep and are unable to effectively report the extent of sleep fragmentation.^{2,29}

DELIRIUM IN INTENSIVE CARE

A diagnosis of delirium presents as a clinical challenge due to its variable clinical presentation and manifestation of symptoms. According to the *Diagnostic and Statistical Manual of Mental Disorders* (Fifth Edition),³⁰ delirium is characterized by an acute onset of impaired awareness and attention, which can be accompanied by disturbance in cognition and exhibits a fluctuating course (hours to days). Three phenotypes of delirium—hypoactive, hyperactive, and mixed delirium—have been reported, with hyperactive states easily identified due to their symptoms.³¹ In contrast, hypoactive and mixed delirium are more challenging to identify and, without defined assessments, can go unrecognized or misdiagnosed. The Confusion Assessment Method (CAM)–ICU or the Intensive Care Delirium Screening Checklist (ICDSC) commonly are used within ICUs to assess for the presence of delirium. The psychometric properties of the ICDSC report a high level of sensitivity (99%), with a lower specificity of 64%, which may result in the misclassification of conditions leading to a misdiagnosis of delirium.³² In contrast, the CAM-ICU has been validated within a larger ICU population, is less subjective than the ICDSC, and allows for rapid assessment (approximately 2 minutes to complete) evaluating 4 domains: acute onset of changes in mental status, inattention, disorganized thinking, and altered level of consciousness.³³ Confounding accurate assessment of delirium is the administration of sedation commonly used within ICU, whereby the accuracy of delirium assessments using either the CAM-ICU or the ICDSC are influenced by the reported Richmond and Agitation-Sedation Scale.³⁴ Similarly, the administration of analgesia and sedation has an impact on sleep architecture through restricting SWS and REM sleep and impedes the ability to accurately assess sleep because electroencephalographic activity is suppressed and behaviorally sedation mimics sleep.

The etiology of delirium is thought to be multifactorial, with predisposition and concurrent exposure to deliriogenic factors thought to be causal components, although these have not been fully elucidated.³⁵ Predictors for the development of delirium in the ICU setting, however, reported in the Prediction Model For Delirium in ICU Patients (PRE-DELIRIC) and the revised Early PRE-DELIRIC, inclusive of age, biochemistry (urea and metabolic acidosis), admission category, urgency of admission, history of alcohol abuse, underlying cognitive impairment, mean arterial blood pressure, pharmacologic agents (corticosteroids, morphine, and sedative administration), and respiratory failure at the time of or within 24 hours of ICU admission, have been shown accurate predictive assessments.³⁶ The implementation of this assessment may allow clinicians to identify patients who have the greatest susceptibility to developing delirium, allowing for targeted and individualized interventions, which concurrently may reduce delirium onset and sleep disturbance and promote a more normalized circadian pattern.

NEUROBIOLOGICAL FEATURES OF SLEEP DISTURBANCE AND DELIRIUM

The adverse effects outwardly manifested secondary to the shared characteristics exhibited by both sleep disturbance and delirium suggest the 2 may not be mutually exclusive, whereby sleep disturbance produces clinical manifestations aligned to hypoactive delirium. The sleep disturbance experienced by ICU patients is characterized by restricted SWS and REM sleep, inducing a sleep debt with a concomitant

increase in sleep pressure. This produces clinical manifestations of daytime somnolence, impaired cognition (memory and attention), altered mood, and circadian dys-synchrony, which reflect the salient features of delirium.³⁷ The neurocognitive dysfunctions demonstrated in sleep disturbance and delirium share similar recovery timelines, in which compromised psychomotor vigilance associated with sleep disturbance can be reversed with 3 nights to 5 nights of unrestricted sleep.³⁸ This recovery timeframe to restore neurobehavioral function is reflective of that reported in delirium.³⁸

Neurobiological research has identified shared neurohormonal effects of delirium and sleep disturbance on the brain. Delirium exerts its effects on the cerebral cortex and brainstem affecting the prefrontal cortex, parietal lobes, and basal ganglia, which are important for attention and working memory.³⁷ Sleep deprivation produces altered electroencephalographic activity indicative of suboptimal prefrontal cortical functioning.^{39,40} The neurobiological effects exerted as a result of sleep disturbance impede cerebral glucose metabolic rate in the parietal cortex and thalamus, which has an adverse impact on the modulation of alertness and cognitive performance.^{39,41}

The neurohormonal changes exhibited in both sleep disturbance and delirium are suggested as secondary to alterations in the dopaminergic systems, primarily related to a reduction in acetylcholine levels.⁴² The neurochemical factors contributing to delirium are putatively an impairment in cerebral oxidative metabolism attributed to a decrease in cholinergic neurotransmitters and a concurrent increase in dopaminergic activity.⁴³ Acetylcholine plays a significant role in the interaction with dopamine, which is deemed important for attention, motor activity, and memory.^{43,44} Research suggests that acetylcholine levels are reduced in REM sleep deprivation, whereas K-complexes are reduced in SWS and are considered important sleep characteristics, which aid in the consolidation of memory.⁴⁵ The dopaminergic dysregulation present in delirium is inadvertently regulated by the administration of antipsychotics, which inhibits dopamine release and balances the dopamine and cholinergic responses.²⁶ These medications appear to have limited beneficial effect on sleep architecture, however, through increasing stage N2 sleep and minimal effect on increasing restorative sleep phases (SWS and REM sleep).⁴⁶

The suppression of the neurohormone melatonin is attributed to both the pathogenesis of delirium and sleep disturbance. The risk factors associated with the onset of delirium, such as underlying dementia, age, and medications, are linked to altered pleiotropic melatonergic functions (Fig. 2).²⁶ Melatonin plays a critical role in the regulation of circadian rhythms, sleep, mood, immune response, and aging.^{47,48} The role of melatonin and its pharmacologic potential is of particular interest within intensive care due to its role in sleep and the reported suppression of melatonin levels in critically ill patients.^{49,50} Shigeta and colleagues⁵¹ identified abnormal melatonin secretion was present among patients who developed postoperative delirium, suggesting that postoperative alterations resulting in the disturbance of the sleep-wake patterns may precipitate the onset of delirium. The administration of supplemental melatonin is being explored and prefaced as an intervention to address primarily sleep and circadian disturbance; concomitantly, it also may play an important role in decreasing the incidence of delirium via a negative feedback system, which reduces serotonin and tryptophan catabolism.⁵²

THE EFFECTS OF ANALGESIA AND SEDATION ON SLEEP AND DELIRIUM

The administration of sedation and analgesia is an integral component to patient care within the ICU, although a paradigm shift has occurred with regard to the quantities

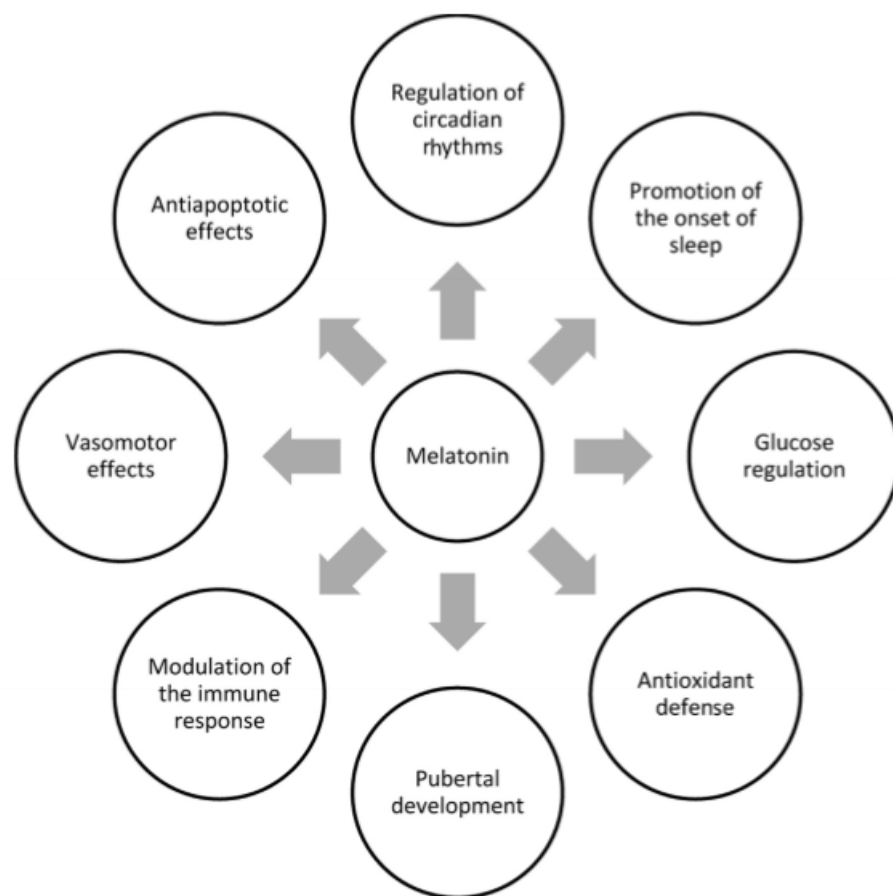


Fig. 2. The pleiotropic role of melatonin.

and types of pharmacologic agents used in order to reduce adverse effects linked to their administration: increased risk of infection, pressure injuries, enteral nutrition intolerance, mechanical ventilation, and ICU length of stay.⁵³ Sedation has established effects on the sleep architecture and development of delirium through the suppression of SWS and REM sleep due to the inhibition of γ -aminobutyric acid (GABA) and Mu-opioid receptors (**Fig. 3**).⁵⁴ GABA and Mu-opioid receptor agonists readily cross the blood-brain barrier, exerting an anticholinergic effect, and are associated with the development of delirium.^{55,56} Research suggests that the administration of GABA agonists, such as propofol and benzodiazepines, is increased during the night (23:00 hours–07:00 hours) among patients receiving mechanical ventilation⁵⁷ and further impedes the excretion of melatonin.^{58–60} Zaal and colleagues⁶¹ attributed the administration of benzodiazepines to an increased risk and causal factor for delirium among intensive care patients. The increased use of sedative medications overnight indicates a potential misalignment between sedation assessment and perceived patient needs, knowledge deficits, and erroneous beliefs that the use of sedation promotes patient sleep. Rather, increased administration of benzodiazepines restricts REM sleep and may compromise cerebral blood flow.^{57,62–64} As a result, there is a call for a more

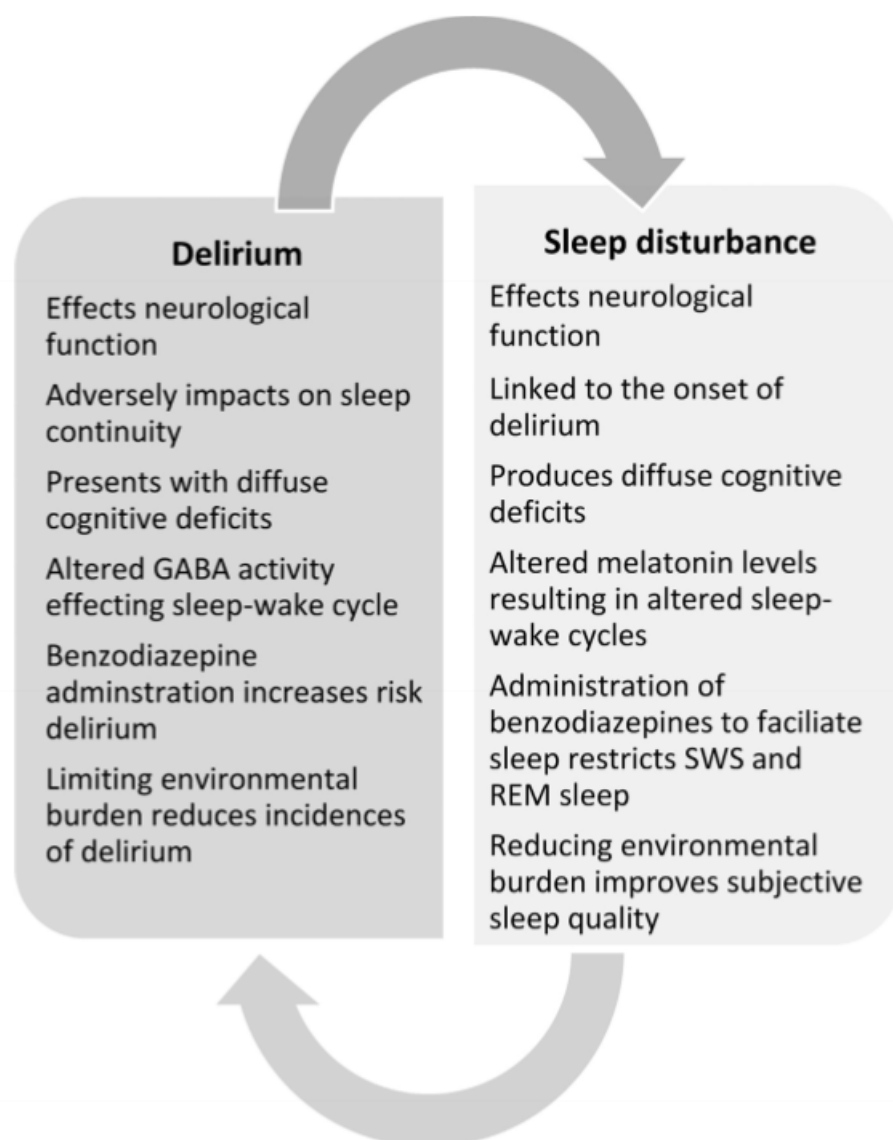


Fig. 3. Bidirectional relationship between delirium and sleep disturbance.

judicious approach to the selection and administration of sedatives prescribed to intensive care patients, with a greater emphasis on targeted and monitored sedation scores.

In an effort to reduce daily administration amounts of sedatives, identification of alternative medication choices, such as α_2 -adrenergic agonists (eg, dexmedetomidine), increasingly are considered. Dexmedetomidine, which exerts several functions, inclusive of sedation, analgesia, and sympatholytic effects, has emerged as a potential option that minimises disruption to normal sleep architecture.^{57,65} Comparably, dexmedetomidine has demonstrated favorable effects in the treatment of delirium.

Findings of the Dexmedetomidine to Lessen ICU Agitation study suggests that dexmedetomidine, compared with a placebo or standard care, reduced mechanical ventilation time and time to extubation and resulted in a reduction in the duration of delirium.⁶⁶ Dexmedetomidine may exert a beneficial effect on sleep architecture, with research involving healthy participants indicating an increase in SWS, and did not adversely affect psychomotor vigilance.⁶⁷ Intensive care-based studies investigating dexmedetomidine's ability to improve sleep report an increase in the percentage of stage N2 sleep, improved sleep efficiency and subjective sleep quality, and a reduction in the percentage of stage N1 sleep.⁶⁸ The emergence of such findings proffers dexmedetomidine as a viable sedative option that may aid in reducing the need and administration of benzodiazepines. Restricting the administration of benzodiazepines would have a concurrent beneficial impact on sleep architecture, because they impede SWS and REM sleep, produce an increase in stage N2 sleep, increase daytime somnolence, and have an adverse impact on psychomotor vigilance.^{67,69} Paradoxically, benzodiazepine administration may contribute to insomnia, hallucinations, and increased agitation.⁷⁰ The effect of dexmedetomidine on sleep quality appears to yield a favorable effect on normalizing sleep-wake patterns and increases sleep efficiency but does not rectify the abnormal sleep architecture reported among ICU patients,^{65,71,72} highlighting the intricacies related to pharmacologic agents' impact on both sleep and delirium and how addressing one of these issues may inadvertently influence the other.

NONPHARMACOLOGIC INTERVENTIONS

Reducing Environmental Burden

Light

The intensive care setting imposes an environmental constancy throughout the 24-hour period, which is not conducive to quietude and obscures the distinction between day and night. Research endeavoring to address the issues of environmental burden to improve sleep concurrently has reported reductions in the incidence and duration of delirium within the intensive care setting. As a result, these nonpharmacologic interventions have formed a basis for specific and bundled interventions in an attempt to improve sleep within the ICU (Fig. 4).

Light exposure has a significant impact on circadian patterns secondary to the human eyes' photosensitive retinal ganglion cells, which communicate with the suprachiasmatic nucleus and act as the circadian pacemaker.⁷³ The ICU environment obfuscates this zeitgeber (external cue to entrain biological rhythms) secondary to the prolonged exposure to artificial lighting. The luminance levels within the ICU are reported to range between 5 lux and 1400 lux, whereby low luminance levels (<500 lux) for 20 minutes can result in a suppression of melatonin levels.^{74,75}

Research attempting to address the issues attributed to restricted exposure to natural light levels suggest that use of bright light therapy (>1500 lux) may have a beneficial effect in reducing the need for pharmacologic intervention,^{76–78} and incidences of delirium among postoperative patients.^{79,80} Potharajoen and colleagues⁷⁸ identified that the combination of bright light exposure in conjunction with oxygen therapy may provide a preventative effect for delirium, secondary to maintaining sleep-wake cycles and stabilizing bicarbonate levels. Understanding the impact of clinical design appears to be an important consideration when attempting to address both sleep disturbance and delirium, whereby the absence of visible daylight is reported to increase the risk of developing delirium (odds ratio 2.39),⁸¹ compared with single-room access and enhanced daylight exposure, which are reported to reduce the

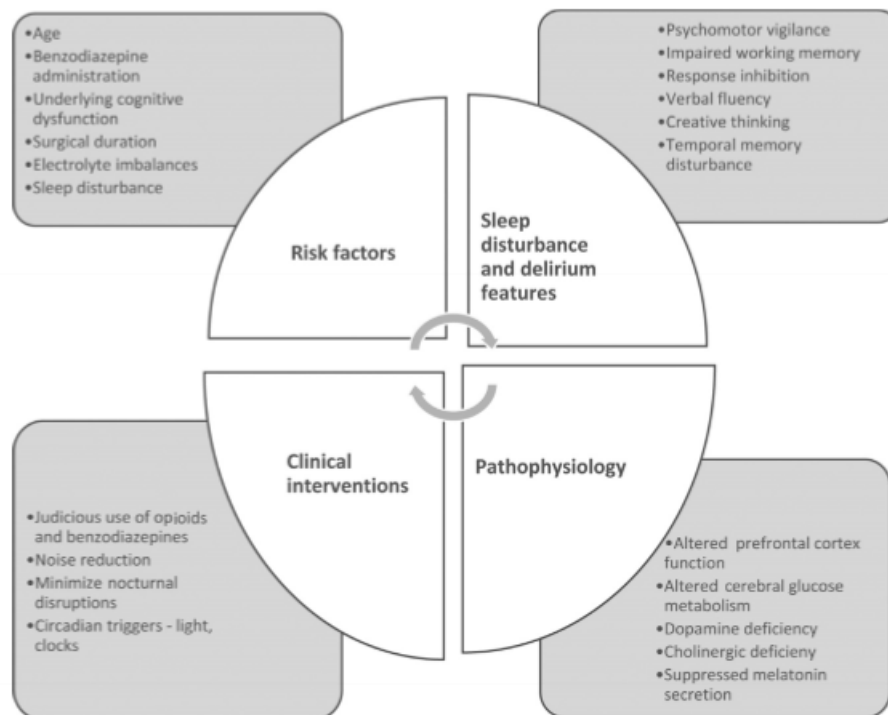


Fig. 4. The comparative clinical characteristics and findings shared between delirium and sleep disturbance.

duration of delirium and concurrently improved sleep quality.⁸⁰ As a result, consideration to chronobiological clinical design features may contribute to improve sleep-wake cycles, while providing a more normalized day-night environment, leading to a reduction in incidences and duration of delirium and sleep disturbance.

Chronobiological research undertaken in the ICU to improve sleep quality largely has focused on addressing the impact of the clinical environment, primarily light and noise exposure; however, reported findings largely have been subjective and have not translated into long-term improvements within the ICU. The adjunct findings in many of these studies is the impact that amendments to the environment have on the incidence and duration of delirium, which reiterates the contention of a bidirectional relationship between sleep and delirium.

Noise

The soundscape of the ICU environment is diverse and highly variable, with noise intensity significantly higher than recommended by the World Health Organization.⁸² The complexity of the clinical environment and the accompanying intensive monitoring and their associated alarms are the primary contributors to the adverse soundscape. Noise has been identified as a factor that frequently is attributed to sleep disturbance in the ICU setting, with research indicating that noise reduction improved patients perceived sleep quality. Biophysiologic research of sleep and patient responsiveness to nocturnal acoustical variations, however, indicates that sleep may not be disrupted primarily by noise events, with previous studies employing polysomnography indicating that noise levels were only able to be attributed to 11% to 25% of sleep arousals.^{22,24}

This suggests that there may be additional contributing factors, such as clinical interactions, neurohormonal changes, and altered physiologic responses to critical illness, that lead to sleep disturbance and, in turn, may precipitate the onset of delirium.

Noise reduction studies have focused on behavior and environmental modifications and sound masking. Behavioral modifications, such as adjusting alarm volumes for a nocturnal environment, making staff more cognizant of conversations and volume of speech occurring in proximity of patients, closing patient doors, and implementing noise-absorbing furnishings, have reported subjective reductions in perceived noise and improved patients' reported sleep quality.⁸³ The ability to sustain the implemented practices remains untested, however, with physiologic measures of sound and sleep being limited. The use of sound-masking strategies, such as earplugs, has been reported to have beneficial effects on sleep quality, along with reducing confusion and onset of delirium.⁸⁴ Van Rompaey and colleagues⁸⁴ demonstrated a risk reduction in the development of delirium by 53% (hazard ratio 0.47; 95% CI, 0.27–0.82), combined with a concurrent improvement in subjective sleep quality ($P = .042$). Findings such as these have been reiterated by Le Guen and colleagues,⁸⁵ who reported an improvement in sleep quality assessed via the Spiegel scale, with a reduction in disorientation with the concurrent implementation of earplugs and eye masks in postoperative patients ($P = .01$). Furthermore, quality improvement initiatives, such as those by Kamdar and colleagues,⁵ also have highlighted the potential positive effect of mitigating noise exposure via the use of earplugs and background music to improve sleep, which resulted in a reduction in subjective noise ratings ($P = .001$) and incidence of delirium ($P = .02$).⁵ In a meta-analysis conducted by Litton and colleagues,⁸⁶ the implementation of earplugs significantly reduced risk of delirium (risk reduction 0.59; 95% CI, 0.44–0.78), and beneficially the intervention was minimally invasive and cost-effective to implement. Despite these findings, the widespread use and implementation of earplugs and ear masks remain largely unadopted, due to a lack of recognized benefit in their implementation among patients requiring sedation and mechanical ventilation. Concerns regarding the additional sensory deprivation that eye masks and earplugs provide and their impact on patient autonomy, particularly when cognitive disturbances are present, may be confounding factors for both staff and patients relating to their wider adoption as a component of care.⁸⁷

Understanding the impact of noise abatement interventions can be challenging due to the variable approaches used to assess and quantify noise and its impact, because many studies do not employ environmental noise monitoring or polysomnography to monitor sleep; rather, they evaluate noise levels and sleep quality via subjective assessments. Noise abatement strategies, such as earplugs, appear to have a variable effect on sleep quality and quantity; rather, they may provide beneficial clinical effects in reducing anxiety and administration of sedatives,^{88,89} both of which can negatively affect sleep via reducing restorative sleep phases (SWS and REM sleep), whereby impaired sleep quality may precipitate the onset of delirium. These suggest that potentially clinicians need to be more attuned to the environmental burden and soundscape of the ICU in relation to its impact on patients. The ability to sustain the positive effect of noise reduction strategies frequently has been challenged, however, because behavioral and cultural practice changes in the ICU require a prolonged and focused approach in order for these to be adopted as normalized practice. In addition, the design of the ICU has an effect on behavior in terms of noise reverberations, and how staff interact within the space, such as locations of nursing stations, utility rooms, workflow, and shared patient care spaces, are factors that may limit the effect and success of noise abatement interventions.

Bundle interventions

The Society of Critical Care Medicine Clinical Practice Guidelines for the Prevention and Management of Pain, Agitation/Sedation, Delirium, Immobility, and Sleep Disruption in Adult Patients in the ICU⁹⁰ advocate for a multicomponent approach to sleep, because studies indicate a multifaceted approach aids in reducing delirium incidences and concurrently promotes sleep.^{90,91} Approaches, such as quiet time interventions, offer patients a potential reprieve from the constant nature of the ICU environment, quiet time interventions are defined as spans of time in which clinical interactions are purposely reduced along with noise and light levels to promote periods of rest. Although the time of day to schedule quiet times is debated, there is a growing body of research that suggests that they have a positive effect on sleep quality,^{92,93} with Olson and colleagues⁹² reporting an increase in observed sleep behavior 1.6 times greater than in those receiving standard care. Van de Pol and colleagues⁹⁴ found sleep to be unaffected by the implementation of a quiet time intervention, although the need for sleep-inducing medication was significantly reduced ($P < .001$). The intervention was found to facilitate a decrease in noise levels ($P = .02$), with a reduced need for pharmacologic intervention proposed as a contributing factor in the concurrent reduction in delirium ($P = .02$). Intuitively, approaches aimed at ameliorating the clinical environment appear to offer some benefit to patients and establish a more patient-centered approach in which sleep may be more likely to be acquired. This, in combination with less physiologic stress related to the soundscape and intensity of the clinical care, may have a synergistic effect in reducing the need for pharmacologic intervention and its impact on sleep architecture and, in turn, reduces the susceptibility to delirium. The contribution of each of the components that comprise a bundled intervention, however, has not been explored sufficiently, resulting in variances in interventions coined quiet time intervention. The intention of quiet time interventions also is susceptible to being derailed and becoming a time where clinical staff can address care needs and interventions that they may not have had the opportunity to undertake at alternate times, inadvertently making the designated period more aligned to staff and workflow needs rather than a patient-centered intervention. The physiologic benefit of quiet time interventions may be debated in that few studies implement the gold standard for sleep monitoring, polysomnography, to ascertain the biophysiologic effect such interventions have on sleep architecture, opting for subjective assessment or proxy measures of sleep quality.

In a randomized controlled study, Boyko and colleagues,⁹³ sought to identify if improvements in the ICU clinical environment, yielded through a quiet time protocol, inclusive of restricted visitation, limiting diagnostic procedures and treatments conducted between 22:00 hours to 06:00 hours, and reduced alarm volumes and luminance exposure, in combination with the implementation of eye masks and earplugs, resulted in increased sleep quality assessed via polysomnography. The study demonstrated a reduction in environmental noise, albeit not a statistically significant reduction ($P = .3$), and no evidence that quiet time improved sleep among mechanically ventilated patients ($P = .7$).⁹³ The findings of the study are limited due to its low recruitment numbers ($n = 17$) and the limited number of polysomnography (53%; $n = 9$) studies that exhibited physiologic characteristics of normal sleep, highlighting the complexity of monitoring and interpreting sleep within the ICU patient population, who frequently exhibit pathologic encephalographic activity. As a result, the impact and contribution of intrinsic factors, such as inflammatory mediators and neurobiological changes in response to critical illness, combined with pain and effects of commonly infused pharmacologic agents to provide sedation and analgesia cannot be discounted for sleep disturbance and as causal factors for delirium. This in part

may account for the positive effects that are yielded by studies administering supplemental melatonin due to its pleiotropic effects.

As a result, the effect of quiet time interventions remains inconclusive and appears to have some beneficial impact in reducing environmental burden but not definitively in promoting sleep. Rather, it may provide a rest period that provides patients with a reduction in stimulus and the need for medication to limit patient responsiveness to their clinical environment. Interventions that address several considerations that have an adverse impact on sleep appear to be more successful in improving subjective sleep quality and in turn may have beneficial impact on delirium, rather than single isolated interventions. This approach integrates various interventions, such as curbing noise exposure through behavior modification and use of earplugs and eye masks to limit intrusive light during the nocturnal phase, earlier mobilization and activity during the day, clustered care, and pharmacologic review. Implementing a multidisciplinary bundle, Patel and colleagues⁹⁴ demonstrated an increase in sleep efficiency ($P = .031$) and a concomitant reduction in noise levels ($P = .002$), reduction luminance ($P = .003$), and reduction in delirium ($P < .001$). A bundled approach primarily targets factors attributed to sleep disturbance, although these may not translate to improved biophysiologic characterization of sleep. There do appear to be some favorable benefits in terms of reduced environmental burden and potentially incidence and duration of delirium. As a result, the relationship between sleep and delirium requires further research and clinical evaluation to ascertain the impact of interventions.

SUMMARY

Sleep disturbance remains a complex issue in the ICU and may have an important link to the onset and duration of delirium and vice versa. The concurrent neurophysiologic effects demonstrate considerable similarities, exerting effects on the cortex and brainstem. Alterations in the secretion of neurotransmitters and hormonal regulation that are critical in maintaining normal circadian patterns appear present in both delirium and sleep disturbance, potentially exacerbated by the administration of pharmacologic agents commonly prescribed in the ICU setting. The ability to distinguish between the primary effects of sleep disturbance and delirium remains unclear; however, as research evolves, there appears to be a consolidation of the ideas that sleep disturbance may be a causative factor for delirium. Understanding these effects is critical, because delirium has been demonstrated to increase morbidity, mortality, and length of ICU stay. As a result, monitoring sleep and sleep promotion need to be integrated as standard components of clinical care for intensive care patients.

CLINICAL CARE POINTS

- Judicious administration of GABA and mu-opioid receptor agonists is needed because these have an adverse impact on sleep architecture, sleep-wake cycles, and psychomotor vigilance. Limiting the administration of benzodiazepines in preference for dexmedetomidine may have a beneficial effect on normalizing sleep patterns, improving sleep quality, and reducing incidences of delirium.
- A multifaceted clinical approach aimed at normalizing wake-sleep cycles is beneficial in regulating circadian patterns and reducing adverse effects related to sleep disturbance and delirium.
- Being cognizant of the environmental burden imposed by an intensive care admission is necessary to recognize and respond to the stimuli that may impede sleep and contribute to the development of delirium.

- Nonpharmacologic interventions, such as bundled interventions and quiet time approaches, may be preferable in the management of delirium, because the use of antipsychotics fails to support a normal sleep architecture and SWS and REM sleep.

DISCLOSURE

The authors have nothing to disclose.

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2.8 Chapter Summary and Linkage

Sleep is fundamental to survival and the maintenance of physiological homeostasis. Research reports a constellation of adverse physiological and psychological effects linked to sleep disturbance that may unwittingly contribute to patients' increased susceptibility to complications and contribute to a prolonged ICU and hospital length of stay. The research suggests that the sleep disturbance experienced by ICU patients is profound and needs to be addressed to optimise patient recovery and rehabilitation from critical illness.

Data obtained from the Australian New Zealand Intensive Care Society (ANZICS) Centre for Outcome and Resource Evaluation (CORE) report (2020) indicates that 95% of patients admitted to the ICU survive and are in turn discharged to clinical wards and rehabilitation units for ongoing care. The demand for rehabilitation services from ICU has increased threefold in recent years. This highlights the need to increase awareness of clinical care components related to patients' ongoing recovery and overall quality of life. Sleep is viewed as one of the three pillars of health, alongside diet and exercise (Vitale et al., 2019), and forms a central component in patient recovery. As a result, greater attention to its status is required within the ICU context. A primary barrier to understanding the impact and level of sleep disturbance experience by this patient population is the lack of feasible methods available for monitoring sleep. In current practice, sleep assessments are infrequently performed, and when undertaken, they are via informal methods such as ad hoc nursing observations and documentation. This, in part, is likely to be attributed to the lack of methods available to clinicians to accurately monitor and assess sleep. The challenges encountered with sleep monitoring within the ICU are addressed in the following chapter (Chapter 3).

Chapter 3: Sleep Monitoring in Intensive Care

3.1 Introduction and Linkage

Sleep's important contribution to an individual's recovery needs to be clinically recognised and acknowledged. In turn, devising methods that permit the early recognition of potential sleep dysfunction are essential to support timely interventions, evaluate their impact objectively with the view to expediting recovery, and minimise complications associated with sleep deprivation. However, the capacity to achieve these objectives has been hampered by the limited ability to accurately monitor sleep within the ICU environment as monitoring devices such as PSG are unable to be widely implemented because of their technical requirements (Beecroft et al., 2008; Cooper et al., 2000; Freedman et al., 2001; Gabor et al., 2003). In addition, observations made by staff are widely considered inaccurate (Aurell & Elmqvist, 1985; Beecroft et al., 2008; Weinhouse & Schwab, 2006). The evolution of wearable technologies has brought emerging surrogate measures of sleep, such as actigraphy (ACTG) based on motion accelerometer monitoring, and may provide clinicians with a feasible sleep monitoring technique. ACTG, in the context of sleep medicine, is employed as a diagnostic tool that has been validated in a variety of clinical settings (Kushida et al., 2001; Sadeh et al., 1995); however, the accuracy of this device has not been determined in the context of the ICU.

3.2 'Sleep Monitoring Techniques in Intensive Care'

The following presents a review of the research regarding the physiological and psychological implications of sleep disturbance among intensive care patients, published 5 February 2015 (<http://dx.doi.org/10.15344/2394-4978/2015/114>), including text, tables and references, and excluding the title page.



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Sleep Monitoring Techniques within Intensive Care

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Abstract

Sleep is an essential biological function that provides important restorative psycho-physiological processes. Patients in the Intensive Care Unit are highly vulnerable to sleep disturbance which can protract their recovery. Despite sleep disturbance being widely acknowledged amongst this patient cohort, the ability to make significant changes to minimise the burden of sleep deprivation remains a challenge. This is further compounded by the difficulties faced by clinicians to identify and implement accurate and feasible sleep monitoring techniques in the intensive care. Whilst objective, behavioural and subjective methods of sleep assessment exist, all have specific limitations when applied to critically ill patients. In an attempt to illuminate these issues, current sleep monitoring techniques are appraised.

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Introduction

Sleep is considered to be an essential biological function required by all species. In humans, sleep was originally hypothesised to have been an adaptive process in promoting survival and avoiding predation [1]. More contemporary perspectives on sleep focus on its importance in regards to physical restoration and mental functioning [2]. Although total sleep function is yet to be fully elucidated, physiological quiescence provides important restorative processes to aid cognitive functioning [3-5], along with metabolic conservation [6-8] and produces an anabolic state [9]. Over the past three decades, there has been an inordinate amount of published research regarding sleep disturbance in highly vulnerable patients, such as those cared for in the Intensive Care (ICU) setting. Although the etiological causes of sleep disturbance are thought to be multi-factorial and the impact of sleep disturbance on patient recovery is widely recognised, sleep monitoring has not been implemented as standard component of clinical care. This has been attributed to the complexities confronting clinicians in identifying a method that is both accurate and feasible for widespread implementation.

Sleep Physiology of Intensive Care patients

Sleep consists of cyclic stages moving between non-rapid eye movement sleep (nREM) and rapid eye movement (REM) sleep, occurring over a duration of 90 minutes which is repeated 5-6 times per night. The physiology of sleep commences with stage N1 and is characterised by the subjective feeling of drowsiness combined with decreased ocular movements [10-11], this is followed by stage N2 (light sleep) which is the predominant sleep state of the nREM phase. During this stage the individual is decreasingly unresponsive to stimuli and ocular movements cease. The final stage of nREM sleep is referred to as N3 or Slow Wave Sleep (SWS), which is characterised by slow wave electroencephalographic (EEG) activity and has the important attributes of being anabolic and physiologically restorative [12].

In contrast, REM sleep is an active stage with a high degree of cerebral and physiological activity [13]. In this phase, heart rate increases along with the brain's metabolic rate to reflect that of a wakeful state, whilst muscle tone and thermoregulation are suppressed

[14-15]. Dreaming predominantly occurs during this phase and is purported to be an important process for mental restoration and emotional healing [16-18].

Polysomnography (PSG) studies reporting the sleep architecture of ICU patients reveal that whilst the total sleep time acquired is relatively normal (6-8 hours) [19-21]; it is often non-consolidated and highly fragmented [22-23]. Research indicates that ICU patients sleep traverses both day and night contributing to circadian disturbances [24-25]. These features lead to qualitative sleep deprivation which is bio-physiologically represented by the predominance of sleep stages N1 and N2, with little to absent SWS and REM sleep [19,24,26-28]. Previous subjective [20,29-32] studies report high rates of nocturnal clinical interactions with patients within the ICU which has been surmised as providing an environment in which quality sleep is unlikely to be achieved. Objective studies support such assertions, for example Kim et al [33] reported that sleep disturbances amongst an ICU patient cohort occurred at a rate of 14.7 ± 12 /hour over a 24 hour monitoring period, whilst Tamburri et al [30] reported a mean number of nocturnal interactions of 42.6 ± 11.3 /night with patient acuity being a significant factor for increased interaction ($r=0.32$, $p<0.05$). The impact of this on sleep was further quantified by Elliot et al [28] who conducted a 24 hour PSG study on ICU patients and reported that the median sleep time was 5 hours, with sleep disturbances occurring 3 minutes.

Survivors of critical illness report inability to sleep as a major stressor associated with their admission and this is supported consistently by biophysiological reports. Both Rotondi et al. [34] and Orwelius and colleagues [35] reported that 38% of patients experienced difficulty falling asleep, and expressed a greater need for sleep during acute

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illness. The inability to acquire restorative sleep (SWS and REM sleep) can exacerbate daytime somnolence resulting in daytime napping, and ultimately dys-synchronisation of the sleep wake patterns contributing to a phase shifting of the circadian rhythm.

The consequences of sleep disturbance on patient recovery are not benign. It has been attributed to a number of deleterious physiological and cognitive effects that protract recovery. These range from a decrease in the immunological response [35-38], endocrine instability [6-8,39], protein catabolism [40], and respiratory muscle fatigue (41-43). Further, cognitive effects of sleep deprivation include inattention, depression, confusion, a decline in quality of life [44] and have been linked to the onset of delirium. Moreover, issues with sleep disturbance developed within the Intensive Care environment has been reported to perpetuate for months after discharge [45].

Assessment of Sleep Disturbance

Evaluation of sleep disturbance amongst ICU patients is fraught with complexity due to the presence of critical illness. Further, identifying techniques that can be readily applied within this patient cohort have not been extensively examined for widespread implementation. Even though objective, behavioural and subjective techniques exists, all still have specific limitations in regards to their application to the ICU patient population. Current biophysiological sleep monitoring technologies: polysomnography, actigraphy and bispectral index monitoring are examined, along with the utility subjective and behavioural assessments of sleep within the Intensive Care setting.

Objective Ssessment of Sleep Disturbance

Polysomnography (PSG) records the biophysiological changes based on electroencephalographic (EEG) activity, combined with concurrent polygraphic monitoring of electro-oculogram (EOG) and electromyogram (EMG) activity which occurs during sleep. This method has long been regarded as the gold standard of sleep monitoring outside of the ICU, and is widely used in sleep medicine to formally diagnose sleep disorders and has been employed in ICU based sleep research to investigate sleep characteristics of complex patients. However, its ability to be integrated widely into the ICU environment is hampered by its costs and methodological complexities; further the technique is labour intensive and requires clinical expertise to interpret the data that exceeds the scope of critical care clinicians. Although portable PSG monitoring has the capacity to reduce the associated costs and the time spent preparing and setting up the device, analysis and interpretation of data remains labour intensive and time consuming, and requires personnel with clinical expertise in the area of sleep medicine. As a result PSG remains impractical and financially unviable for widespread implementation in the ICU setting. The development of computer based interpretation methods have the capacity to overcome the need for expertise to interpret the data, however these are frequently critiqued as being less than optimal as the reliability of this method ranges from 65% to 85% in the normal sleep clinic population, and their use in the ICU population is not validated [46]. Further compounding the issue is the potential reduction in EEG activity in critically ill patients secondary to conditions such as encephalopathy's (hepatic, septic, neurological), administration of sedation and acute neurological injuries, thus making it difficult to decipher between sleep states and the resultant impact of critical illness [47-49].

Subsequently, the traditional polysomnographic interpretative methods used in Sleep Medicine may have reduced utility in the ICU setting. Atypical biophysiological sleep activity has been widely reported amongst ICU patients, which confounds the ability to distinguish between NREM sleep stages [23,28,50-51]. PSG based studies reveal a lack of discernible sleep spindles and K complexes, along with challenges associated with electrical interference, and the impact of pharmacological agents in detecting submental muscle atonia [23,28,50-52]. Further, Drouet et al [53] reported that 28% of PSG recordings obtained within ICU, could not be classified based on the conventional scoring rules.

Nonetheless, PSG has been used extensively in sleep research involving ICU patients and has consistently provided information regarding alterations in sleep architecture. Many of the studies conducted have only monitored nocturnal sleep, despite ICU patients acquiring up to 50% of their total sleep time during the day [19-20]. The sleep architecture of ICU patients have been consistently reported to be fragmented with long sleep onset and REM latencies, and poor sleep efficiencies [19,25-26]. The primary etiology of these abnormalities remains unclear, and is thought to be multifactorial.

Alternative bio-physiological methods such as Bispectral index (BIS) have been investigated as an adjunct objective assessment of sleep within the ICU which may be preferable to PSG. This method employs an electroencephalogram parameters, which was initially developed to assist in the titration of anesthesia. This assessment provides a scale from 0 to 100, with scores between 90-100 identifying a wakeful state, 70-80 being unconscious, 60-70 deep level sedation and under 60 being anaesthetised [54], based on an integration of parameters inclusive of EEG, and spectral and bispectral power analysis to determine states of consciousness [55].

Whilst BIS has cemented itself as a useful objective assessment of levels of anaesthesia, its broader application to assess sleep has only been tentatively explored. Limited studies have been conducted within the Intensive Care environment, with one study conducted by Patel, Sleight and Nicholson [56] reporting that BIS assessment of sleep levels was consistent with PSG data. However, the values employed to assess sleep stages via BIS contain overlap and therefore the accuracy of distinguishing sleep stages is potentially compromised. Further, factors that impact on the accuracy of PSG are also confounders for the accuracy of BIS. Although, this method has not been extensively explored within the critical care environment it does have a distinct advantage compared to PSG, in that the interpretation of data does not require extensive clinical expertise and can be rapidly evaluated at the bedside.

Behavioural Assessment of Sleep Disturbance

Although objective bio-physical assessments are preferable due to their ability to provide specific information on sleep stages, behavioral assessments such as actigraphy have the potential to yield important information over longer periods of time. Actigraphy has emerged as a potentially viable alternative assessment to monitor sleep, and has been recognised by The American Academy of Sleep Medicine as an adjunctive clinical assessment of sleep disorders [57]. Researchers attest that there exists parallelism between the sleep-wake and rest-activity patterns suggesting that actigraphy could be a surrogate for polysomnography for sleep-wake activity [58-60].

Actigraphy (ACTG) is an accelerometer which estimates sleep-wake cycles by the measurement of activity through the use of omnidirectional omnidirectional sensors to identify movement

suggestive of wakeful or sleep states. The device is worn like a wrist watch making its application and removal uncomplicated for clinicians. This is in contrast to PSG which requires electrodes to be positioned at specific anatomical landmarks, with good skin adherence via the aid of pastes and adhesives to ensure accurate data collection. ACTG provides objective data that is independent of personal judgements of sleep and may offer a low-cost, and non-invasive assessment of sleep compared with PSG. However, the clinical utility of ACTG remains unclear in a variety of settings, with few studies investigating the sensitivity of actigraphy compared to PSG [19,61]. Studies conducted by Mullaney, Kripke and Messin [62] and Cole, Kripke, Gruen, Mullaney and Gilline [58] reported the concordance between ACTG and PSG to range between 81% to 87%, suggesting that its potential application to more diverse clinical settings is potentially viable. Although widely employed within the context of sleep laboratories, the potential of actigraphy has had limited testing within the critical care environment.

Due to the method employed by ACTG to distinguish between sleep and awake states, the information generated regarding sleep is limited in comparison to PSG. ACTG provides information regarding total sleep time, wake time and sleep fragmentation, but it provides no information about whether SWS or REM sleep is present in a recording. This device has the potential to provide valuable information regarding sleep-wake patterns, with added benefit of being able to monitor data over a 7 day period and computerised interpretation of data readily available and uncomplicated.

The application of ACTG monitoring has the potential capacity to identify circadian disturbance which is common amongst ICU patients, and in turn a patient's response to treatment interventions to improve sleep and circadian synchrony. Although previous research involving the ICU patient population is limited and frequently involved small numbers, this technology may have a useful application in specific clinical situations and may not be suitable for all ICU patients as indicated by Beecroft *et al.* [63]. In their study involving mechanically ventilated patients (n=12) the accuracy of actigraphy compared with PSG was reported to be less than 65%. However, there was no statistical difference between ACTG and PSGs ability to assess awakening from sleep. Similarly, Van der Kooi *et al.* [64] (2012) in a study involving post cardiac surgery patients (n=7) found significant correlation ($r=0.76$) between PSG and actigraphy in determining the number of awakenings. In clinical environments where the use of sedation is administered judiciously and, ICU's that provide combine services to high dependency patients the application of this device may have clinical merit. The increased emphasis on controlled sedation administration and targeted sedation scores, along with emerging sedation options, patients are increasing conscious and interacting with health professionals within the ICU environment. The ability to monitor sleep with methods other than EEG is potentially emerging as being more feasible and increasingly important in order to optimise patient outcomes. The primary limitation associated with ACTG in the Intensive Care environment is associated with immobile patients such as those with neuromuscular complications, spinal injuries, and those receiving paralytic agents and moderate levels of sedation which impede spontaneous movement. The accuracy of both ACTG and PSG remains problematic in this patient group.

Subjective Assessment of Sleep Disturbance

Subjective assessments of sleep and sleep quality, inclusive of both clinician-based observations and patient self-reports, offer a cost effective method of evaluating sleep. These clinical approaches are

frequently implemented when sleep issues become evident, but are subject to interpreter bias. Clinicians have difficulty in determining the difference between sleep and sedation, as sedation mimics many of the features of sleep and this also confounds the interpretation of objective bio-physical measures such as PSG and BIS. Nonetheless, subjective assessments may have an important role amongst those patients who are recovering from critical illness, particularly when the assessment is not being obscured by the impact of sedating agents.

Although patient's self-appraisal of sleep is considered an optimal assessment of sleep quality as it acknowledges the subjective nature of sleep quality, it is not always achievable amongst the ICU population due to the impact of illness, surgical intervention and pharmacological agents. Furthermore, there are reported discrepancies between how long individuals report that they have slept for compared to the physiological data reporting total sleep time in studies that have employed concurrent PSG monitoring and patient self-reports [20,65]. The ability to implement self-reports is limited to a small population of patients (< 50%) in the ICU setting who have capacity to complete these [17], which significantly compromises their efficacy.

As a result, observational assessments performed by clinical staff are often the first point of call when there is concern regarding a patient's sleep characteristics, and is the most practical and cost effective method available to clinicians. However, nursing assessments have been found to consistently over-estimate sleep compared to objective, subjective and behavioural assessments [66-68], in addition to problems associated with missing data [68].

A number of self-report methods have been applied to the ICU environment to assess patient's quality of sleep, the most commonly employed assessments are the Pittsburgh Sleep Quality Index (PSQI), Verran and Synder- Halpern Sleep Scale (VSH) and the Richardson-Campbell Sleep Questionnaire (RCSQ). These three scales have been widely researched and utilised within ICU environment that affirmed sleep is of a poor quality and subjected to frequent interruptions. The RCSQ was developed specifically for the critical care environment [69], unlike PSQI which was originally developed to assess sleep disturbance in psychiatric populations [70] and VSH which was developed to assess sleep quality for hospitalized patients without pre-existing sleep disorders [71]. Although, all three report similar domains such as sleep quality, sleep disturbance, sleep time and sleep latency, the PSQI and VSH are more labor intensive for critically ill patients due to the higher number of questions and the need for cognitive acumen and ability to recall information. Comparatively, the 5 item visual analogue RCSQ that has been tested for its reliability against PSG and proxy assessors reported mixed results regarding quality of patients' sleep.

Original research conducted by Campbell [72] reported that there was a high correlation ($r=0.869$, $P<.001$) between patient self-reports and nurse sleep rating, however more contemporary studies [17,73] suggest that staff continue to overestimate patient sleep when completing RCSQ compared to patient self-reports. Kamdar *et al.* [73] investigated the inter-rater patient-nurse reliability of the RCSQ and found overall that nurses scored higher, perceiving sleep to be of a better quality than patients for sleep depth and quality. This suggests that using nursing staff to complete the questionnaire in lieu of patients would produce a moderate representation of the patient's experience at best. Despite efforts to devise strategies to enhance subjective assessments of sleep, findings consistently identify this technique as one that over estimates patient sleep.

Conclusion

The clinical importance of sleep in the recovery of critically ill patients is frequently acknowledged and is associated with a sequelae of complications, yet remains an issue within Intensive Care Units that has not been remedied. Numerous strategies have been devised ranging from behaviour modifications approaches, curtailing the impact of environmental stimuli through to non-invasive strategies such as ear-plugs and pharmacological intervention, along with diversionary therapy approaches. Despite these efforts reduce sleep disturbance; the ability to accurately monitor sleep continues to elude clinicians, as current biophysical and behavioural assessment approaches have significant limitations in the ICU setting. Self-appraisals of sleep quality can only be completed by a small proportion of patients and clinician observations over-estimates quality and quantity of sleep. Whilst biophysiological methods are hampered by the impact of critical illness and clinical management strategies that obfuscates the ability to distinguish between sleep stages and impedes the sensing of movement. As a result, there is currently no one viable and accurate sleep monitoring tool suitable for widespread ICU application. Further research is required to devise algorithms that permit the ability to decipher sleep stages within the ICU patient population, in order to be able to accurately quantify sleep, along with developing methods that are feasible for widespread implementation.

The development of reliable biophysiological monitoring techniques is imperative in order to fully elucidate the impact of external and internal factors that contribute to sleep disturbance during critical illness. Presently, studies are hampered by small sample sizes with limited capacity to performed large comparative studies in order to ascertain the impact of interventions in improving sleep disturbance amongst critically ill patients. Cost effective bio-physiological monitoring, which produces easily interpretable data will provide clinician with important clinical information regarding an important facet of patient recovery, and promote a greater understanding and awareness of sleep in the overall well-being of patients.

Competing Interests

The author(s) declare that they have no competing interests.

Author Contributions

Lori J. Delaney-Conception of the article and manuscript preparation.

Frank Van Haren-Revising and drafting the manuscript.

Marian Currie and Violeta Lopez-Editing of manuscript

Hsin-Chia Carol Huang-Revising and editing of the manuscript.

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3.3 Research Aims and Objectives

The identified gap in the ability to monitor sleep and the emergence of novel approaches provide an opportunity to explore their potential application in the ICU setting.

The evolution of ICU practices that have resulted in the reduction in sedation administration (Page & McKenzie, 2021; Wiatrowski et al., 2016) and interventional approaches that potentially reduce the need for mechanical ventilation (ANZICS CORE, 2019) gives rise to the potential application of sleep monitoring via motion accelerometers. The need to maintain sleep homeostasis to support recovery and the concepts of humanisation and patient-centred care, highlight the need to consider sleep in the context of individualised patient care (Heras La Calle et al., 2017). Humanisation and patient-centred approaches in the context of intensive care patients emphasise the need to consider the individual in their entirety and shift the emphasis and focus on treatment interventions to consider individualised needs and responses to experience and treatments (de la Fuente-Martos et al., 2018; Heras La Calle et al., 2017). The tenets of this approach to care also extend to the impact of the clinical environment and how it may positively or negatively affect an individual. As mortality rates within the ICU decrease, there is an increasing need to recognise the impact an ICU admission may have on the patient's overall recovery, with sleep playing an integral role in the recovery process.

3.3.1 Aims

The study employed a within-subject study design to compare the accuracy (sensitivity and reliability) of ACTG in monitoring total sleep time and sleep fragmentation against PSG and subjective behavioural assessments, nursing observations and patient self-reports. The research protocol (Chapter 4) was formally recorded within the Australian Clinical Trials Registry ([ACTRN12615000945527](#); Pre-results), and the study protocol was formally developed and published.

The secondary aim of the study was to identify and quantify the impact of environmental factors including noise, light, temperature and clinical care on patients' sleep.

3.3.2 Objectives

This research aimed to:

11. determine the prevalence of adverse environmental stimuli on patient sleep;
12. determine the sleep quality of patients admitted to ICU;
13. assess the accuracy of subjective nursing assessments of patients' sleep; and
14. evaluate the sleep architecture of patients admitted to the ICU.

3.4 Chapter Summary

Patients cared for in the ICU are vulnerable to sleep disturbance because of a panoply of intrinsic and extrinsic factors. The impact that sleep deprivation has on those surviving critical illness can be profound. Consequently, there exists a need to investigate strategies that enable clinicians to accurately monitor patients that are feasible for widespread implementation. Studies have typically identified noise as a major factor for sleep disturbance and amenable to behaviour modification (Aaron et al., 1996; Delaney et al., 2019; Freedman et al., 2001; Gabor et al., 2003; Simons et al., 2018). As a result, behaviour modification has been a significant focus of altering the ICU environment to improve patients' ability to sleep (Aparício & Panin, 2020; Kamdar et al., 2020; Ifitkhar et al., 2019). Although these studies have reported some levels of success in reducing noise, many studies omit to integrate environmental noise monitoring and formalised sleep assessment to quantify the effects of the interventions.

This proposed study builds upon previous research that investigated the impact of environmental factors on sleep within the ICU and permits the observation of numerous factors that may disrupt patients' sleep through PSG. Few studies have been undertaken within the ICU patient population investigating the utility of ACTG in monitoring patient sleep compared with PSG. As sedation levels in ICU are reduced in the effort to avoid delayed extubation, it becomes increasingly important to ensure patients are provided with an

environment that permits adequate sleep to facilitate their recovery and rehabilitation. Complications associated with sleep deprivation, such as delirium, can prolong patients' recovery and contribute to permanent neurological decline (Cole et al., 2015; Sato et al., 2017; Shi et al., 2012). Therefore, efforts need to be undertaken to promote the basic need for sleep and identify a method to monitor sleep within the ICU. The research investigating sleep in the ICU environment predominantly emanates from Northern America and Europe, with limited studies conducted within Australian ICUs. Further, many of these studies have involved small participant numbers and homogeneous patient populations. These factors, combined with limited research investigating the potential application of motion accelerometers, suggest that there is a need for a large study involving a heterogeneous patient population, in addition to characterising sleep and sleep-disturbing factors within Australia ICUs.

Chapter 4: Study Protocol

4.1 Introduction and Linkage

The research design employed for this study was an observational evaluative design, which endeavoured to identify the feasibility of implementing novel sleep monitoring techniques within the ICU to facilitate and improve the clinical care of patients. The central purpose of this design and the study is to improve clinical practice and enhance our understanding of sleep disturbance that patients are subjected to when admitted to the ICU.

In this observational study, there was no manipulation of the independent variable (sleep), with no random assignment of participants. The study included a within-subjects monitoring approach to concurrently monitor patients' sleep with ACTG and PSG, in conjunction with a subjective behavioural assessment of sleep to ascertain the accuracy of the assessment methods in identifying sleep fragmentation, TST and sleep latency. Environmental monitoring of sound, light, and aspects of clinical care was undertaken to ascertain their effect on patients' sleep. Details of the study protocol are outlined in the below publication title: 'A Prospective Study Investigating the Application of Motion Accelerometers as a Sleep Monitoring Technique and the Clinical Burden of the Intensive Care Environment on Sleep Quality: Study Protocol'.

4.2 'Investigating the Application of Motion Accelerometers as a Sleep Monitoring Technique and the Clinical Burden of the Intensive Care Environment on Sleep Quality: Study Protocol for a Prospective Observational Study in Australia'

The following presents the study protocol and process applied to undertake the research study and was published 24 November 2017 in the *British Journal of Medicine Open* (doi:10.1136/bmjopen-2017-019704), including text, tables references.

BMJ Open Investigating the application of motion accelerometers as a sleep monitoring technique and the clinical burden of the intensive care environment on sleep quality: study protocol for a prospective observational study in Australia

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ABSTRACT

Introduction Sleep is a state of quiescence that facilitates the significant restorative processes that enhance individuals' physiological and psychological well-being. Patients admitted to the intensive care unit (ICU) experience substantial sleep disturbance. Despite the biological importance of sleep, sleep monitoring does not form part of standard clinical care for critically ill patients. There exists an unmet need to assess the feasibility and accuracy of a range of sleep assessment techniques that have the potential to allow widespread implementation of sleep monitoring in the ICU.

Key measures The coprimary outcome measures of this study are to: determine the accuracy and feasibility of motion accelerometer monitoring (ie, actigraphy) and subjective assessments of sleep (nursing-based observations and patient self-reports) to the gold standard of sleep monitoring (ie, polysomnography) in evaluating sleep continuity and disturbance. The secondary outcome measures of the study will include: (1) the association between sleep disturbance and environmental factors (eg, noise, light and clinical interactions) and (2) to describe the sleep architecture of intensive care patients.

Methods and analysis A prospective, single centre observational design with a within subjects' assessment of sleep monitoring techniques. The sample will comprise 80 adults (aged 18 years or more) inclusive of ventilated and non-ventilated patients, admitted to a tertiary ICU with a Richmond Agitation-Sedation Scale score between +2 (agitated) and -3 (moderate sedation) and an anticipated length of stay >24 hours. Patients' sleep quality, total sleep time and sleep fragmentations will be continuously monitored for 24 hours using polysomnography and actigraphy. Behavioural assessments (nursing observations) and patients' self-reports of sleep quality will be assessed during the 24-hour period using the Richards-Campbell Sleep Questionnaire, subjective sleepiness evaluated via the Karolinska Sleepiness Scale, along with a prehospital discharge survey regarding patients' perception of sleep quality and disturbing factors using the Little Sleep Questionnaire will be undertaken. Associations

between sleep disturbance, noise and light levels, and the frequency of clinical interactions will also be investigated. Sound and luminance levels will be recorded at 1 s epochs via Extech SDL600 and SDL400 monitoring devices.

Clinical interactions will be logged via the electronic patient record system Metavision which documents patient monitoring and clinical care.

Ethics and dissemination The relevant institutions have approved the study protocol and consent procedures. The findings of the study will contribute to the understanding of sleep disturbance, and the ability to implement sleep monitoring methods within ICUs. Understanding the contribution of a clinical environment on sleep disturbance may provide insight into the need to address clinical environmental issues that may positively influence patient outcomes, and could dispel notions that the environment is a primary factor in sleep disturbance. The research findings will be disseminated via presentations at national and international conferences, proceedings and published articles in peer-reviewed journals.

Trial registration number ACTRN12615000945527; Pre-results.

INTRODUCTION

Sleep is widely acknowledged to be important for optimal physical and psychological performance and well-being.¹⁻³ Patients cared for in intensive care unit (ICU) experience substantial sleep disturbance,⁴⁻⁶ for which the aetiology is likely multifactorial. Intrinsic factors associated with critical illnesses (eg, disruption of the circadian rhythm) and extrinsic environmental factors (eg, noise, light and clinical interactions) contribute to poor sleep among this patient cohort.⁷⁻¹⁰

Previous research has shown that the sleep architecture of patients admitted to the ICU is characterised by significant fragmentation and lack of deep sleep, with their sleep



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architecture predominantly comprising non-rapid eye movement (ie, stages 1 and 2 of the sleep cycle). This may limit the restorative functions of sleep and exacerbate deranged circadian rhythms.^{1 11 12} Previous studies have described the somatic, cognitive and physiological effects of sleep disturbance.^{13–16} Neurocognitive disturbances have been reported to persist postdischarge and are associated with a permanent decline in working memory.^{17–20}

For critically ill patients, alteration to circadian patterns is associated with a decrease in overall well-being and prolonged recovery from critical illness.^{21–23} Further, poor sleep is considered a major stressor for patients, which is acknowledged by family members and clinical staff,^{24 25} and is associated with an increased incidence of delirium.^{3 26} Preventing and treating sleep disturbance in the ICU may reduce morbidity and mortality. However, understanding and monitoring the sleep patterns of ICU patients require the identification of accurate and feasible sleep monitoring techniques suitable for widespread implementation.

Sleep monitoring

Polysomnography (PSG) is the gold standard of sleep monitoring and can provide objective information of the sleep architecture of patients both during ICU admission and subsequent to discharge.^{1 8 11 12 27} However, its application to the ICU environments is limited due to the costs associated with monitoring, the technical skills required to interpret the results and the uncertainty in describing common PSG patterns observed in critically ill patients according to standard physiological sleep patterns.^{28–31}

In contrast, the implementation of subjective behavioural assessment performed by clinical staff to assess patients sleep is an inexpensive process. However, few of the commonly employed sleep questionnaires have been validated for use within the ICU population, and there are concerns regarding the clinical accuracy of subjective assessments compared with biophysiological-based monitoring.³² While, the implementation of questionnaires is inherently less complex, their clinical utility is questionable given that 50% of ICU patients do not have the mental acumen required to complete such questionnaires.³³ Despite these issues, research conducted by Litton *et al* indicated that nursing staff are confident in documenting the differences between sleep and sedation.³⁴ However, research also suggests nurses overestimate patients' total sleep time regardless of the method employed to document sleep (real time or morning after documentation), and has been found to correlate poorly with patients' perceptions of their sleep.^{4 12 29 35–37} For example, research undertaken by Kamdar *et al*¹⁴ investigating the nurse–patient reliability of the Richards-Campbell Sleep Questionnaire (RCSQ) found the nurses significantly overestimated sleep depth and sleep quality. Similar findings have been reported in studies which required five minutely nursing documentation of patients sleep status, whereby nurses significantly overestimated sleep compared with PSG.³⁸ In contrast,

Edwards and Schuring³⁹ who compared 15 minutely nursing-based assessment of patient's sleep–wake status compared with PSG identified nursing assessment as being correct 82% of the time. However, the authors noted issues attributed to missing data and the impact of confounding factors such as sedation on the assessment process. A primary limitation of this study was the brief documentation period (4 hours), which may not adequately reflect the extent of monitoring required to evaluate sleep sufficiently. More recently, it has been suggested that subjective and objective measures may be complementary to inform staff regarding patients sleep quality.³⁹ As a result, the evolution of new devices such as motion accelerometers may be a valuable adjunct to monitoring sleep in the ICU.

Presently, there is an unmet need for an inexpensive and accurate method to assess total sleep time and sleep fragmentation. Motion accelerometers, such as actigraphy (ACTG) are a non-invasive method employed to monitor human rest/activity cycles. ACTG represents a more feasible sleep monitoring method compared with PSG, as it is relatively cheap, easy to implement and discontinues and produces easy to interpret results. ACTG has been found to have a high level of agreement (ie, >90%) with PSG in healthy participants; however, limited research has been conducted on the reliability and accuracy of ACTG in ICU populations, and the research that has been undertaken has yielded conflicting results.^{40–42}

Extrinsic disruption to sleep: the clinical environment

The apportionment of the clinical environment to sleep disturbance has been reported subjectively by patients, and in studies using objective assessments such as noise (dB-A and dB-C) and light (lux) monitoring. However, the relative contributions of the specific elements of the clinical environment on sleep disturbance are uncertain. A review undertaken by Xie *et al* reported that the effect of noise on sleep contributed to between 17% and 57% of arousal and awakenings.⁴³ In contrast, Gabor *et al*⁶ and Freedman *et al*⁸ reported that only 11%–24% of sleep arousal was attributable to noise events, suggesting that these results may reflect an adaptive response to clinical environments.

The ability of the patient to adapt to the clinical environment has been questioned, and emerging research suggests that noise variability may be a significant factor for sleep disturbance rather than the ambient noise levels. Delaney *et al*⁴⁴ reported noise variability in the ICU environment to range between 9.9 and 44 dB(A) over 5 min intervals, with noise sources >70 dB(A) occurring 10 times per hour. Secondary to the unpredictability of the environment, it is unlikely that patients could become accustomed to the diverse and rapid noise variations. Efforts to implement behavioural-based interventions to reduce noise levels have demonstrated limited success, with studies reporting a reduction in the subjective perception of noise levels.^{44 45} Although, these have not translated to a measurable reduction in noise levels, or an

ability to sustain the reported reductions.⁴⁵ Subsequently, there has been an emergence of research investigating environmental masking, such as the effects of earplugs and eye masks as methods to reduce patients' exposure to noise and light.^{46 47}

Extrinsic disruptions in the form of clinical interactions are frequent among this patient cohort. Early observational studies^{48 49} reported that patients are disturbed between 1 and 14 times per hour, with the longest period of uninterrupted sleep being 43 min. In contrast, studies conducted by Tamburri *et al*⁵⁰ and Celik *et al*⁵¹ reported much higher patient to staff interactions, with both studies reporting between 40 and 60 interactions per night, and as high as 20–60 interactions per hour in mechanically ventilated patients. This has significant implications on patients' ability to sleep, with reports indicating that 50% of ICU patients recall being woken two to five times throughout the night, and once woken up expressed difficulty in falling asleep again.^{1 10 52} The frequency of clinical interaction can adversely impact on total sleep time and contributes to sleep disturbance, and in turn leads to poor quality of sleep. However, minimal studies have been conducted that concurrently monitors the biophysiological component of sleep to identify if some or all interaction contributes to sleep disturbance.

Intrinsic disruption to sleep: critical illness

Intrinsic factors associated with critical illnesses (rather than clinical environments) may be the leading causes of sleep disturbance.^{7 53 54} The effects of extrinsic factors compared with intrinsic factors on sleep quality have not yet been fully elucidated; however, emerging neuroimmunological research suggests that sleep disturbance may have an adverse impact on immunological responses. In particular, the suppression of the adaptive immune response and the increased activity of proinflammatory cytokines exacerbating sleep fragmentation.^{55 56}

Understanding the dynamics between extrinsic and intrinsic factors and their effect on sleep is complex, which is further compounded by a lack of congruence between patients' subjective reports and physiological measurements of sleep. Subjective studies indicate that ICU survivors perceived light exposure to be minimally disruptive to their ability to sleep,⁵⁷ although it appears to have a detrimental effects on circadian patterns. Melatonin plays an important role in regulating the sleep wake cycle, with research indicating the ICU patients demonstrate a suppression in endogenous melatonin secretions.^{58–60} The role that melatonin plays in regulating circadian patterns continues to be of interest to researchers, with studies investigating optimal administration patterns and assessment of its biophysiological impact on sleep architecture.

STUDY AIMS

The aims of this study are to:

1. Determine the accuracy and feasibility of motion accelerometer monitoring (ie, ACTG) and subjective

assessments of sleep (nursing-based observations and patient self-reports RCSQ) to the gold standard of sleep monitoring (ie, PSG) in evaluating sleep continuity and disturbance.

2. Identify the association between sleep disturbance environmental factors (eg, noise, light and clinical interactions).
3. Describe the sleep architecture of intensive care patients.

METHODS AND ANALYSIS

Study design and setting

The observational study will have a within-subject design. Specifically, concurrent sleep monitoring will be performed using ACTG, PSG, nurses' subjective assessments documented hourly and questionnaires (RCSQ, Karolinska Sleepiness Scale (KSS) and the Little Sleep Questionnaire (LSQ)) completed by patients. Further, the effects of the clinical environment (ie, noise, light and clinical interactions) as factors affecting sleep disturbance will be investigated. The information obtained from the environmental monitoring will be compared with the arousal and wakeful event findings recorded by the PSG to ascertain their effects on patients' sleep.

The study site is a 31-bed tertiary referral ICU at an Australian teaching hospital that provides combined ICU and high dependency care. The unit admits approximately 2000 patients per year, including medical and surgical, admissions for trauma, neurosurgical and cardiothoracic care. The unit is located on the second floor of the hospital and has an open plan design with large fixed casement windows, two open plan nursing stations, shared bed spaces separated by disposable polypropylene non-woven curtains, partially enclosed walls and four dedicated isolation bays.

Participants

Adults (aged 18 years and above), requiring ICU level care beyond the next calendar day, who score between +2 (ie, agitated) and –3 (ie, moderate sedation) on the Richmond Agitation-Sedation Scale (RASS) will be eligible for inclusion in the study. Sleep monitoring will be commenced between 13:00 and 16:00 hours and conducted over a single 24-hour period, as patients' sleep frequently traverses both day and night. The exclusion criteria are summarised in [box 1](#).

Demographics and clinical data

The following variables will be collected: gender age, Acute Physiology and Chronic Health Evaluation (APACHE II) score, and APACHE II diagnostic classification, continuous renal replacement therapy, type of respiratory support, length of ICU admission when sleep monitoring was commenced, the use of eye masks or ear plugs, the presence or absence of physical restraints, delirium score (confusion assessment method: ICU), ICU length of stay (LOS), hospital LOS and mortality (alive/deceased in ICU or hospital). Further, the use of

Box 1 Exclusion criteria for study participation

Patients will be excluded from this study if on initial assessment.

- ▶ Admitted to the intensive care unit primarily for a neurological condition.
- ▶ Treatment intent is palliative and/or not expected to survive for more than 24 hours.
- ▶ Confirmed or suspected drug overdose.
- ▶ Likely to be administered a neuromuscular blocking agent during the 24 hours study period.
- ▶ Likely to be administered a barbiturate during the 24-hour study period.
- ▶ History of cognitive impairment, for example, Alzheimer's disease.
- ▶ Have inadequate English language skills to allow completion of a sleep survey.
- ▶ Have facial or skull injuries that prohibit the placement of the polysomnography electrodes.
- ▶ Have injuries that preclude the placement of actigraphy.
- ▶ Spinal cord injury.
- ▶ Have clinically suspected encephalopathies (ie, septic, hepatic or uraemic encephalopathies).

analgesia, antipsychotic and hypnotic medications, administration of melatonin, inotropes and vasopressors will be documented to assess the heterogeneity of the sample and enable the measurement of predictive factors.

Sample size and power

The sample size for the study was based on Cohen's⁶¹ power primer, with an alpha value of 0.05 and a power of 80%, resulting in a minimum sample size of 67 patients to be recruited into the study in order to determine an absolute difference (moderate size effect; 0.3) between the sleep monitoring methods PSG and ACTG. To account for missing data such as incomplete monitoring and discharge prior to completion the sample size was increased by 20% to a total of 80 participants for the study.

Sleep monitoring protocol and interventions**Actigraphy**

ACTG will be applied to a patient's wrist (similar to a wristwatch). ACTG is capable of sensing motion with the resultant forces of at least 0.01 g, and has a sampling rate of 32 Hz. An Actiwatch (by Phillips Respironics) will be applied to the wrist of each participant in the study on the side that has the least invasive devices (eg, intravenous cannulation, arterial line and sphygmomanometer). Recordings will be synchronised with the PSG to determine the reliability and accuracy of the device. ACTG data will be collected at 30 s epochs.

Polysomnography

The Embla PSG (VMedical) ambulatory monitoring device will be used to continuously monitor participants' PSG scores for a period of 24 hours. The data obtained from the PSG (Embla) will be downloaded to a secure digital data card manager so that the information can be transferred to a personal computer. A board-certified sleep scientist (Registered Polysomnographic

Technologist) experienced in PSG scoring will review the PSG data to ensure accuracy and consistency in the data analysis. To prevent any undue influence secondary to knowledge, ascertainment bias and limit the effect of the assessors' inclinations or attitudes towards the sleep measures, the sleep scientist reviewing the PSG data will be blinded.⁶²

The international 10–20 electrode placement standards for portable PSG monitoring will be used to determine the positioning of the PSG electrodes; electroencephalogram electrode placement: C4/M1, C3/M2, F4/M1, F3/M2, O2/M1 and O1/M2. The electro-oculogram (EOG)-L (left) electrode will be positioned 1 cm lateral and below the left eye outer canthus, EOG-R (right) electrode 1 cm lateral and above the right eye outer canthus, EOG-C electrode positioned in the centre of the forehead. The electromyography of the submental (EMG), EMG+andEMG– electrodes positioned under the chin and approximately 3 cm apart.

Subjective behavioural monitoring

Subjective assessment of sleep will be based on the Edwards and Schuring's³⁹ method, with nursing staff required to manually record each hour the sleep status of the patient: awake, asleep for 15 min or less, asleep for 15–30 min, asleep for 30–45 min, or has been asleep for the hour (60 min). The nursing staff will be blinded to the PSG and ACTG data, and will not be able to base their assessments on this information. The subjective assessment will be integrated into the computerised electronic patient data system of MetaVision (iMDsoft), used in the ICU to document patients' clinical care.³⁴

Patient self-reports

The research team will assess each patients' competency based on: (1) the feedback of clinical staff in relation to each patient's cognitive ability; (2) the patient's negative confusion and assessment method results across three subscales (ie, inattention, altered level of consciousness and disordered thinking) and (3) whether the patient has a RASS between –1 (drowsy, but sustained awakening) and +1 (restless, but not agitated) (figure 1). Patients deemed competent will be invited to complete the RCSQ and the KSS, with assistance from clinical staff if required. A follow-up questionnaire: LSQ will be undertaken within 7 days of the patients identified hospital discharge date. Where patients do not meet the competency-based criteria, patient self-reported sleep quality via the RCSQ, KSS and LSQ will be omitted (refer to figure 1).

The Richards-Campbell Sleep Questionnaire

The RCSQ is a five-item questionnaire designed to evaluate ICU patients' quality of sleep and will be completed after each patient's night recording between 09:00 and 10:00. The RCSQ has previously been validated against PSG and comprises five subscales: (1) sleep depth, (2) sleep latency, (3) number of awakenings,

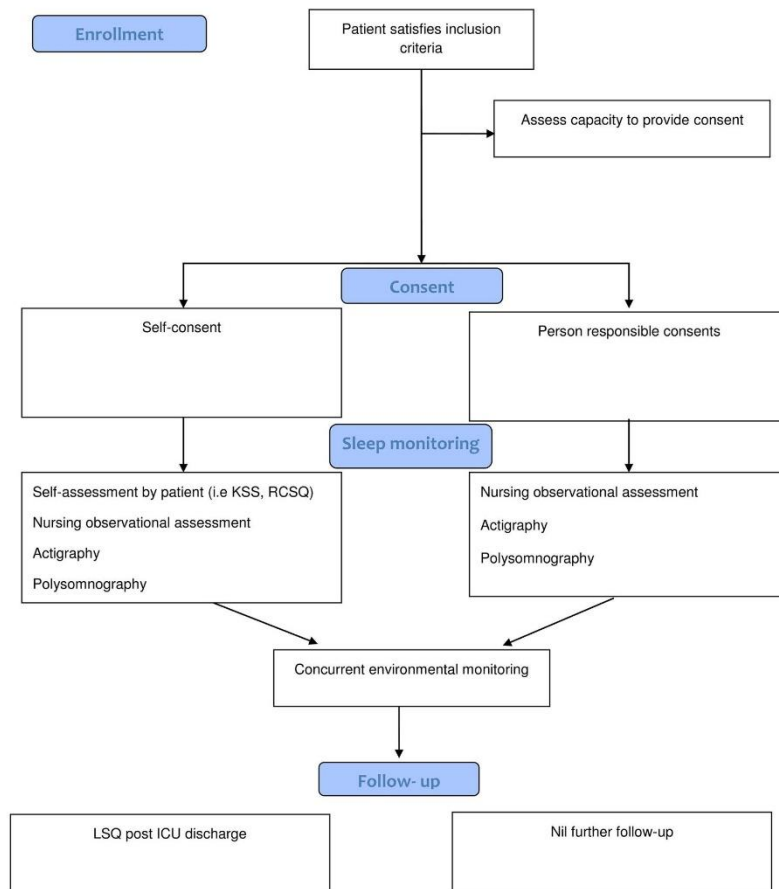


Figure 1 Flow diagram of the monitoring procedure. ACTG, actigraphy; ICU, intensive care unit; KSS, Karolinska Sleepiness Scale; LSQ, Little Sleep Questionnaire; PSG, polysomnography; RCSQ, Richards-Campbell Sleep Questionnaire.

(4) efficiency and (5) sleep quality ($\alpha=0.90$).⁶³ The RCSQ is recorded using a 100mm visual analogue scale. A mean score will be derived from the five subscales to provide an overall score reflecting patients' perceptions of their sleep quality. A higher score on the questionnaire indicates a better quality of sleep.

Karolinska Sleepiness Scale

The KSS is a self-reported nine-point Likert scale of subjective drowsiness at the point in time of testing to evaluate if this precipitates the patient's onset of sleep. The KSS has been widely used, particularly to describe changes over time in study participants, and will be completed on initiation of monitoring, between 21:00 and 22:00 hours and the following morning within 2 hours of awakening. A KSS score >7 reflects a state of drowsiness under which an individual may be susceptible to involuntary microsleep

behaviours with episodic losses of awareness, followed by returns of awareness.⁶⁴

Little Sleep Questionnaire

The LSQ was modelled on the ICU memory tool and developed for the use among ICU patient to explore the sleep experiences of patients, secondary to a lack sleep questionnaires addressing primary issues experienced by ICU patients.⁶⁵ This questionnaire explores patients' perceived quality and quantity of sleep at home prior to ICU admission, during their ICU stay and following discharge from the ICU; ICU-related factors contributing to poor sleep and possible changes in the ICU that could improve sleep. The survey will be excluded in instances where the patients' clinical condition or recovery precludes their ability to complete the LSQ. The LSQ will be conducted post the participants discharge from

the ICU and within 7 days of the participants' estimated hospital discharge date.

Environmental monitoring protocol

Extech sound meter (SDL600: frequency range 31.5 Hz–8 kHz, decibel range 30–180 dB) and lux metres (Extech SDL460: luminance range of 0–1999 lux, accuracy: $\pm 4\%$ +2 disability glare threshold) positioned at a height of 155 cm behind the head of patients' beds will be used to monitor noise and light. This positioning of the sound meter will allow the noise and light sources to which each patient is subjected to be monitored without interfering with or disrupting a patient's clinical care. These monitors will log noise and light level data at 1 s epochs over the 24-hour study period. Noise will be recorded on the A-weighted decibel (dB) scale that most closely reflects the sound and loudness perceived by the human ear. Whereas light levels will be recorded in lux, the standard unit of measurement in photometry and a measurement that is representative of the intensity of light perceived by the human eye.

Clinical interactions with patients will be recorded by the inpatient electronic data system, Metavision. This system documents patient care, including patients' vital signs, medication administration, titrations and clinical activities.

Outcome measures and instruments

The primary outcome measure of the study is to determine the accuracy and feasibility of motion accelerometer monitoring (ie, ACTG) and subjective assessments of sleep (nursing-based observations and patient self-reports) compared with the gold standard of sleep monitoring (ie, PSG) in evaluating sleep continuity and disturbance.

Sleep onset will be defined in accordance with the American Academy of Sleep Medicine Manual for Scoring Sleep and Associated Events (V2.4) as the first epochs of any sleep stage.⁶⁶ Sleep features such as total sleep time, total wake time, wake after sleep onset, arousal index and sleep efficiency will be correlated to sleep data derived from ACTG. The sensitivity (percentage of ACTG data that agreed with sleep determined via PSG), specificity (percentage of ACTG data that agreed with awake determined using PSG) and accuracy (ability to detect both sleep and wake compared with PSG=number to sleep and wake epochs of PSG scored sleep and wake epochs) between PSG and ACTG findings will also be analysed.⁶⁷ PSG hypnograms will be used to depict sleep and sleep stages over time, along with reporting the percentage of total sleep time in sleep stages N1, N2, N3 and REM sleep.

Atypical sleep patterns are known to occur within the ICU patient cohort, which hampers the ability to interpret sleep staging based on traditional criteria. In cases where atypical PSG data is identified, these will be analysed based on Watson *et al's*³¹ revised ICU sleep scoring criteria.

Box 2 Secondary outcome measures of the study

- ▶ Report the sleep architecture of intensive care patients.
- ▶ Compare the accuracy of polysomnography (PSG) compared with actigraphy, nursing assessment and patient self-reports.
- ▶ Determine the accuracy of patient self-reports of sleep quality compared with their biophysiological data.
- ▶ Determine the accuracy of nurses' observations of patients' total sleep times compared with PSG.
- ▶ Determine the effects of noise events (>70 dB (A)) on sleep stages.
- ▶ Determine the effects of exposures to artificial, nocturnal light during the sleep stages.
- ▶ Identify whether any clinical interactions are causal factors that arouse patients' from sleep.

Box 2 outlines the secondary outcome measures of the study, including the percentage of time that participants spend in each of the sleep stages as identified by PSG. In addition, to comparisons between the subjective sleep assessment conducted by clinical staff and the patient participants, and sleep disturbances associated with environmental factors will be performed.

Statistical methods

The data analyses will involve descriptive and analytic statistics, calculated using the Statistical Package for Social Science (V.20). Descriptive statistics (ie, means, SD and ranges) will be used to describe and summarise the demographic and clinical features of the study cohort, and the categorical data will be presented in frequency tables (n, %). The reasons associated with missing data attribute to PSG and ACTG monitoring will be documented and included in the analysis to explore the clinical application of these monitoring techniques. In the instances where data is missing for nursing-based observations of patient sleep an imputation method of the last observation carried forward will be applied.⁶⁸ While, missing data pertaining to the measure of noise and light will be addressed via the multiple imputation (multiple regression) method, as a means to reduce the likelihood of type 1 error.

Inferential statistical procedures, including parametric and non-parametric statistical analyses, will be used to analyse any data that violates the principles for the normal distributions of nominal or ordinal data. Cohen's kappa coefficients (κ) will be employed to determine the inter-rater agreement between PSG and ACTG in determining the mutually exclusive states of wakefulness and sleep. The values derived from the Cohen's kappa will be characterised as follows: a result of <0 will indicate no agreement, a result of 0–0.20, will indicate slight agreement, a result of 0.21–0.4 will indicate a fair level of agreement, a result of 0.61–0.80 will indicate substantial agreement and a result of 0.81–1 will be deemed to be an almost perfect agreement.⁶⁹

Bland-Altman plots will be used to determine the clinical comparability of PSG and ACTG and their level of agreement will be used to determine patients' waking

and sleep states, as a high a level of correlation does not necessarily indicate agreement. The computations will be based on a 95% limit of agreement for each comparison. The level of agreement between nurses' observations and patients' self-reports of sleep will also be measured using the Bland-Altman plot to visually present the differences in patients (x-axis) and nurses' (y-axis) reports. The RCSQ scores will be classified across three domains: poor sleep (0–33), moderate sleep (34–66) and a good night's sleep (67–100). The sleep domains of overall sleep quality and number of awakenings, ICU LOS, and APACHE II scores will be investigated via the non-parametric Spearman's correlation coefficient. The Mann-Whitney test will be used to test the differences between groups based on diagnostic classifications.

The environmental data will be analysed against the PSG monitoring to determine the effects of noise events, light levels and clinical care on patients' sleep. A non-parametric analysis using Spearman's correlations (r) will be conducted to ascertain the effect of these environmental factors on sleep quality. Categorical outcomes will be analysed using the X^2 test or Fisher's exact test. The significance level will be set at 0.05 (two tailed).

Ethics and consent

Patients admitted to the ICU for an anticipated admission period of 24 hours, with prehospital discharge follow-up for patients meeting the criteria to complete self-report will be identified by the ICU medical team and assessed by the chief investigator to determine whether they meet the study's eligibility criteria. Potential participants will be approached and asked to provide written consent to participate. A patient's severity of illness on admission may mean that some potential participants cannot consent. In such cases, the identified next of kin will be approached, provided information on the study and asked to provide or decline consent. In accordance with the relevant territory laws, patients who are under guardianship orders or subject to an Enduring Power of Attorney will be excluded from the study. In circumstances where family members have provided consent, once the patient is able, he/she will be provided with an opportunity to retrospectively withdraw from the study, or formally consent to participate in study.

DISSEMINATION

Sleep is considered an important component of recovery and can minimise the neurocognitive complications associated with sleep deprivation. Previous studies have revealed a number of themes that continue to go unaddressed in critical care environments, including identifying a method to monitor sleep, understanding the underlying factors that contribute to sleep disturbances and developing interventions that reduce the impact of adverse effects of sleep disturbance on patients.^{4 8 11 14 22} If the challenges faced in the field are to be successfully

overcome, research investigating sleep in the critical care needs to be ongoing and progressive.

This observational study will endeavour to ascertain the potential and ability of a motion accelerometer to accurately identify ICU patients' total sleep time and sleep fragmentation. Acquiring cost-effective and easily interpretable data on ICU patients' sleep and sleep disturbances will provide clinicians with important information on which they can base clinical management strategies to enhance patients' overall well-being and recovery. There are, however, limitations associated with the study, these include, it being a single centre study which may limit the generalisability of the findings, although it may provide the impetus for future multicentre studies. Further, PSG is deemed the gold standard of sleep monitoring, however, its ability to monitor sleep within the intensive care patient cohort presents challenges in regards to the data acquired. The impact of missing data will be investigated as outlined and may further highlight the issues and complexity of sleep monitoring among ICU patients and the clinical feasibility of PSG monitoring. Additionally, the results of this study will enhance understandings of how and to what extent environmental factors contribute to sleep disturbance and thus provide valuable information that can be used to inform the future designs and characteristics of ICUs. The findings derived from this study will be submitted to academic peer-reviewed journals for publication and presented at relevant international and national conferences. The transfer of knowledge obtained from this study will also be provided to the institution's healthcare policy makers and clinicians via seminars and study synopses to aid in the improvement of clinical care.

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4.3 Chapter Linkage

This chapter presented the research method employed for the study to investigate the feasibility and accuracy of sleep monitoring methods. The clinical rationale and explanation

of the monitoring processes are detailed, inclusive of the planned statistical analysis. The following chapters (5, 6 and 7) present the findings of the study.

Chapter 5: Feasibility of Sleep Monitoring Approaches in Intensive Care Patients

5.1 Introduction

This chapter presents the findings associated with the feasibility of a novel sleep monitoring approach within the Intensive care setting. The study, ‘The Feasibility and Reliability of Actigraphy to Monitor Sleep in Intensive Care Patients: An Observational Study’, seeks to explore the application of motion accelerometers as a potential surrogate assessment of sleep in the ICU, which is minimally invasive and easy to implement. Presently, viable objective measures that are both feasible and reliable are lacking to monitor and evaluate sleep in the ICU environment. Therefore, exploring novel and emerging approaches that may provide a surrogate measure of sleep is required to understand and quantify the extent of sleep disturbance and response to treatment interventions to guide clinicians in their assessment of sleep disturbance.

5.2 ‘The Feasibility and Reliability of Actigraphy to Monitor Sleep in Intensive Care Patients: An Observational Study’

The following presents the study protocol and process applied to undertake the research study and was published 29 January 2021 in *Critical Care* (<https://doi.org/10.1186/s13054-020-03447-8>), including text, tables and references.

RESEARCH

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The feasibility and reliability of actigraphy to monitor sleep in intensive care patients: an observational study

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Abstract

Background: Sleep amongst intensive care patients is reduced and highly fragmented which may adversely impact on recovery. The current challenge for Intensive Care clinicians is identifying feasible and accurate assessments of sleep that can be widely implemented. The objective of this study was to investigate the feasibility and reliability of a minimally invasive sleep monitoring technique compared to the gold standard, polysomnography, for sleep monitoring.

Methods: Prospective observational study employing a within subject design in adult patients admitted to an Intensive Care Unit. Sleep monitoring was undertaken amongst minimally sedated patients via concurrent polysomnography and actigraphy monitoring over a 24-h duration to assess agreement between the two methods; total sleep time and wake time.

Results: We recruited 80 patients who were mechanically ventilated (24%) and non-ventilated (76%) within the intensive care unit. Sleep was found to be highly fragmented, composed of numerous sleep bouts and characterized by abnormal sleep architecture. Actigraphy was found to have a moderate level of overall agreement in identifying sleep and wake states with polysomnography (69.4%; $K = 0.386$, $p < 0.05$) in an epoch by epoch analysis, with a moderate level of sensitivity (65.5%) and specificity (76.1%). Monitoring accuracy via actigraphy was improved amongst non-ventilated patients (specificity 83.7%; sensitivity 56.7%). Actigraphy was found to have a moderate correlation with polysomnography reported total sleep time ($r = 0.359$, $p < 0.05$) and wakefulness ($r = 0.371$, $p < 0.05$). Bland–Altman plots indicated that sleep was underestimated by actigraphy, with wakeful states overestimated.

Conclusions: Actigraphy was easy and safe to use, provided moderate level of agreement with polysomnography in distinguishing between sleep and wakeful states, and may be a reasonable alternative to measure sleep in intensive care patients.

Clinical Trial Registration number ACTRN12615000945527 (Registered 9/9/2015).

Keywords: Sleep, Intensive care, Polysomnography, Actigraphy, Sleep quality, Sleep disturbance

Introduction

Sleep is an important biological function essential for survival and maintaining circadian homeostasis. Patients cared for in the intensive care are reported to experience significant sleep disturbance; characterised by sleep fragmentation and a propensity for low quality sleep comprised of stages 1 and 2 of the sleep cycle [1–4]. Polysomnography (PSG) based studies have highlighted

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the atypical sleep architecture of intensive care patients, and the near absence of slow wave sleep (SWS) and rapid eye movement (REM) sleep [1–7]. The etiology of sleep disturbance amongst intensive care patients is widely acknowledged and thought to be multifactorial, stemming from a combination of intrinsic and extrinsic factors. However, interventional studies have had limited success in improving the sleep architecture (the distribution of different sleep states across cycles through the night) of patients [6, 8–13].

Sleep disturbance is linked to a wide range of adverse physiological and psychological outcomes that potentially impact on patient recovery [8–14]. Emerging research suggests that sleep disturbance may be a contributing factor in the onset of delirium and prolonged mechanical ventilation, both of which have been independently attributed to increased patient mortality and intensive care length of stay [14, 15]. As a result, there is an increased awareness of the important role sleep plays in individual well-being and health, and in turn on patient outcomes.

The paradigm shift of Intensive Care Units (ICU) to be more person centred has identified sleep quality and quantity as an issue for patients receiving care, that can mitigate recovery and contribute to protracted ICU length of stay [16]. However, these person-centred aspects of care are often negated due to the rapid development, and advancement of technology that is employed within ICU intended to support survival [17]. Increasingly, the contribution of sleep in the recovery process and the overall care of the patient in the ICU, has emerged as an aspect of clinical care that has garnered considerable attention. The ability to clinically monitor sleep in the intensive care remains a challenge, secondary to issues with feasibility and accuracy of sleep monitoring methods that are commonly available [5, 18, 19]. Although PSG is considered the gold standard of sleep monitoring, its application in the intensive care setting has not been validated. Further, the interpretation of data is compounded by the abnormal electroencephalographic (EEG) activity induced by medications, and physiological changes related to critical illness [20–22]. In addition, PSG is not considered a feasible method for widespread implementation into the critical care setting due to its costs, which have been reported to be \$606.35 (AUD) per patient [23], complex set up, and the technical skills of a sleep technician required to interpret results with its application primarily limited to research.

Identifying methods to monitor and assess sleep activity is central to supporting patients physiologically and their outcomes, in addition to evaluating the effectiveness of sleep promoting interventions. Exploring the application of alternative methods for sleep monitoring

is needed, in order to identify feasible methods capable of gathering accurate, and objective biophysiological data regarding sleep suitable for clinical implementation. Whilst observational assessment of sleep by nurses are considered cost effective and implementation is uncomplicated, this approach has been shown to be subject to observer bias. Studies conducted suggest that nurses overestimate the sleep that a patient acquires and are unable to identify the extent of sleep disturbance a patient may experience [24–26]. In contrast, actigraphy (ACTG) provides an objective physiological assessment via non-invasive use of motion accelerometers to detect multiplanar gross motor activity. Pre-determined algorithms translate the identified activity counts into epochs to report sleep and wakeful states [27]. This method may provide some advantages over PSG in that it is less-expensive, non-invasive and interpretation of data is less complex. In addition, it has superior data management capabilities compared with PSG, and may provide beneficial information on sleep related outcomes in response to extended interventions as it can monitor activity patterns for a period of 30 days [28].

The purpose of the study was to investigate the feasibility of 24 h continuous sleep monitoring through the application of actigraphy compared to the gold standard of sleep monitoring (polysomnography) for patients admitted to an intensive care setting.

Methods

Study design and setting

The study employed an observational research approach, using a with-in subject design to concurrently monitor sleep via polysomnography and actigraphy in a 31-bed tertiary referral ICU. The intensive care unit provided both medical and surgical services, inclusive of trauma, neurosurgical and cardiothoracic care, within an open plan design whereby patient care spaces are shared in either a two or four bed configuration, with a total of four isolation rooms. Patient care spaces are separated by patient curtains and semi partitioned walls separate the patient rooms. The registered nurse to patient ratio was comprised of 1:1 for intensive care patients and 1:2 for high dependency patients; at the time of the study the unit did not have in place a specific sleep promotion protocols other than offering eye masks and ear plugs for patients.

Participants

The sample size for the study was determined using Cohens power primer previously described with an alpha value of 0.05% and a power of 80% [29]. A total of 80 patients admitted to the intensive care who met the inclusion criteria; aged 18 years or older, required an ICU

admission for 24 h or greater and, whose Richard Agitation–Sedation Scale (RASS) was assessed as between +2 (agitated) and –3 (moderate sedation) were recruited into the study according to previously published criteria [29]. The structured assessment of sedation and agitation via the RASS has previously been reported to have robust inter-rater reliability and validity and, is employed to assess level of consciousness and agitation amongst ICU patients [30]. Patients receiving mechanical ventilation were not excluded from the study. Rather, patients were excluded from the study based on treatment intention (palliative care), medication (admitted secondary to drug overdose, administration of neuromuscular blocking agents or barbiturates), underlying cognitive or neuromuscular degenerative disorders, and suspected encephalopathies as previously published [29]. Recruitment into the study did not impose any restrictions or amendments to the provision of clinical care, with staff being able to perform clinical care and interventions as they deemed appropriate.

Demographic and clinical data were obtained from the patient's electronic medical record (Metavision, iMDsoft). Diagnoses at ICU admission were derived from the Acute Physiological Chronic Health Evaluation (APACHE II) classifications and the reported APACHE II score reported at admission was applied to determine the severity of illness.

Sleep monitoring

Sleep monitoring was initiated between 13:00–16:00 h and with the aim to continue for a period of 24 h. Recording commencement between the ACTG and PSG was synchronized using the data acquisition computer.

ACTG monitoring was undertaken via Actiwatch Plus (Spectrum, Phillips Respironics), worn as a wristwatch. The device was applied to participants wrist with the least amount of invasive instrumentation (e.g. arterial line). ACTG accelerometer monitoring is based on cantilever bilayer piezoelectric sensors to detect multiplanar motor activity with forces at 0.01 g and has a sampling rate of 32 Hz. The sensitivity threshold settings for ACTG range from low (20), medium (40 and high (80) as default settings, for the purposes of this study the threshold setting applied medium. Medium is considered to recommended threshold setting based on the validation studies conducted using ACTG. Whereby, the number of activity that exceed 40 are deemed to wakeful states and 40 and under activity counts assessed as sleep.

Ambulatory PSG monitoring (Embla PSG, VMedical) commenced with skin preparation conducted according to standard techniques, and gold cup electrodes applied according to the international 10–20 electrode placement. The bedside nursing staff assigned to the patient

were instructed on electrode replacement and device shut down procedure in the event of patient transfer from the ICU or due to clinical necessity (e.g. defibrillation, MRI procedure). Clinical staff were not instructed to replace electrodes in the event they became displaced. PSG data was scored by a senior sleep technologist (SST) using specialised analysis software (Remlogic), who was blinded to the results of ACTG. Further detailed information related to the sleep monitoring protocol and clinical environment is reported elsewhere [29].

Data analysis

ACTG data was analyzed as sleep or wake at 30-s epochs via the actigraphy analysis software (Actiware version 6.0.9; Phillips Respironics), using the predetermined activity count for each epoch within the software algorithm. PSG data was downloaded using data acquisition software (Remlogic-E, version 3.4.1; Embla systems) and scored by a board-certified SST in 30-s epochs according to published criteria [31]. The SST was blinded to the results of actigraphy to avoid ascertainment bias.

The contributing factors leading to missing data from the sleep monitoring methods (PSG and ACTG) were documented and included into the analysis as a factor addressing the clinical feasibility and acceptability of the monitoring techniques. In the cases where a recording method failed, data acquired of less than 2 h were excluded from the analysis. Incomplete data was integrated in the epoch by epoch analysis of PSG and ACTG accuracy using the binary assessments of sleep or wakeful states. PSG and ACTG data were analyzed based on concurrent recording to allow for direct comparison, where data could not be directly compared this data was excluded from analysis.

Descriptive analysis reporting means and medians were applied to describe continuous data, and percentages to report categorical data. Agreement between the two sleep monitoring techniques was determined via the Kappa Cohen Coefficient to identify if the two assessment methods were reliable and not occurring secondary to chance. The outcome measure of interest in the study was to determine the accuracy of ACTG compared to PSG in reporting total sleep time, wake time, sleep percentage and extent of sleep disturbance. Sensitivity of actigraphy data was evaluated and defined as the percentages of epochs score in agreement with PSG for sleep [5]. Specificity was determined to be the percentage of agreement between actigraphy and polysomnography for epochs scored as a wakeful state [5].

Pearson Correlation coefficient was used to identify if the two measures correlated regarding the assessment of sleep and wakeful states. Bland–Altman concordance technique was applied to determine if a meaningful

agreement occurred between ACTG and PSG assessments of sleep and wakeful states. Comparisons of the mean PSG and ATCG were plotted on the *x-axis*, with the difference between ACTG and PSG plotted on the *y-axis*. Statistical analysis of the acquired data was conducted via Statistical Packages for Social Sciences (Version 21), with *p* values < 0.05 deemed statistically significant.

Ethics

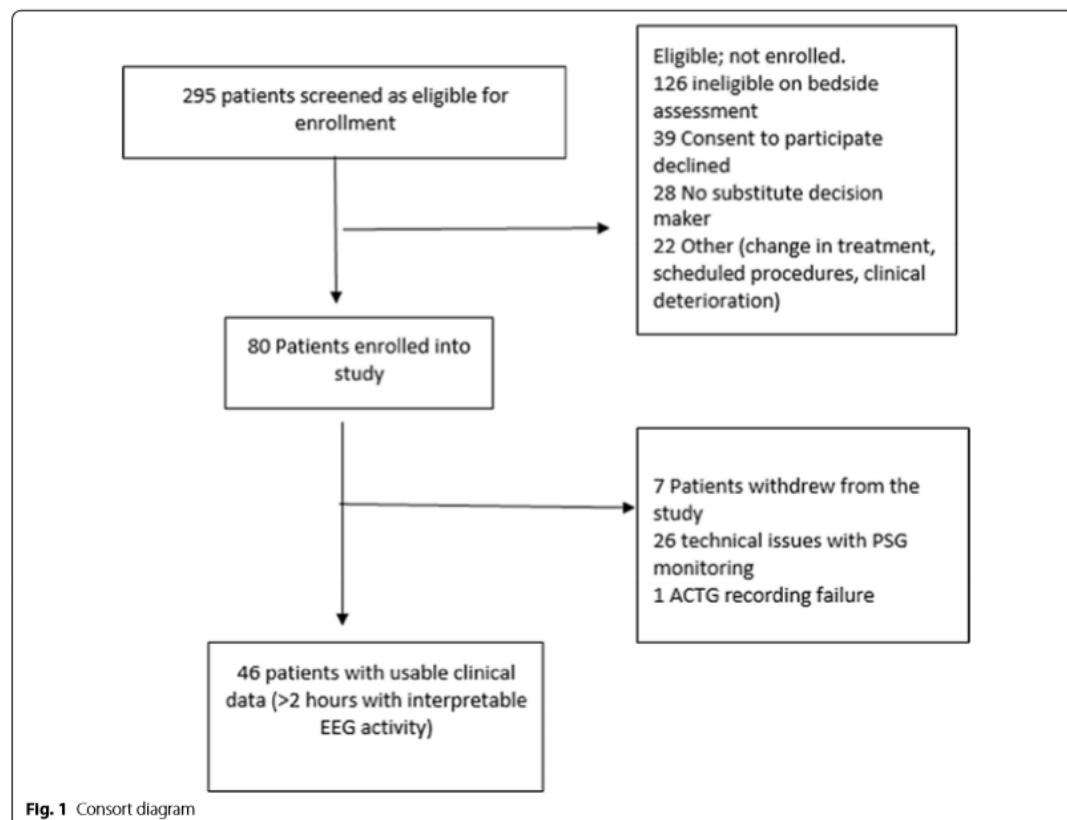
Consent for participation in the study was sought either verbally or in writing from those patients who were able to provide their own informed consent. Patients who were unable to provide their own consent due to their clinical acuity, consent for participation was sought from the assigned decision-maker documented for the patient. Patients and proxy consent providers were able to withdraw their consent from the study at any point without prejudice. The study was approved by the institutions Human Research Ethics Committee (ETH.5.16.071) and was formally registered as a clinical trial with the

Australian New Zealand Clinical Trial Registration Number; ACTRN12615000945527 (Registered 9/09/2015).

Results

Demographic profile; application and tolerability of sleep monitoring

A total of 295 patients were screened and 80 patients were enrolled into the study (Fig. 1). Technical issues associated with PSG monitoring such as electrode displacement (19%, *n* = 15), data transfer and equipment failure contributed to several lost studies (14%, *n* = 11). The primary reasons for early cessation of PSG monitoring once enrolled into the study was identified as patient's inability to tolerate the monitoring technique for the 24-h duration (24%, *n* = 11). In these instances, PSG data that was obtained was used for epoch analysis between the two monitoring methods. Comparatively, ACTG monitoring was found to be less burdensome for patients and better tolerated with all participants able to maintain the ACTG monitoring for 24 h. One ACTG recording was



lost due to technical issues, with all other studies having data available with intermittent loss of 1.8% of monitoring time occurring in 8 cases, attributed to removing the monitoring device to attend to patient hygiene.

The final data analysis of participants ($n = 46$) included medical and post-operative admissions with a median age of 60.5 years (IQR 45.75–72), median APACHE II score of 20.5 (IQR 14–25.25) (Table 1). Participants were primarily classified as intensive care admissions (56.5%), with 30.4% receiving mechanical ventilation during the study, and opioids were prescribed to 52% of patients.

Sleep characteristics

Total sleep time (TST) acquired by intensive care patients ($n = 46$) was found to be 462.5 ± 341.4 min ($M \pm SD$) reported by PSG (Table 2). Sleep bouts were found to traverse both day and night over the monitoring period, with ACTG identifying an average of 15 sleep bouts. The percentage of recorded time asleep reported via PSG was $42\% \pm 27.3\%$ ($M \pm SD$), and was characterized by frequent awakenings (43.3 ± 35.3 per hour; $M \pm SD$). Slow wave sleep and REM sleep were reduced, while the sleep–wake transition (Stage 1) was found to be increased, along with Stage N2; 75.5% of TST.

Actigraphy monitoring of sleep

There was a moderate level of agreement between PSG and ACTG independent assessment of sleep and wakeful states (69.4%). Adjusting for the probability of chance, the agreement between the two assessments was found to be statistically significant ($\kappa = 0.386$, $p < 0.05$), identifying a moderate level of correlation between accuracy of ACTG compared with PSG for assessing sleep and wake states ($r = 0.368$, $p < 0.00$). A moderate level of specificity (agreement in the identification of wakefulness) was identified between PSG and ACTG (76.1% agreement), and sensitivity for the agreement between the assessments for sleep (65.5%). Sensitivity and specificity of actigraphy was found to fluctuate depending on ventilation status and the time-period being monitored (daytime 06:00–22:00 h compare to night-time 22:00–06:00 h), with non-ventilated patients having higher percentages of specificity and sensitivity (Table 3). The administration of benzodiazepines and opioids amongst ventilated and non-ventilated patient were not identified as a significant factor between the groups ($\chi^2 = 0.351$ and $\chi^2 = 0.148$ respectively). Rather a higher APACHE II score (> 20) was linked to mechanical ventilation ($p > 0.05$).

Concurrent ACTG analysis of sleep and wake states compared to PSG was found to correlate the reported total sleep times ($r = 0.873$, $p < 0.01$) with ACTG over reporting total sleep time, and wakefulness ($r = 0.769$, $p < 0.01$) over reported by ACTG (Table 4). Post hoc analysis

Table 1 Baseline characteristics of patients

Demographic profile ($n = 46$)	
Age (years) (Median: IQR)	60.5 (45.75–72)
Gender: male/female (% , n)	69.6/30.4 (32/14)
Patients with known sleep disorder (% , n)	28.3 (13)
Weight (kg) (Median: IQR)	89 (74.75–97.25)
Height (cm) (Median: IQR)	175.5 (170–181)
BMI (kg/m ²) (Median: IQR)	28.1 (23.83–30.9)
Clinical acuity (Median: IQR)	
APACHE II score	20.5 (14–25.75)
Relative mortality risk	36.8 (18.65–55.97)
SOFA score	13 (9–16)
RASS score (% , n)	
Lightly sedated (– 2)	0
Drowsy (– 1)	26.1 (12)
Calm and co-operative (0)	50 (23)
Restless (+ 1)	17.4 (8)
Agitated (+ 2)	4.3 (2)
Very agitated (+ 3)	2.2 (1)
Confusion assessment method: positive (% , n)	2.2 (1)
Admission classification (% , n)	
ICU/HDU	56.5/43.5 (26/20)
Reason for admission (% , n)	
Bacterial pneumonia	13 (6)
Cardiovascular	19.6 (9)
Respiratory failure	15.2 (7)
Multi-trauma	10.9 (5)
Sepsis	15.2 (7)
Cardiac arrest	4.3 (2)
General surgical	13 (6)
Other	8.8 (4)
Respiratory support (% , n)	
Nil	8.7 (4)
Oxygen therapy	23.9 (11)
Hi Flow Nasal Prongs	32.6 (15)
Non-invasive ventilation	4.3 (2)
Mechanical ventilation	30.4 (14)
CRRT (% , n)	15.2 (7)
IABP	6.5 (3)
Pharmacological agents (% , n)	
Benzodiazepine	10.9 (5)
Opioids	52.2 (24)
Melatonin	10.9 (5)
Length of ICU stay: hours (Median: IQR)	152.5 (75–330.25)

BMI body mass index, APACHE II acute physiologic assessment and chronic health evaluation 2, SOFA sequential organ failure assessment, CRRT continuous renal replacement therapy, IABP intra aortic balloon pump

of mechanically ventilated patients compared to non-mechanically ventilated patients identified a reduction in ACTGs ability to distinguish wakefulness [$r = 0.565$, $p < 0.05$: non-mechanically ventilated ($r = 0.788$, $p < 0.00$)].

Table 2 Reported sleep parameters determined by polysomnography and actigraphy

Parameter	Polysomnography (n = 46)	Actigraphy (n = 46)
Total minutes analysed	37,938	37,938
Total sleep time: min (mean ± SD)	462.5 ± 341.3	508.8 ± 321.8
Wake time: min (mean ± SD)	308.2 ± 259.1	292 ± 234
Sleep fragmentation index (mean ± SD)		46.5 ± 19.7
% recording time asleep (mean ± SD)	41.8 ± 27.15	69.2 ± 19.4
Awakenings (mean ± SD)	43.3 ± 35.3	19.8 ± 19.3
Arousal index	14.3 ± 13.1	
Stage N1 (%)	10.4	
Stage N2 (%)	75.5	
SWS (%)	10	
REM (%)	4.1	

SWS slow wave sleep, REM rapid eye movement

Table 3 Specificity and sensitivity of actigraphy based on mechanical ventilation requirements

	Specificity (%)	Sensitivity (%)	Kappa Cohen
Study cohort	76.10	65.50	0.386 $p < 0.05$
Patient receiving mechanical ventilation	51	84.10	0.363 $p < 0.05$
Non- mechanically ventilate patients	83.70	56.70	0.371 $p < 0.05$
Daytime hours (06:00–22:00)	84.10	54.60	
Night-time hours (22:00–06:00)	52.90	78.30	
Daytime hours (06:00–22:00) + non-ventilated patients	90.20	41.40	
Night-time hours (22:00–06:00) + non-ventilated patients	62.30	73.50	
Daytime hours (06:00–22:00) + mechanical ventilation	60.90	80.00	
Night-time hours (22:00–06:00) + mechanical ventilation	32.30	89.70	

Table 4 Correlations of Polysomnography and Actigraphy sleep parameters

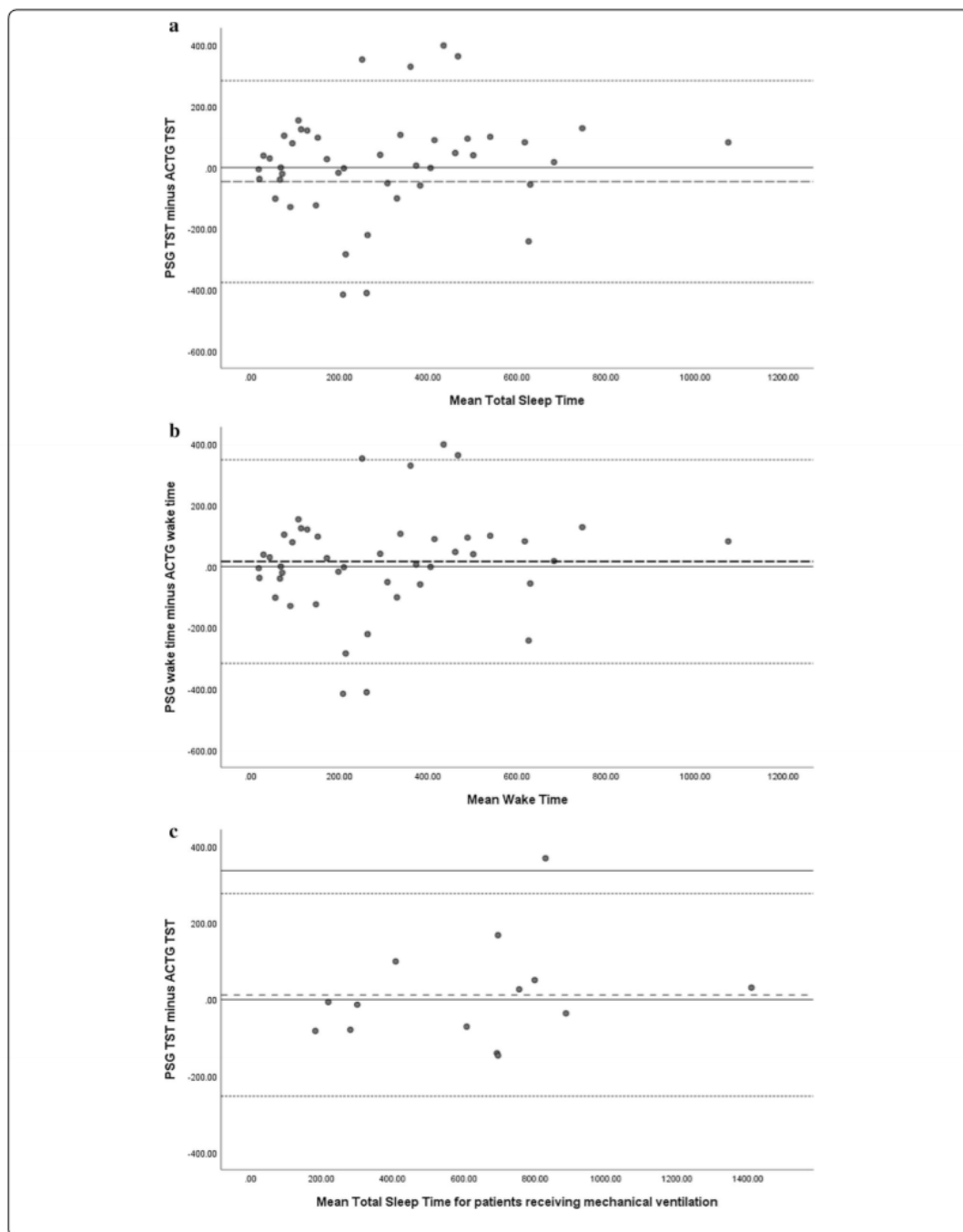
	ACTG wake time	ACTG TST	ACTG sleep percentage	ACTG awakening	ACTG fragmentation index
PSG Wake time	0.769**	0.052	0.045	0.408**	0.338*
PSG TST	− 0.079	0.873**	0.375*	0.323*	− 0.262
PSG sleep percentage	− 0.233	0.687**	0.411*	0.269	− 0.359*
PSG awakening	0.298*	0.308*	0.139	0.227*	0.052
PSG arousal index	0.257	− 0.204	− 0.051	0.101	0.322*

** $p < 0.00$; * $p < 0.05$

Whilst, TST reported by PSG and ACTG was found to have a high correlation amongst both mechanically ventilated patients ($r = 0.924$, $p < 0.000$), and non-mechanically ventilated patients ($r = 0.841$, $p < 0.00$). Sleep percentage retained a low level of correlation between PSG and ACTG in non-mechanically ventilated patients ($r = 0.411$, $p < 0.05$).

(See figure on next page.)

Fig. 2 Bland–Altman plots: Horizontal line drawn at the mean difference and at the mean difference plus and minus 1.96 times the standard deviation of the differences, with the y-axis reporting mean duration determine by polysomnography. **a** Polysomnography versus Actigraphy assessment of total sleep time. **b** Polysomnography versus Actigraphy assessment of wakeful states for the study cohort. Graphs **c** and **d** depict Polysomnography versus Actigraphy assessment of total sleep time amongst mechanically ventilated patients (**c**) and Polysomnography versus Actigraphy assessment of wakeful states for patients receiving mechanical ventilation (**d**). Non-ventilated patient total sleep time (PSG vs ACTG), and wake time (PSG vs ACTG) is represented in graph **e** and **f**



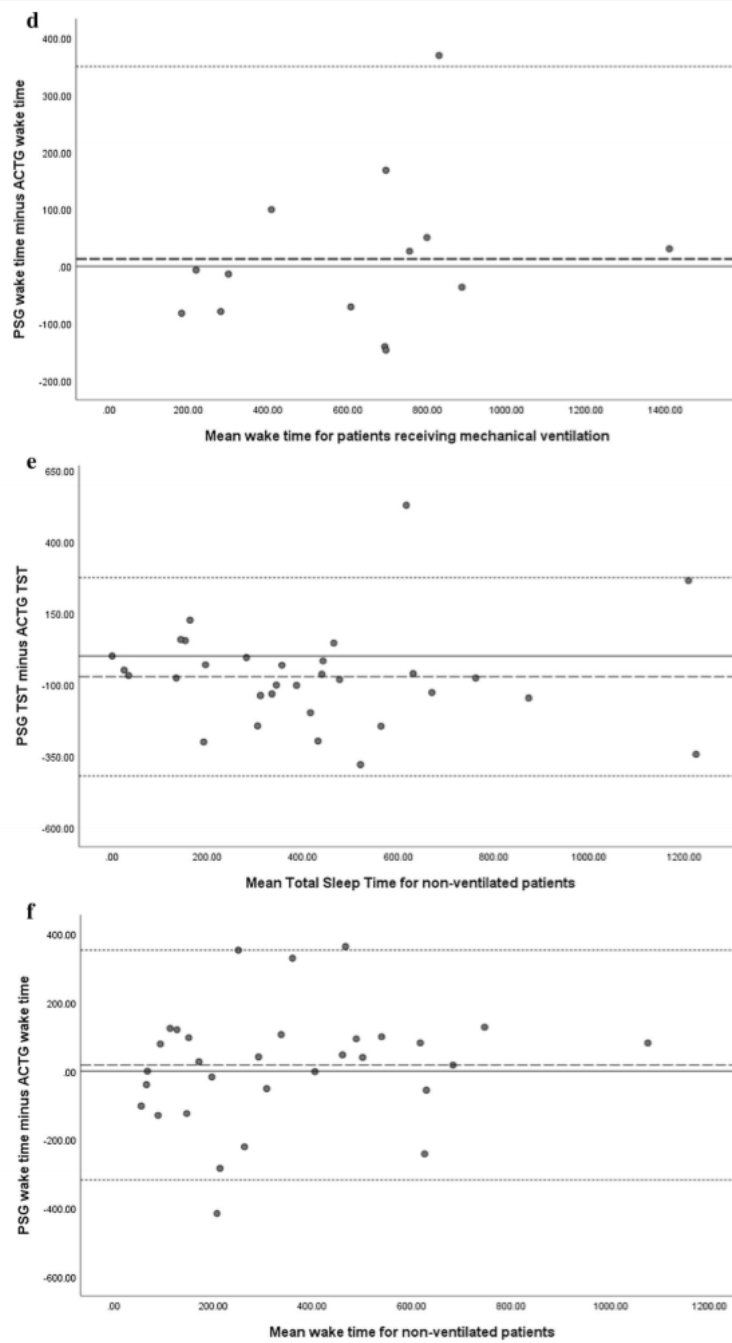


Fig. 2 continued

Bland–Altman plots of total sleep time and wake time indicated that ACTG overall overestimated TST by 46 min and underestimated wakeful states (16 min) (Fig. 2). The overestimation of TST was further increased amongst non-ventilated patients (73 min) and remained underestimated for wakeful states (18 min). The large standard deviation identified with the data is reflected by the level of agreement and suggest that there is large variability between the two measures. Linear regression analysis was performed on the assessments of wake time and total sleep time assessed by polysomnography compared to actigraphy amongst the group analysis indicated an absence of proportional bias ($p > 0.05$).

Discussion

Identifying a feasible objective physiological assessment of sleep is necessary to understand the impact of sleep disturbance on intensive care patients. This study undertook a comparison of sleep monitoring techniques to assess sleep and wakeful states using the accepted gold standard of sleep monitoring: polysomnography and motion accelerometer monitoring via actigraphy. Findings suggest that ACTG has a moderate level of sensitivity and specificity in identifying binary states of sleep and wakefulness, compared to PSG. Ventilation status (mechanical ventilation: non-mechanically ventilated) of patients was found to impact on the accuracy of the ACTG in distinguishing sleep and wake states. However, this was not found to be attributed to the administration of opioid or benzodiazepine infusions, rather higher APACHEII scores were linked to the need for mechanical ventilation. ACTG was found to have moderate to high levels of correlation with PSG in identifying sleep duration and wakefulness in non-ventilated patients.

Sleep is increasingly recognised as an important factor in patients' overall well-being and recovery, resulting in its integration into the Clinical Practice Guidelines for the Prevention and Management of Pain, Agitation/Sedation and Delirium developed by the Society of Critical Care Medicine [32]. Despite its inclusion, the ability for clinicians to feasibly monitor sleep and evaluate the effectiveness of sleep protocols and interventions has been problematic. However, our findings suggest ACTG may provide a surrogate method that can be clinically applicable amongst select ICU patients. This study is one of the first studies to report the feasibility of ACTG as a sleep monitoring technique within ICU, to assess sleep duration and disruption compared to PSG. Findings indicate that ACTG provides a clinically viable method for non-ventilated patients that is minimally invasive, easy to establish unattended monitoring and interpret findings [28].

Previous research in non-critical care contexts has validated ACTG against PSG (level of agreement $> 90\%$) in distinguishing sleep and wake states [33, 34]. However, its application in critically ill patients is limited, with previous research conducted by Beecroft et al. [5] and van der Kooi et al. [19] reporting low levels of agreement between PSG and ACTG. The findings of this study contest these and report an overall moderate level of agreement (69.4%), and accuracy to identify sleep (65.5%) and wakeful states (76.1%). The non-ventilated patient subset were found to have a improved level of agreement, which may be attributed to lower APACHEII scores (< 20), a reduction in the administration of opioids and benzodiazepines and RASS scores within the cohort. Sensitivity and specificity were found to vary considerably based on ventilation status with an increased specificity to identify wakeful states in non-ventilated patients and an increased sensitivity towards identifying sleep in mechanically ventilated patients. ACTG accuracy appears to decline when physiological activity is reduced which is consistent with mechanically ventilated patients. The findings of this study suggest that higher APACHEII scores may be an impacting factor on the accuracy of ACTG compared to PSG.

ACTG monitoring of non-ventilated patients reported a higher level of correlation to PSG in detecting wakeful and sleep states. This may be related to this patient demographic having more distinct physiological activity consistent with increased movement during wakefulness, with distinct reductions during sleep. In contrast, ACTG was found to correlate to PSG in reporting sleep states amongst mechanically ventilated patients, with a poor ability to detect wakefulness. This patient cohort are the greatest challenge in monitoring as spontaneous movement is frequently reduced due to pharmacological agents, higher clinical acuity, and atypical EEG activity which may be present in patients with higher APACHEII scores. As a result, ACTG's inability to distinguish between sleep and diminished physiological activity during wakeful states contributes to an erroneous interpretation. Mechanically ventilated patients within this study were assessed as having prolonged total sleep times, with limited arousals and spontaneous movements detected by both PSG and ACTG. The findings suggest that there is considerable variability between the two measures with ACTG having a modest level of agreement with PSG. The clinical application of ACTG for sleep monitoring may be more appropriate for non-ventilated patients cared for in the Intensive Care, whose wake states are observable.

Actigraphy was found to overestimate sleep and underestimate wakefulness which reiterates previously

published findings [5, 19, 35]. The sleep architecture of patients in this study was found to be atypical despite limited administration of benzodiazepines and less than 50% of the recruited patients requiring mechanical ventilation. Sleep was comprised of primarily stage N2 sleep and highly fragmented, with limited restorative components identified (SWS and REM sleep), which has been previously reported amongst ICU patients. Actigraphy's overestimation of sleep has been purported to be related to its lack of sensitivity in distinguishing between sleep, motionless resting activity and movement occurring during sleep or the provision of clinical care [5]. Specifically, how the commencement of sleep is recognised may be a critical factor impacting on accuracy. With ACTG denoting immobility as the beginning phase of a sleep period, whereas PSG identifies changes in neuroelectrophysiological activity patterns marking the onset of sleep. As these changes commence well after a period of wrist immobility, actigraphy is frequently reported to overestimate sleep time. This finding has been reported to be more pronounced in those patients with abundant wakefulness through the night [36]. The presence of sedating medication often effects EEG characteristics, which limited the accuracy of distinguishing between traditional sleep stages. When this occurred stage N2 was used as a default stage to indicate sleep.

The findings of this study affirm the challenges encountered in monitoring sleep via PSG within this cohort. As sleep traverses across the 24-h spectrum maintaining electrode placement over this duration is challenging as identified in this study. Further, PSG tethers patients to additional invasive monitoring, and increases the logistical complexities of providing patient care and increases patient discomfort. Technical issues included both poor signal quality due to electrode instability, which was exacerbated by the provision of clinical care in manoeuvring patients on and off the bed, as well as data loss due to the implications of the complexity of recording PSG. These factors frequently resulted in studies with usable data of less than 14 h, and highlight that PSG is suitable for widespread clinical implementation. As a result, it is imperative that assessment methods are identified that are both feasible and capable of prolong monitoring and, imposes a limited burden to the patient and does not further increase the complexity of providing patient care is required. Recording tolerance was identified as an issue amongst conscious patients with requests to terminate monitoring upon waking from the night of sleep. This was consistent with findings reported by Knaure et al. [18] who reported 31% of medical ICU patients experience issues with monitoring tolerance related to discomfort. The combination of technical issues and patient acceptability of PSG monitoring reiterates that it is an

unfavourable approach for widespread sleep monitoring in the ICU and may exacerbate sleep disturbance as a result.

Acknowledging the complexities of PSG monitoring and the limitations of ACTG in terms of patients with limited mobility and higher sedation scores are important considerations when implementing current available sleep monitoring techniques. Judicious assessment of patients should be considered when implementing ACTG for ICU sleep monitoring. In this study the devised exclusion criteria were developed based on previously reported sleep research, and the identified factors that can confound electroencephalographic activity and interpretation. The sedation level primarily reported in this study was a RASS score of zero (calm and cooperative), limited benzodiazepine administration, reduced requirement for invasive mechanical ventilation support, and lower APACHE II scores may be critical factors that aided in ACTG's ability to track patients sleep–wake patterns more accurately. As a result, ACTG monitoring was not implemented in clinical cases where it would have been deemed futile secondary to immobility and high sedation levels.

Sleep disturbance is recognised as a clinical issue that can negatively affect the rehabilitation of ICU patients and their engagement in activities aimed at expediting their recovery [35]. Furthermore, functional, and cognitive recovery has been reported to be impeded amongst patients who are subjected to sleep disturbance and fragmentation [36, 37]. The important role sleep has in functional recovery is supported by clinical research which indicates that addressing sleep disturbance amongst critically ill patients leads to reduced disability at discharge [38, 39]. Patients capable of spontaneous movement appear to be vulnerable to high levels of sleep disturbance and are potentially a target population within the ICU for sleep promoting interventions. Although, ACTG will not provide detailed information on sleep architecture, its potential application for monitoring sleep characteristics for those with protracted ICU admission may be of value, in that it can track sleep–wake cycles over extended durations, along with assessing the potential response to sleep supporting interventions.

Limitations

The findings reported in this study need to be considered before extrapolating them more widely, acknowledging that the research involved a single study centre, and as a result the findings may not be transferrable to other Intensive Care Units who have their own unique features and patient demographics. The research site employs a minimal sedation and early mobilisation practice in the provision of care, and as a result, patients may have

a lower RASS scores making patients more aware and interactive with their environment.

The implemented exclusion criteria for the study prohibited the recruitment of the most critically ill patients from participating in the study, and the findings cannot be transferred to this patient cohort. The ability to effectively monitor sleep in heavily sedated patients remains clinically challenging, with PSG likely to be the most appropriate assessment method currently available. It may be contended that in most critically ill patients within the ICU the focus of care is primarily on preserving life, and the sleep quality and quantity may not be a critical factor at this point of care. Rather, sleep may be a critical factor in the transitioning of care to recovery, weaning from mechanical ventilation and rehabilitation from critical illness whereby, sleep disturbance and deprivation may contribute to the potential onset of delirium [24, 40–43]. It is amongst this cohort, that ACTG may be most appropriate to implement. ACTG monitoring is not infallible and its limitations need to be acknowledged in terms of its potential to distinguish between voluntary and involuntary movements. Whereby, patients' wakeful inactivity may be identified as rest or sleep, and activity associated with care interventions such as repositioning may be inaccurately identified as a wakeful state [44].

Conclusions

Actigraphy was found to have a moderate level of agreement with PSG in distinguishing between sleep and wakeful states. There is a large variability between the two measures of sleep amongst both mechanical ventilation and non-ventilated patients. Correlations between ACTG and PSG were stronger amongst non-ventilated patients compared to those requiring mechanical ventilation. Although PSG is the gold standard for sleep monitoring its feasibility is debatable in the ICU environment when sleep traverses the 24 h. ACTG offers a modest level of agreement in identifying sleep, wakefulness, and sleep disturbance, was found to be more tolerable and less cumbersome than PSG, and data loss was minimal. Consideration should be applied to patient selection for ACTG sleep monitoring, with patients whose care has transition to recovery with reduced sedation being potential candidates. Future research is needed to ascertain the transferability of research findings to broader ICU environments that may have their own unique characteristics. Whilst ACTG is not able to provide information regarding sleep architecture, it does provide clinicians with useful objective biophysiological assessment of sleep quantity and fragmentation.

Abbreviations

ACTG: Actigraphy; ACTRN: Australian Clinical Trials Registration Number; APACHEII: Acute Physiologic Assessment and Chronic Health Evaluation 2; AUD\$: Australian Dollars; BMI: Body Mass Index; CCRT: Continuous renal replacement therapy; EEG: Electroencephalogram; ETH: Ethics; HDU: High Dependency Unit; Hz: Hertz; IABP: Intra-aortic balloon pump; ICU: Intensive Care Unit; IQR: Inter quartile range; K: Kappa; M: Mean; MRI: Magnet Resonance Imaging; N: Number; PSG: Polysomnography; R: Pearson correlation; RASS: Richard Agitation–Sedation Scale; REM: Rapid eye movement; SD: Standard deviation; SOFA: Sequential organ failure assessment; SST: Senior Sleep Technologist; SWS: Slow wave sleep; TST: Total Sleep Time.

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Authors' contributions

LJD, FH, EL, H-CCH, VL contributed to the project development and study design. LJD and KLM contributed data collection and interpretation of the data. LJD, KLM, FH, EL and H-CCH contributed to data analysis. LJD developed the manuscript. LJD, FH, EL, H-CCH, VL and KLM critically edited and revised the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets analyzed during the current study are not publicly available due to the clinical study report being finalized but will be available from the corresponding author on reasonable request at a later time.

Ethics approval and consent to participate

The study was approved by an institutional Human Research Ethics Committee and was conducted in accordance to the National Health and Medical Research Council Ethical Guidelines. Informed consent was obtained from either the patient or the patients legally authorized representative if the patient was unable to consent. This trial was registered at the Australian and New Zealand Clinical Trials Registry: (No: ACTRN12615000945527).

Consent for publication

Not applicable.

Competing interests

Nil competing interests to declare.

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5.3 Chapter Linkage

The application of motion accelerometers presents a potential monitoring approach that may be viable for implementation in the ICU. It provides a feasible and minimally invasive method that is uncomplicated for clinicians. The study highlights the potential for

this monitoring approach among non-ventilated patients cared for in the ICU. The following chapter presents the findings related to the nocturnal monitoring (22:00 – 07:00 hours) of sleep among conscious ICU patients. Conscious patients make up a large percentage of ICU admissions and are particularly susceptible to sleep disturbances due to extrinsic factors. The following chapter integrates the reported sleep experience of patients cared for in the ICU.

Chapter 6: Sleep Among Conscious Intensive Care Patients

6.1 Introduction

The paradigm shift towards lighter sedation of patients has resulted in a change of practice that aims to reduce the duration of mechanical ventilation and hospital length of stay, resulting in an increased number of conscious ICU patients (Heffner, 2000; Vincent et al., 2016). This, combined with a reduced need for mechanical ventilation secondary to early identification of patients needing specialist support and evolving approaches to ventilatory support, such as high-flow nasal prongs (Ni et al., 2018; Sztrymf et al., 2012), non-invasive ventilation (Scala & Pisani, 2018) and advancing mechanical ventilation modalities, has contributed to a changing demographic profile of patients cared for in the ICU. Increased consciousness may result in increased vulnerability to sleep disturbance because of their cognitive awareness, increased interactivity with the clinical environment, and frequently cared for bed spaces in which multiple patients are cared for with variable clinical acuity. Importantly, these patients have an increased capacity to communicate their experiences and issues related to poor quality and quantity of sleep, providing valuable insights into potentially addressing sleep disturbance in the ICU.

6.2 ‘The Accuracy of Simple, Feasible Alternatives to Polysomnography for Assessing Sleep in Intensive Care: An Observational Study’

The following presents the research findings regarding the sleep experience of conscious ICU patients and the feasibility of ACTG as a surrogate measure of sleep, published 8 March 2022 in *Australian Critical Care* (<http://doi.org/10.1016/j.aucc.2022.02.004>), including text, tables, figures and references.



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Research paper

The accuracy of simple, feasible alternatives to polysomnography for assessing sleep in intensive care: An observational study

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ABSTRACT

Background: Sleep disturbance is common in intensive care patients. Understanding the accuracy of simple, feasible sleep measurement techniques is essential to informing their possible role in usual clinical care.

Objective: The aim of the study was to investigate whether sleep monitoring techniques such as actigraphy (ACTG), behavioural assessments, and patient surveys are comparable with polysomnography (PSG) in accurately reporting sleep quantity and quality among conscious, intensive care patients.

Methods: An observational study was conducted in 20 patients admitted to the intensive care unit (ICU) for a minimum duration of 24 h, who underwent concurrent sleep monitoring via PSG, ACTG, nursing-based observations, and self-reported assessment using the Richards–Campbell Sleep Questionnaire.

Results: The reported total sleep time (TST) for the 20 participants measured by PSG was 328.2 min (± 106 min) compared with ACTG (362.4 min [± 62.1 min]; mean difference = 34.22 min [± 129 min]). Bland–Altman analysis indicated that PSG and ACTG demonstrated clinical agreement and did not perform differently across a number of sleep variables including TST, awakening, sleep-onset latency, and sleep efficiency. Nursing observations overestimated sleep duration compared to PSG TST (mean difference = 9.95 ± 136.3 min, $p > 0.05$), and patient-reported TST was underestimated compared to PSG TST (mean difference = -51.81 ± 144.1 min, $p > 0.05$).

Conclusions: Amongst conscious patients treated in the ICU, sleep characteristics measured by ACTG were similar to those measured by PSG. ACTG may provide a clinically feasible and acceptable proxy approach to sleep monitoring in conscious ICU patients.

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1. Introduction

More than 60% of patients treated in intensive care units (ICUs) within Australia and New Zealand do not require mechanical ventilation¹ and, therefore, do not receive large doses of sedative medications which potentially affect the interpretation of polysomnography (PSG) and render the patient inactive leading to overestimations of total sleep time (TST) when assessing sleep using actigraphy (ACTG). Moderate to severe sleep disturbance is

reported by 70% of patients admitted to the ICU and adversely affects sleep quality and quantity.² Sleep disturbance is associated with increased psychoneuroimmunological stress^{3–5} and deleterious effects including impaired recovery and quality of life.^{6,7}

PSG is the gold standard for sleep monitoring but is not feasible in routine clinical care due to the associated time, complexity, and expertise required for undertaking monitoring. Despite its diagnostic application, it is poorly tolerated by patients as a standardised sleep monitoring approach.⁸ The emergence of wearable technology, such as ACTG, has contributed to a digital health revolution. ACTG provides a novel approach to sleep monitoring and is an accepted alternative to PSG in nonlaboratory settings.⁹ The application of ACTG within the clinical setting is an emerging field

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of research, and studies conducted within the ICU suggest that ACTG has the propensity to overestimate TST and sleep efficiency (SE) compared to other measures, such as PSG, nursing observation, and patient reports.^{10–13}

Commonly implemented sleep assessments in the ICU include behavioural assessments (patient self-reports and staff-based observations); although cost-effective, these are perceived as less reliable than objective measures. These approaches exclude patients who lack the mental acumen to complete surveys/questionnaires, are susceptible to incomplete documentation, and provide rudimentary information regarding sleep. Their clinical accuracy has been debated due to the difficulty in determining sleep from rest and impact of medication^{11,14,15} and may be reflective of a general estimation or clinical guess work. Exploring the feasibility of surrogate measures is required to identify alternative sleep monitoring techniques that reduce the reliance on subjective information, are accurate, and have the potential for widespread implementation.

Sleep emerges as a component of clinical care necessary to support patient recovery within a changing demographic of ICU admissions, with a trend towards less sedation and increased consciousness. Exploring the benefit of implementing adjunct monitoring methods provides objective assessments of patients' sleep profile (sleep duration, sleep disturbance, and circadian patterns). The aim of this study was to investigate whether ACTG, nursing-based observations, and patient self-reports via the Richard–Campbell Sleep Questionnaire (RCSQ) are comparable with PSG in measuring sleep quantity and quality amongst conscious, intensive care patients. The study hypothesis proposes that ACTG provides an accurate assessment of sleep duration, fragmentation, and quality compared to PSG and is superior in its assessment of sleep quality and quantity compared to the RCSQ and nursing-based observations.

2. Methods

2.1. Study design and setting

This study reports on a secondary analysis from the prospective cross-sectional observational ICU sleep study.¹⁶ A single night's sleep monitoring was performed using a within-subjects design with concurrent sleep monitoring techniques—PSG, ACTG, nursing observations, and the RCSQ—within an Australian 39-bed level 1 tertiary referral ICU. The nocturnal period for sleep monitoring was deemed to be from 22:00 to 06:00 h to reflect the time when lights are dimmed for the commencement of night and increased in the morning in preparation for increased clinical activity. The topography of the clinical environment included four isolation rooms and shared patient care bays; nurse-to-patient ratios within the unit were 1:1 for ICU admissions and 1:2 for high-dependency unit (HDU) admissions. All patients admitted to the ICU are cared for in the same clinical environment irrespective of being assessed as an ICU or HDU admission. Patient classification of ICU/HDU was determined by the assessment of the treating medical team and based around patient acuity and clinical care needs. The ICU permitted open visitation hours and did not have established policies or guidelines regarding patient sleep.

2.2. Participants

The substudy sample was recruited between June 2017 and September 2019 and represents the patients admitted to the ICU who met the following inclusion criteria: adult patients (aged 18 years or older) admitted to the ICU with an anticipated length of

stay of greater than 24 h, Glasgow Coma Scale (GCS) of 15/15, Confusion Assessment Method for ICU (CAM-ICU) negative, and English language proficiency to complete the survey items were eligible to participate in the study. All potential study participants were screened for enrolment each morning using the published study protocol.¹⁶ Exclusion criteria for the study included diagnosis and treatments that impeded biophysiological monitoring and included admission for a primary neurological condition, treatment related to palliation or expected survival less than 24 h, confirmed or suspected drug overdose, administration of neuromuscular-blocking agents or barbiturates during the monitoring period, injuries that prohibited the placement of PSG electrodes or ACTG such as facial or limb fracture, spinal cord injury, and clinically suspected encephalopathies (i.e., septic, hepatic). Demographic data pertaining to the patient and admission characteristics were obtained from the ICU electronic monitoring system (Metavision; iMDsoft, Tel Aviv, Israel) including age, gender, Acute Physiological and Chronic Health Evaluation II (APACHE II), Sequential Organ Failure Assessment (SOFA), Richmond Agitation Sedation Scale (RASS), admission diagnosis, respiratory support, height and weight.

2.3. Outcome measures

2.3.1. Polysomnography

Sleep monitoring was initiated at 22:00 and ceased at 06:00 h to reflect the time when lights are dimmed within the unit for night and when the lights are turned back on to reflect increased morning activity. PSG monitoring was conducted using Embla PSG (VMedical) ambulatory device, with electrode placement based on the international 10–20 electrode placement standards for portable monitoring (details previously published).¹⁶ Derived data were downloaded using RemLogic Software (Embla@RemLogic™ MPR) and analysed by a registered polysomnographic technologist. Sleep scoring was performed in accordance with the American Academy of Sleep Medicine Manual for Scoring Sleep and Associated Events (version 2.6); TST was defined as the duration of sleep acquired during the monitoring period.¹⁷ SE was determined to be the TST expressed as a percentage of the total recording time, with an SE >80% indicating a good quality of sleep.¹⁷ Arousal was defined as an increase in alpha activity present for 3–15 s, whilst an awakening was determined to be an activation lasting for >15 s.¹⁷

2.3.2. Actigraphy

A piezoelectric motion accelerometer (Actiwatch Plus: Spectrum, Phillips Respironics) was applied to the participants' wrist with the least amount of instrumentation (e.g., arterial line, peripherally inserted venous catheters) from 22:00 to 6:00 h. ACTG detects multiplanar motion activity to determine sleep–wake states of forces at 0.01 g with a sampling rate of 32 Hz and was synchronised with PSG monitoring via the data acquisition computer. ACTG threshold sensitivity setting was programmed to moderate in line with validation studies for this setting and analysed as sleep or wake at 30-s epochs using the ACTG analysis software (Actiware, version 6.0.9; Phillips Respironics). TST determined by ACTG was defined as the number of epochs for the given interval scored as sleep multiplied by the epoch length in minutes, while SE was the calculated as the percentage of assessed sleep during the TST (sleep time/TST × 100).¹⁸ The fragmentation index was determined as the sum of percent mobile and percent 1-min immobile bouts divided by the number of immobile bouts for the given interval. Awakenings were determined to be the total number of wake bouts within the sleep intervals.¹⁸

2.3.3. Subjective behavioural monitoring

Behavioural assessments of sleep–wake states were conducted by intensive care nurses based on the Edwards and Schuring's method.¹⁹ Intensive care nurses were blinded to both ACTG and PSG data and were required to manually document the patients sleep–wake state each hour between 22:00 and 06:00 h. Documentation of their observations included awake (patient did not sleep for that hour) or asleep for 15 min or less of the hour, 15–30 min, 30–45 min or was observed to be asleep for the entire hour. Hourly sleep documentation data were integrated into the electronic patient record (Metavision: iMDsoft). TST was calculated through accumulating the hourly totals reported, and SE was calculated based on their documented assessments.

2.3.4. Richards–Campbell Sleep Questionnaire

The five-item RCSQ was completed between 09:00 and 10:00 the morning after the ACTG and PSG monitoring. Patients rated their sleep characteristics (sleep depth, sleep latency, awakenings, SE, time awake, and perceived noise exposure) according to the visual analogue scale (0–100 mm).²⁰ Patients were also asked to quantify their sleep duration in hours the following morning based on their perceived experience.

2.4. Sample size and data analysis

The sample size in this subanalysis ($n = 38$) was derived from the 80 participants who participated in the ICU sleep study. The ICU sleep study sample size was calculated based on the Cohen power primer to determine a moderate effect size (0.3).

Descriptive analysis reporting parametric (means, standard deviations, and ranges) and nonparametric (median and interquartile range [IQR]) were applied to continuous data, with percentages and frequencies to describe categorical data. Paired *t*-tests were conducted to identify differences in the sleep assessment domains of TST, SE, onset latency, and awakening. The mean score of the RCSQ was derived by combining the reported score from questions 1 to 5 and represented the overall perception of sleep. The total RCSQ score for participants were converted into an estimate of the sleep efficiency index (SEI) using the following formula: $SEI = 46.88 + (0.39 \times RCSQ)$ derived from the regression formula reported by Richards et al. in which 33% of variance in the SEI measure by PSG could be explained by the RCSQ total score.^{20,21}

Pearson's correlation coefficient was performed on PSG, ACTG, and the RCSQ to identify the presence of linear relationships between sleep assessment parameters. A limit of agreement approach comparing the sleep monitoring techniques was applied using the Bland–Altman concordance assessment. Statistical analysis of the acquired data was conducted via SPSSTM,²² with *p* values < 0.05 deemed statistically significant. The study was undertaken and reported in accordance with the Strengthening of Reporting of Observational Studies in Epidemiology (STROBE) guidelines.

2.5. Ethical approval

Patients provided either independent written or verbal consent to participate in the study. Determination of the patient's ability to provide consent was made based on assessment findings including the GCS, CAM-ICU, and RASS and in consultation with the bedside clinical staff. The study was approved by the institution's Human Research Ethics Committee (ETH: 5.16.071), and the primary study was formally registered as a clinical trial with the Australian New

Zealand Clinical Trial Registry [ACTRN 126150000945527] (Registered 9/9/2015).

3. Results

3.1. Demographic profile

A total of 38 patients were enrolled into the study to undergo concurrent sleep monitoring. PSG sleep monitoring was found to be more challenging as a result of dislodgement of electrodes, technical problems interpreting the data and reduced patient tolerance compared with ACTG, nursing observations, and patient-completed RCSQ (Fig. 1). A small number ($n = 3$) of ACTG recordings were lost due to staff removing the device to address patient hygiene ($n = 2$) and failure to initiate recording ($n = 1$). The final cohort included 20 participants (Fig. 1).

The mean age of participants was 53.8 years (± 16.7 years). Participants were primarily assessed (60%; $n = 12$) as being alert and calm (RASS score of 0) and had a median length of ICU stay of 5.6 days (IQR = 5.8 days), with 80% ($n = 16$) of patients being discharged home after their ICU and hospital admission (Table 1). The median APACHE II score of ICU participants (median = 20; IQR = 9.3) was significantly higher than that of HDU (median = 14.5; IQR = 4.3) participants (Mann–Whitney $U = 20.5$ $p = 0.33$).

3.2. PSG-reported sleep characteristics

PSG sleep monitoring reported a mean sleep duration of 328.2 min (± 106) (Table 2), with 74% of the TST being comprised of light sleep (stage N2). Restorative sleep stages are slow wave sleep and rapid eye movement sleep comprised of less than 12% of the TST, whilst 14% was made up of stage N1. Good quality of sleep (SE > 80%) was detected in 25% ($n = 5$) of patients undergoing PSG sleep monitoring.

3.3. Assessment of agreement between PSG and ACTG

The differences between the TST recorded by ACTG compared to PSG were found to be nonstatistically significant ($t(20) = -1.19$ $p > 0.05$), with ACTG more likely to overestimate (mean difference = 34.22 ± 129 min) TST (Table 2). Agreement between the sleep monitoring techniques reported by Bland–Altman plots depict the systematic differences between the measurements, with the standard deviation indicating variability between the two measures (Fig. 2). Linear regression revealed the presence of a proportional bias (Beta = 1.08 $p = 0.028$) (Fig. 2a) between the range of measurements involving PSG and ACTG assessments of TST. Bland–Altman plots comparing the mean and difference between PSG and ACTG in reporting SE and awakening suggest the presence of clinical agreement and that the measures do not perform differently (Fig. 2b and c). Onset latency (Fig. 2d) identified a proportional bias between PSG and ACTG (Beta 1.22, $p = 0.000$), and the predicted difference between the means was found to be $42.2 \text{ min} + 1.22 \times \text{mean}$.

Linear relationships between assessments were not identified between PSG TST and ACTG TST ($r = -0.117$; $p = 0.624$). PSG sleep characteristics were also not correlated with ACTG sleep characteristics ($p > 0.05$). PSG-evaluated SEI did not correlate with ACTG-evaluated SE ($r = 0.026$, $p > 0.05$). Overall ACTG correlated poorly with PSG across a variety of paired variables: PSG sleep latency compared to ACTG sleep latency ($r = 0.282$, $p > 0.05$), PSG wake after sleep onset compared with ACTG awakenings ($r = -0.127$, $p > 0.05$).

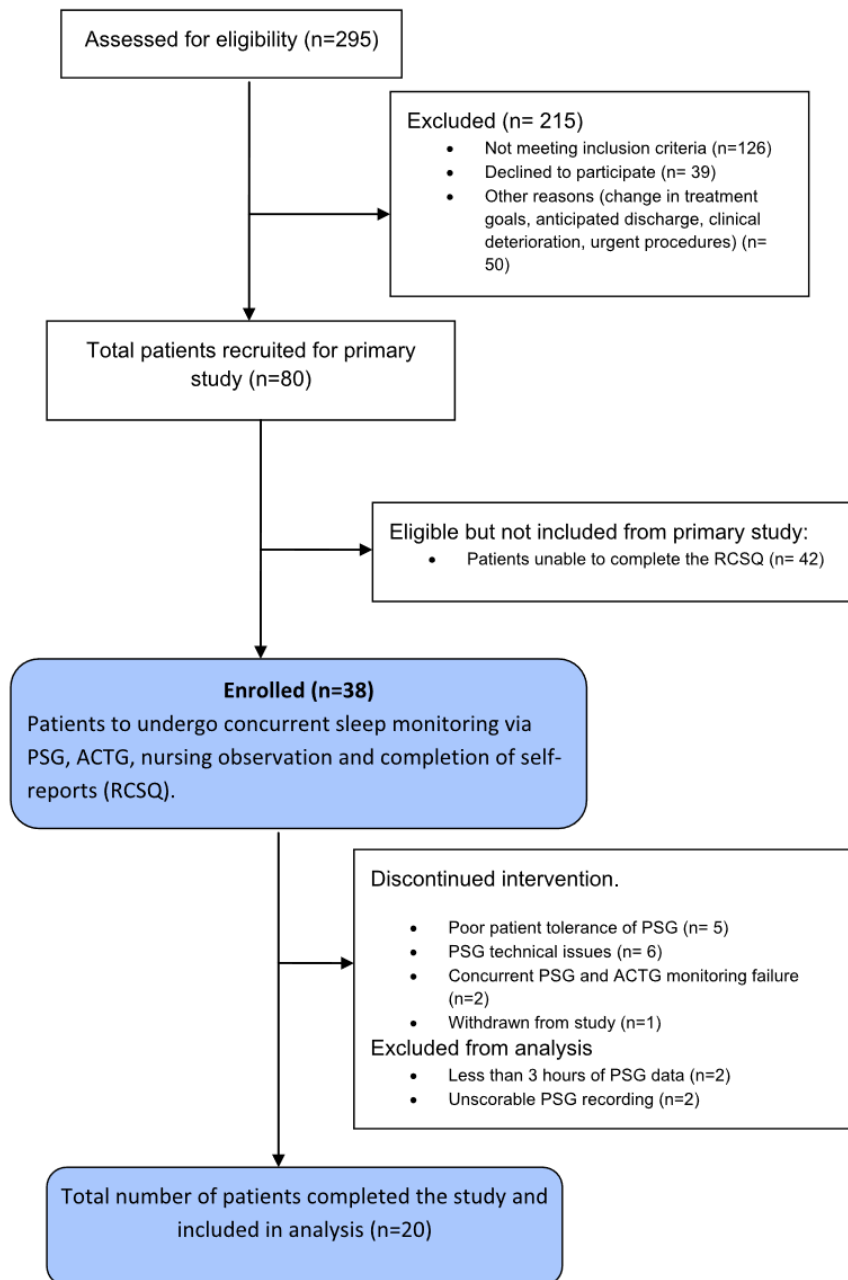


Figure 1. STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) flow diagram. RCSQ, Richard–Campbell Sleep Questionnaire; ACTG, actigraphy; PSG, polysomnography.

Table 1
Demographic characteristics of the patient cohort.

Demographic variables	Category	N (%)	Range
Age (years) [mean $\pm$ SD]	53.8 (16.7)		27–87
Gender	Male	10 (50)	
	Female	10 (50)	
Admission classification	ICU	8 (40)	
	HDIU	12 (60)	
APACHE II [mean $\pm$ SD]	15.75 (5.8)		6–28
APACHE II relative risk (%) [mean $\pm$ SD]	25.5 (15.7)		6.7–73.3
SOFA [mean $\pm$ SD]	11.2 (4.4)		4–21
ICU LOS at recruitment (days) [median; IQR]	2.1 (3.4)		
Total ICU LOS (days) [median; IQR]	5.6 (5.8)		
Total hospital LOS (days) [median; IQR]	14.4 (16.3)		
Discharge outcome:	Home	16 (80)	
	Other Acute Care	3 (15)	
	Hospital		
	Rehabilitation	1 (5)	
Height (cm) [mean $\pm$ SD]	172.7 (8.1)		152–187
Weight (kg) [mean $\pm$ SD]	89.6 (22.1)		63–140
BMI [mean $\pm$ SD]	30.5 (9.8)		19.9–60.6
RASS	Drowsy (–1)	5 (25)	
	Alert and Calm (0)	12 (60)	
	Restless (+1)	3 (15)	
Oxygen therapy	Nil	5 (25)	
	Standard oxygen therapy	3 (15)	
	High-flow oxygen therapy	9 (45)	
	Noninvasive ventilation	1 (5)	
	Mechanical ventilation	2 (10)	
Admission classification	Respiratory	7 (35)	
	Sepsis	3 (15)	
	Multitrauma	2 (10)	
	Cardiovascular	1 (5)	
	Cardiothoracic	3 (15)	
	General surgical	4 (20)	
Diagnosed sleep disorder	Yes	4 (20)	
	No	16 (80)	
Sedation	Propofol	1 (5)	
Medication	Melatonin	3 (15)	
	Corticosteroids	2 (10)	
	Beta blocker	4 (20)	
	Diuretics	3 (15)	
	Calcium channel blocker	1 (5)	
	Opioids	11 (55)	
	Benzodiazepines	1 (5)	
	Vasoactive	7 (35)	

APACHE II: Acute Physiological and Chronic Health Evaluation II; BMI: body mass index; cm: centimetre; HDIU: high-dependency unit; ICU: Intensive care unit; kg: kilogram; LOS: length of stay; RASS: Richmond Agitation Sedation Scale; SD: standard deviation; SOFA: Sequential Organ Failure Assessment.

3.4. Assessment of agreement between PSG, nursing observations, and patient surveys of sleep

Nursing observation of sleep were found to overestimate sleep duration compared to PSG; however, the two assessments were found not to be significantly different (mean difference = 9.95 ± 136.3 min) ($t(20) = -0.326$, $p > 0.05$). Conversely, patient self-assessment of sleep underestimated TST by almost 1 h compared to PSG (mean difference = -51.81 ± 144.1 min) ($t(16) = 1.44$, $p > 0.05$). The PSG results showed that the mean TST and differences between TST compared with nursing-based observations indicated an absence of proportional bias (Beta = 0.246, $p = 0.581$) (Supplementary file).

PSG was found to correlate poorly with the patient-completed RCSQ across a variety of paired variables: PSG sleep latency compared to RCSQ sleep latency ($r = -0.316$, $p > 0.05$); PSG wake

after sleep onset compared with RCSQ returning to sleep ($r = -0.117$, $p > 0.05$). PSG-evaluated SEI was found to not to correlate with RCSQ SEI ($r = 0.274$, $p > 0.05$). Bland–Altman analysis of the mean TST and differences in TST between PSG and patient-reported sleep duration revealed the presence of proportional bias (Beta = 0.067, $p = -0.041$) (Supplementary file).

3.5. Sleep quality measured by the RCSQ

Patients perceived their sleep quality to be low, with each of the five RCSQ domains showing a score less than 50 mm, with a SEI below 85% (good quality of sleep) (Table 3). These appear consistent with the reported findings derived from PSG and ACTG. Patients who reported higher RCSQ total scores (>67) were not found to have higher TSTs reported by PSG ($M = 303.1$ min $\pm$ SD = 136.7) and ACTG ($425.3 \pm$ SD = 33.8) than patients who reported moderate (RCSQ total score = 34–66; PSG TST $M = 351 \pm$ SD = 78.4 min; ACTG TST $M = 331.1 \pm$ SD = 22.4 min) to poor sleep (0–33; PSG TST $M = 310.5 \pm$ SD = 135 min; ACTG TST $M = 267.5 \pm$ SD = 37.5 min) via the RCSQ. The RCSQ was found to have a high level of internal consistency (Cronbach $\alpha = 0.906$).

4. Discussion

Patients cared for in the ICU consistently report sleep disturbance. The clinical challenge to address sleep disturbance in the ICU is to first identify methods that allow for ongoing clinical monitoring. The sleep monitoring techniques applied in this study are suggestive of both a reduction in sleep quality and quantity consistent with previous research.^{12,23,24} Although linear relationships between proxy sleep assessments and PSG as a reference standard were not identified, there appears to be an emerging presence of agreement between measurements, whereby ACTG may present as a clinically feasible proxy assessment of sleep quality and quantity within a nonsedated ICU patient population. Presently, PSG remains the only validated assessment for sleep; however, it is more susceptible to data loss than alternate assessments such as ACTG. Subjective behavioural assessments conducted by patients and intensive care nurses were found to have considerable clinical variability in their concordance potentially impacted by the ability to recall the sleep experience and attention to documenting sleep and may have limited clinical application.

Sleep monitoring performed via PSG, ACTG, and nursing observation indicated restricted (less than 6 h) nocturnal sleep that was highly fragmented and are reflective to similar previous PSG studies monitoring nocturnal sleep.^{24–28} Sustained sleep restriction adversely impacts patient performance and contributes to adverse health consequences,²⁷ acting as an impediment to physical and cognitive rehabilitation.^{28–31} A polyphasic sleep distribution was evident amongst patients, characterised by sleep fragmentation and frequent stage shifts producing a higher prevalence (74%) of nonrestorative sleep comprised of stage N2 sleep similar to that reported by Darbyshire et al.¹³ The extent of the sleep disturbance experienced is reiterated in the patients reported RCSQ total score under 50 (47.5 ± 22.7), which is the cutoff score for good-quality sleep (sensitivity of 82% and specificity of 87%).³²

Objective proxy measures of sleep are required to support widespread implementation, which yields clinical information regarding sleep characteristics such as sleep duration, SE, and fragmentation. Comparison of differences between PSG and ACTG across a number of variables indicated an absence of statistical differences, with ACTG having a propensity to overestimate sleep by 35 min in our study. The variance in measures is attributed to the

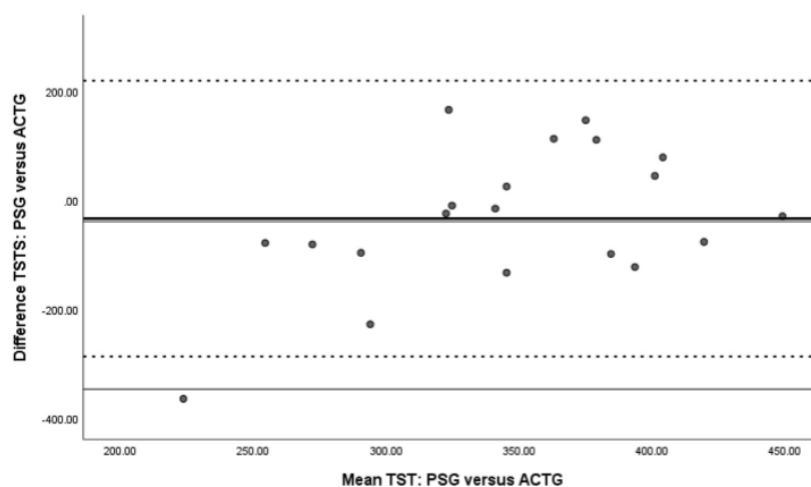
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Table 2

Sleep profiles reported via the used sleep monitoring techniques.

Sleep parameter	Polysomnography (n = 20)	Actigraphy (n = 20)	Nursing observations (n = 20)	Patient assessment (n = 20)
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Sleep duration (min)	328.2 (106)	362.4 (62.1)	338.1 (92.9)	270 (115.9)
Wake after sleep onset (min)	24 (28.36)	49.58 (29.25)		
Onset latency (min)	35.34 (82.39)	33.65 (32.67)		
Awakenings (number)	31.2 (17.7)	36.8 (14.96)		
Fragmentation index		36.51 (12.5)		
Sleep efficiency (%)	64.94 (25.62)	74.87 (14.58)		
Arousals (number)	68.21 (44.5)			

(A)



(B)

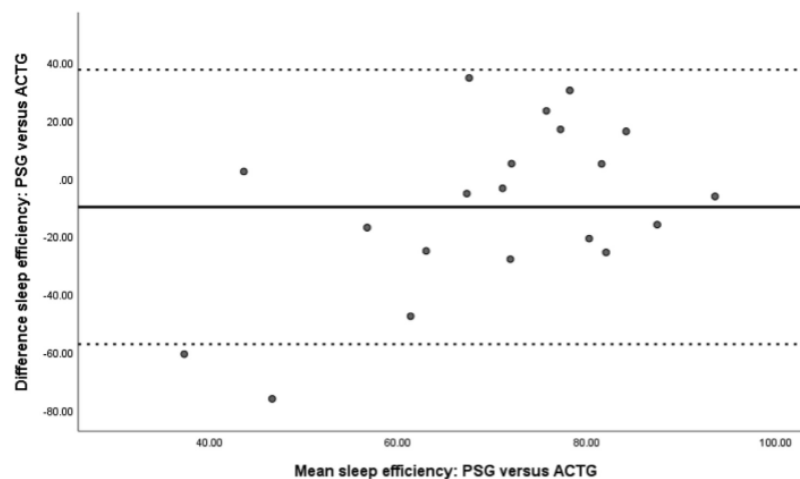
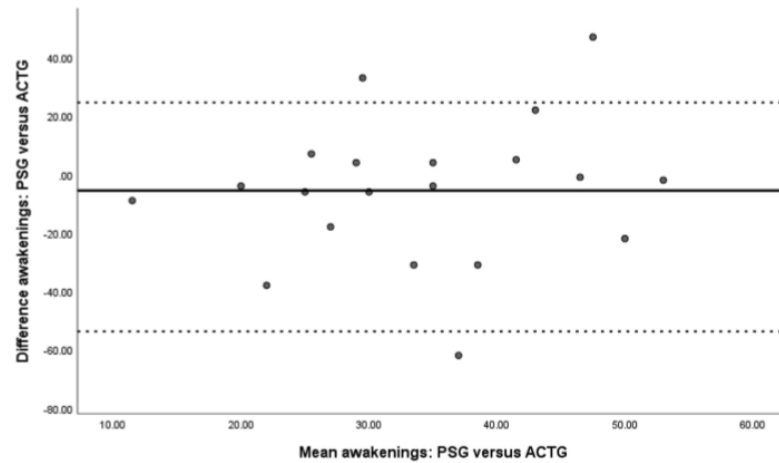


Figure 2. Bland–Altman plots depicting the level of agreement reported by the sleep monitoring techniques. Horizontal lines indicate the mean difference and the mean difference plus and minus 1.96 times the standard deviation of the difference; (A) PSG versus ACTG reported TST; (B) PSG versus ACTG reported sleep efficiency; (C) PSG versus ACTG reported awakenings; (D) PSG versus ACTG reported onset latency. ACTG, actigraphy; PSG, polysomnography; TST, total sleep time.

(C)



(D)

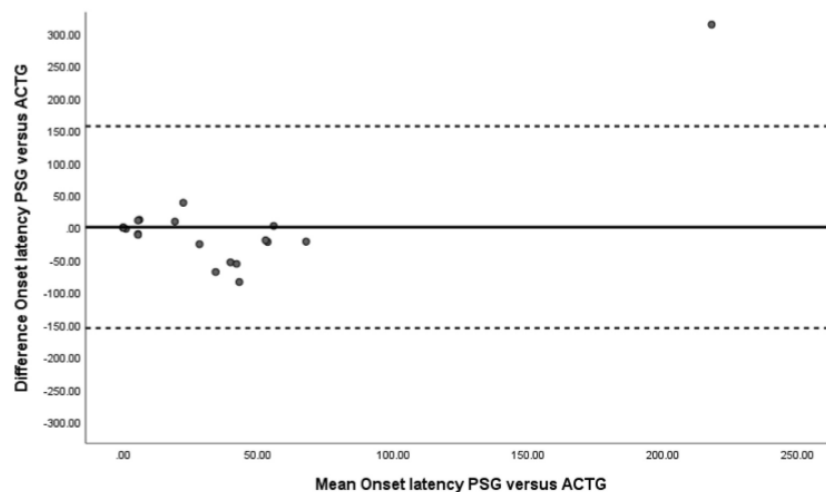


Figure 2. (continued).

Table 3
Patient (n = 20)-reported quality of sleep in the intensive care.

Sleep questionnaire measure	Mean (SD)	Range
Sleep depth (Q1)	42.4 (26.7)	9–100
Sleep latency (Q2)	49.8 (27.9)	8–100
Awakenings (Q3)	47.3 (24.3)	14–100
Returning to sleep (Q4)	52 (28.9)	9–100
Sleep quality (Q5)	45.6 (30.5)	5–100
Overall sleep score ^a	47.5 (25.2)	12–100
RCSQ sleep efficiency index **	65.4 (9.8)	51.6–85.9

RCSQ, Richard–Campbell Sleep Questionnaire; SEI, sleep efficiency index; SD, standard deviation.

** RCSQ sleep efficiency index calculated via $SEI = 46.88 + (0.39 \times RCSQ)$.

^a Average of five items (Q1–Q5), RCSQ sleep efficiency index calculated via $SEI = 46.88 + (0.39 \times RCSQ)$.

differences in the two methods detecting the onset of sleep and the algorithms applied in ACTG monitoring which leads to an earlier sleep onset phase than in PSG.³³ Beneficially, ACTG offers clinicians a cost-effective approach to sleep monitoring compared to PSG, providing a dearth of objective clinical data to evaluate sleep quality and quantity that can be rapidly assessed and responded to in real time which is not captured with nursing-based observations or patient self-reports. The concordance between the measures suggests that ACTG as a proxy assessment of sleep may provide a clinically sufficient sleep assessment method, noting an absence of predefined acceptable levels of agreement and intention to formally diagnose a sleep disorder. Minimally invasive, ACTG monitoring has been previously reported to be more acceptable to patients than PSG and is clinically uncomplicated allowing for sleep monitoring to be conducted over a protracted period unlike PSG.⁸

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Subjective approaches to assessment afford the ease of implementation, and these are uncomplicated and financially favourable for organisations. However, behavioural monitoring using either nurses observations or patient self-reports have been challenged in terms of their clinical accuracy. Despite their ease of implementation, a recent report suggests sleep is formally documented less than 20% of the time and may be rarely acted upon,³⁴ whilst issues impeding patients' ability to complete self-reports range from 20% to 50%.^{11,35} As a result, these approaches are impractical for the ICU environment, as it is not feasible for staff to complete focussed sleep assessments whilst concurrently meeting the care needs and workflow processes (admitting and discharging patients, assisting with other patient care and work breaks) within the ICU. The absence of correlation between subjective sleep assessment and PSG in this study confirms the findings reported by Locihova et al.¹² and Beecroft et al.¹⁰ who found that subjective sleep assessments lack diagnostic effectiveness. The application of visual observation undertaken by staff may be limited to identifying patients who may require more formalised sleep monitoring to evaluate the extent of sleep disturbance and profile of sleep.

Patients' ability to accurately evaluate their sleep quality and quantity was found to be variable and the least accurate assessment method. The accuracy of patient assessment is influenced by factors such as the number of awakenings experienced overnight, whereby awakenings extending beyond 4 min have been found to result in patients significantly underestimating their sleep quality, whilst those with frequent but short awakenings who are able to rapidly return to sleep tended to overestimate sleep quality.³⁶ Administered pharmacological agents in the context of acute illness can adversely affect patients' self-assessment, along with the negative impacts sleep disturbance has on memory can contribute to inaccurate perceptions of sleep and time.^{11,37} Previous research in both non-ICU³⁷ and ICU settings^{38,39} have asserted that patients are inaccurate in their assessment of sleep quantity compared to behavioural assessment and patients' subjective sleep assessment correlates poorly with PSG TST.

Nonetheless, they provide important insights into the patient experience which consistently support the PSG findings that sleep quality and quantity is impaired. Therefore, acknowledging the patient experience may provide the initial assessment mitigating the need for costly interventions such as PSG to consider the impact of sleep disturbance on patients' well-being. Patient-reported RCSQ SEI (65%) in this study supports the PSG- and ACTG-reported SE and reiterates the experiences of poor quality of sleep in the ICU. The reported RCSQ SEI in this study is comparable to those previously reported in the UK^{16,19,23} and Australian⁴⁰ studies. Globally sleep disturbance is experienced by ICU patients and is frequently attributed to the clinical environment in which they are cared for. Organisations may need to critically analyse the way in which they deliver and organise care for conscious ICU patients to address the preventable harm that can ensue as a result of sleep disturbance. To redress this issue, there is a need to identify feasible methods to aid in monitoring patients sleep during their ICU admission, and there is an emerging range of potential approach inclusive of ACTG, single-channel electroencephalography (EEG) monitoring,^{13,41} and bed sensors.⁴² As a result, further research is needed to explore the potential of these assessments in identifying feasible approaches to assessing patients' quality of sleep within the ICU and the hospital setting more broadly.

4.1. Limitations of the study

Although this study provides important insights from ICU patients' experiences of sleep, there are acknowledged limitations of the study that should be considered prior to extrapolating the

findings more broadly. The study sample is limited to 20 patients who are conscious and able to provide consent and in doing so excluded patients with higher acuity and longer lengths of stay who may be more profoundly impacted by sleep disturbance, in addition to patients with altered cognitive states such as delirium. As a result, the impact of delirium on sleep and vice versa was not considered within this study. The monitoring of sleep was conducted over a single night and may be impacted by events and experiences that occurred at that time and may not depict the experience of patients over the duration of their ICU admission. Documenting of nursing observations of patients sleep was undertaken by numerous intensive care nurses, and as a result, attention to assessment may be impacted by a variety of clinical demands. In turn, a larger study cohort and consecutive nights' monitoring may provide further insights into the application of novel sleep monitoring techniques and how they may benefit ongoing patient care.

5. Conclusion

ICU patients—reported poor sleep quality characterised by polyphasic sleep primarily composed of light sleep. Patients appear to be perceptually inaccurate in their overall reporting of sleep duration, whilst ACTG and nursing observations both overestimate sleep. Sleep monitoring remains a difficult but important component of patient care and recovery to monitor, although ACTG may provide a feasible sleep monitoring technique in nonsedated patients to assess and monitor sleep continuity.

CRediT authorship contribution statement

Lori J. Delaney: Conceptualisation, Investigation, Methodology, Investigation, Data Curation, Writing - Original Draft; Edward Litton: Methodology, Investigation, Writing - Review & Editing; H-C Carol Huang: Methodology, Investigation, Writing - Review & Editing; Violeta Lopez: Methodology, Investigation, Writing - Review & Editing; Frank MP van Haren: Conceptualisation, Methodology, Investigation, Writing - Review & Editing.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at <https://doi.org/10.1016/j.aucc.2022.02.004>.

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6.3 Conclusion and Linkage

Despite decades of research attesting to the poor sleep experience of intensive care patients, little appears to have been accomplished to improve this basic physiological need. Patients cared for continue to report poor quality of sleep; however, their ability to quantify the specific attributes of their sleep profile is not consistent with that reported via biophysiological monitoring. The findings indicate that patients are inaccurate in their reports of TST, which may be related to the frequency and duration of awakenings. Fontaine (1989) suggests that when awakening extends beyond 4 minutes, patients significantly underestimate their sleep duration. This, combined with the limited clinical impact of reported sleep assessment documented by nursing staff, highlights the need to identify physiological sleep monitoring methods that may provide data that can be more reliably acted upon. Sleep monitoring via surrogate measures, such as ACTG, provides clinicians with necessary information regarding the sleep characteristics of patients and beneficially can be easily implemented, interpreted, and used for a sustained duration. These are important considerations in the ICU environment as patients are often subjected to a range of monitoring procedures that can be uncomfortable and invasive. As a result, devising approaches to monitoring sleep that minimise potential discomfort and do not contribute to further sleep disturbance is a critical consideration. Clinical interpretation of data provided by ACTG is uncomplicated and visually decipherable, along with quantifiable data reporting the extent of sleep disturbance, circadian patterns and duration of sleep, without the development of further extended clinical expertise. While PSG will remain the gold standard, it is cumbersome for widespread clinical implementation compared with ACTG, which is minimally invasive. ACTG appears to be a monitoring technique that provides a monitoring approach that produces data reflective of PSG for TST and fragmentation.

Sleep is an individualised and highly subjective experience, and this should not be discounted in the broader exploration and understanding of sleep disturbance. Understanding the factors that contribute to sleep disturbance as experienced by patients provides critical insights into the clinical components that may need to be addressed in providing care. While external factors are widely identified as contributing to sleep disturbance, the ability to curtail these has been challenging. Chapter 7 presents the findings related to patients' perceived quality of sleep and factors that contribute to poor quality of sleep in the ICU.

Chapter 7: Patient-Reported Experience of Sleep in Intensive Care

7.1 Introduction

Sleep quality is often considered an important parameter in the assessment of sleep among patients. The concept of sleep quality can be influenced by the subjective experience of sleep reported by individuals, with research indicating that perceived sleep quality may not be aligned to biophysiological data (Delaney et al., 2022); that is, studies employing concurrent PSG monitoring and patient self-reported sleep assessment have been demonstrated to be incongruent with each other (Beecroft et al., 2008; Delaney et al., 2022; Gabor et al., 2003). Nonetheless, in the ICU setting, patients consistently report poor quality of sleep, which they attribute to the clinical environment. Understanding and identifying the factors that patients report as adversely affecting sleep provide clinicians with important information on which to base organisational change and to support the development of guidelines and procedures to support sleep in the clinical environment.

7.2 ‘Intensive Care Patients’ Quality of Sleep and Identification of Sleep-Disturbing Factors: An Observational Study’

The following presents the research findings related to patients’ experience of sleep in the ICU. The paper is authored by Lori J. Delaney, Edward Litton, Hsin-Chia Carol Huang, Violeta Lopez and Frank Van Haren.

7.2.1 Abstract

7.2.1.1 Aims and objectives

This study aimed to explore the self-reported quality of sleep of intensive care patients and sleep-disturbing factors experienced by conscious patients cared for in the ICU.

7.2.1.2 Background

Sleep is a fundamental physiological requirement. Intensive care patients experience considerable sleep disturbance characterised by atypical sleep architecture and high levels of fragmentation. Sleep disturbance is associated with several adverse effects that may affect patient recovery. Intensive care patients report that the clinical environment is a leading factor contributing to disrupted sleep and that the effects remain unabated.

7.2.1.3 Research design

Prospective observational study.

7.2.1.4 Methods

Conscious intensive care patients were recruited from a tertiary referral ICU to complete the Richards–Campbell Sleep Questionnaire (RCSQ) to evaluate quality of sleep while in intensive care. Participants were followed up post-discharge from intensive care and completed the Little Sleep Questionnaire (LSQ) to report their sleep experience in intensive care, their perceived sleep disturbing factors, and how their sleep has changed since discharge from intensive care. The study methods were compliant with the STROBE checklist.

7.2.1.5 Results

Patients ($N = 37$) reported poor quality of sleep, reduced sleep depth and increased awakening in the ICU. Sleep disturbing factors experienced in intensive care included noise, loud conversation, hunger and absence of family. Sleep was reportedly improved post-discharge from intensive care because of a reduction in disturbance overnight.

7.2.1.6 Conclusion

Sleep disturbance is commonly experienced by patients cared for in intensive care, and the contributing factors leading to impaired quality of sleep are modifiable with improved awareness and clinical practices that recognise sleep as an essential component in overall patient care.

7.2.1.7 Relevance to practice

Increased organisational and clinician awareness of the negative effect of sleep disturbance on patient recovery is required in order to operationalise interventions to improve sleep hygiene practices in intensive care.

7.2.2 Introduction

Sleep is considered essential for survival; however, its purpose remains debated. Research suggests sleep plays a significant role in supporting various physiological functions including immunological (Papaioannou et al., 2014), hormonal (DePietro et al., 2017) and memory consolidation (Pilcher & Huffcutt, 1996). As a result, it would appear logical that sleep should form a vital component of critically ill patients' overall care and recovery.

Sleep among intensive care patients is reported to be highly fragmented, with a propensity for increased N2 (light sleep) and reduced restorative sleep (SWS and REM sleep) (Boyko et al., 2012; Delaney et al., 2021), with patients reporting poor sleep quality and quantity frequently cited within the literature (Aitken et al., 2017, Menear et al., 2017). Sleep disturbance is identified as a significant physiological stressor by patients (Ding et al., 2017; Little et al., 2012; Novaes et al., 1999) and is attributed to reduced quality of sleep, frequent awakenings, and daytime somnolence (Kelly & McKinley, 2010; Orwelius et al., 2008). The adverse effects of sleep disturbance can manifest long after discharge from the ICU (Kelly & McKinley, 2010; Orwelius et al., 2008) and is linked to the onset of delirium and post-traumatic stress disorder (Cox et al., 2017).

The extent to which sleep disturbance affects patient outcomes remains indefinable. However, research reports various deleterious effects associated with reduced sleep quality, which may adversely affect patient recovery and quality of life (Orwelius et al., 2008; Caruana et al., 2018). The need for sleep among critically ill patients is increasingly recognised to support physiological healing (Knutson et al., 2007), neurohormonal responses

(Friese et al., 2009; Vgontzas et al., 2004) and emotional wellbeing (Alvarez & Ayas, 2004; Ding et al., 2017). However, the sleep disturbance experience by intensive care patients may predispose them to additional complications such as delirium, increased interventions and prolonged hospital length of stay.

Sleep is a highly subjective experience, and perceptions of sleep quality vary between individuals, with incongruence reported between objectively measured sleep duration and patient-reported sleep (Delaney et al., 2022a). The reported factors that obfuscate sleep are primarily attributed to extrinsic factors within the clinical environment, such as noise. However, polysomnographic studies suggest that noise disturbance may only account for a small (11% to 20%) portion of sleep experienced by patients (Freedman et al., 2001; Gabor et al., 2003). Despite these findings, patients frequently report noise as the major factor leading to sleep disturbance, with reported noise sources being potentially modifiable. Addressing the factors that negatively affect sleep may concurrently benefit patients recovering from critical illness and reduce the incidences of delirium (Boyko et al., 2017; Kamdar et al., 2013; Litton et al., 2016).

Exploring the sleep quality and sleep-disturbing factors experienced by patients is important for the advancement of clinicians' and organisations' understanding of factors that adversely affect sleep in order to develop future guidelines and practices to improve sleep in the clinical setting. This study aimed to explore the self-reported sleep quality of intensive care patients and identify sleep-disturbing factors experienced by conscious patients cared for in the ICU.

7.2.3 Methods

7.2.3.1 Study design and setting

This observational study was conducted in a 39-bed open planned tertiary referral ICU providing adult critical care services inclusive of cardiothoracic, neurosurgical, trauma

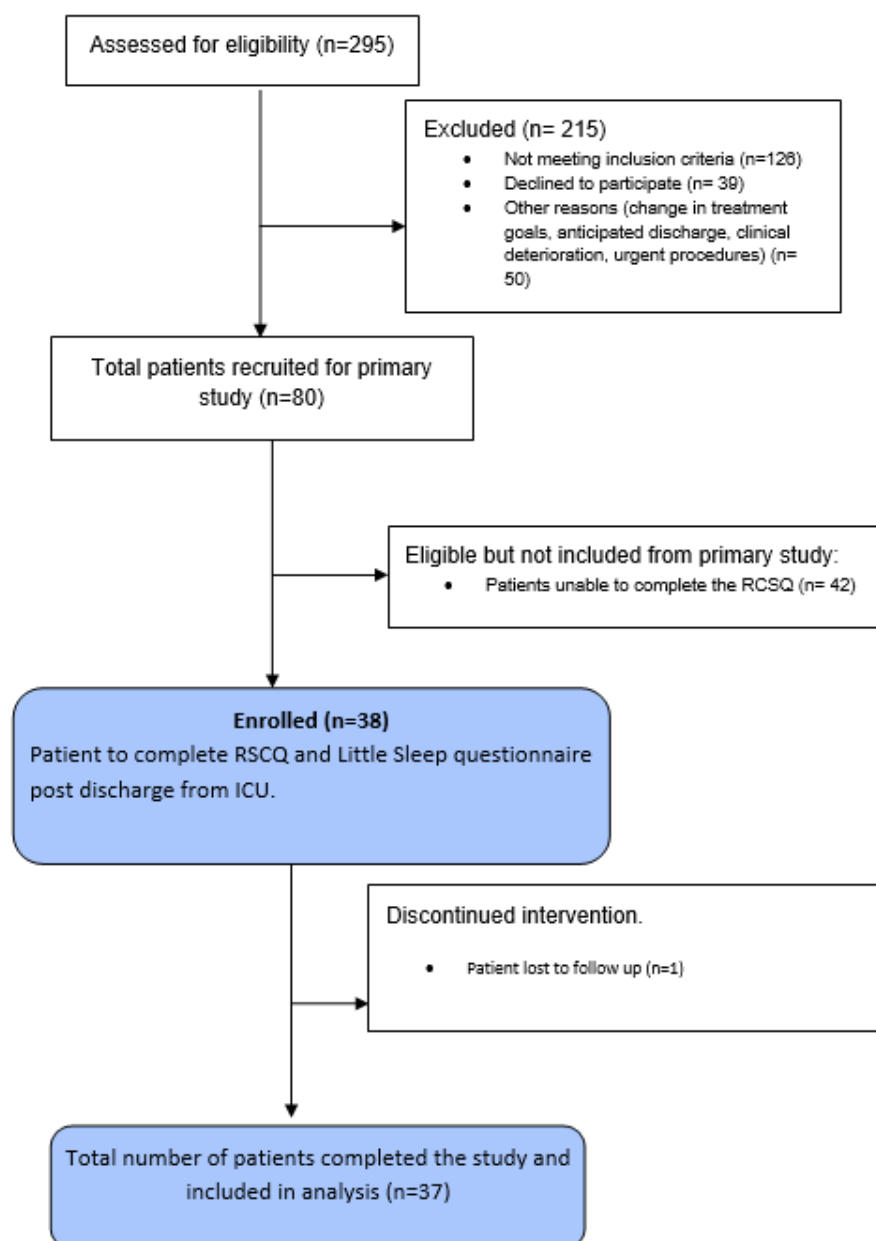
and general ICU care, which admits over 2500 patients annually. At the time of the study, the ICU did not have a formalised sleep policy or guidelines, and sleep monitoring did not form a standard component of care. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement checklist was applied to guide the reporting of the study (Figure 1).

7.2.3.2 Participants

Participants were eligible to participate in the study if they were assessed by the treating ICU team as requiring an admission of 24 hours or greater, aged 18 years or greater, Glasgow Coma Scale 15/15, Confusion Assessment Method for ICU (CAM-ICU) negative, and having English language proficiency to complete the survey items related to sleep quality and experience of sleep in the ICU. Patients were deemed ineligible for the study if they were admitted for a primary neurological condition, if treatment intent was for palliative care or the patient was not expected to survive more than 24 hours, with confirmed or suspected drug overdose, if they had received barbiturates or neuromuscular blocking agents during the 24-hour monitoring period, with a history of cognitive impairment (e.g., Alzheimer's disease), with clinically suspected encephalopathies (septic, hepatic or uremic), or with inadequate English language proficiency to complete the study questionnaires.

The demographic profiles of participants were extracted from the data entered into the electronic monitoring system, Metavision (iMDsoft), employed within the ICU of the study site and included age; gender; Acute Physiological and Chronic Health Evaluation II (APACHE II); Sequential Organ Failure Assessment (SOFA); respiratory support; body mass index (BMI), and inflammatory markers (C-reactive protein and white cell count) reported on the day the RCSQ was completed; and ICU and hospital length of stay.

Figure 1. STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) flow diagram.



7.2.3.3 Procedure

Patients were screened daily for eligibility for enrolment in the study based on the inclusion and exclusion criteria. Enrolled patients were requested to complete the RCSQ the following morning to report their quality of sleep. Participants were followed up daily by a member of the research team to ascertain their discharge planning and status. The LSQ was

distributed by a member of the research team to participants 24 hours – 72 hours post-discharge from the ICU.

7.2.3.4 Sleep assessment

7.2.3.4.1 Richards–Campbell Sleep Questionnaire

Participants were requested to evaluate their quality of sleep via the RCSQ between 09:00 and 10:00 hours the following morning post-study enrolment. The RCSQ is a five-item questionnaire that applies a visual analogue scale ranging from 0 mm to 100 mm, with 0 mm indicating the lowest sleep quality and 100 mm indicating optimal sleep quality. The RCSQ contains five subscales that assess sleep depth, sleep latency, awakenings, sleep efficiency, and time awake, with a sixth item evaluating perceived noise exposure included in the modified RCSQ. The RCSQ has been previously validated against PSG ($\alpha = 0.90$), providing a subjective assessment of the patient's sleep quality (Richards et al., 2000). In this study, the Cronbach's alpha for the RCSQ was 0.907.

7.2.3.4.2 Little Sleep Questionnaire

The LSQ is a non-validated 12-item questionnaire developed to evaluate the experience of patients' sleep in the ICU because of a lack of questionnaires that explored the sleep experience and identification of sleep-disturbing factors experienced by ICU patients (Little et al., 2012). The questionnaire explores the recollections of the ICU environment; patients' perceived sleep quality and quantity at home, during their ICU admission, and post-discharge from the ICU; intensive care-related factors contributing to poor sleep; and possible amendments during the ICU admission that could be implemented to improve sleep. The questionnaire is comprised of four yes/no questions relating to experiences, four questions assessing sleep quality and quantity based on a 5-point Likert scale (from *very poor* to *excellent*), and four questions involving checkboxes to identify factors that impede or improve sleep quality. The LSQ was completed within 72 hours of patients being discharged

from the ICU to explore their perceived sleep experiences (quality, quantity, and sleep-disturbing factors) during their ICU admission, and subjective sleep experience (quality and quantity) at home and post-discharge from the ICU.

7.2.3.5 Data analysis

The sample size in this sub-analysis ($N = 37$) was derived from the 80 participants who participated in the ICU sleep study and were able to complete the RCSQ and LSQ (Delaney et al., 2018). Parametric (means, standard deviations and ranges) and nonparametric (median and interquartile ranges) descriptive statistics were applied to report continuous data, with percentages and frequencies used to describe categorical data. Statistical analysis of the acquired data was conducted via SPSSTM (IBM SPSS Statistics for Windows, Version 26.0; IBM Corp, Armonk, NY).

7.2.3.6 Ethics

Patients were required to provide their own written or verbal consent to participate in the study. The study was approved by the institution's Human Research Ethics Committee (ETH: 5.16.071), and the primary study was registered with the Australian New Zealand Clinical Trial Registry (ACTRN 126150000945527; registered 9/9/2015).

7.2.4 Results

A total of 37 patients fulfilled the inclusion criteria and were included in the sub-study analysis. The demographic profile of patients included a median age of 68 years (IQR 49–73.5 years), a mean APACHE II score of 16.7 (SD 5.8) and admission to the ICU for a median of 2.3 days (IQR 1.1–4.5 days) at the time of recruitment (Table 1).

Table 1

Demographic characteristics of the cohort and subdivided based on the Richards–Campbell Sleep Questionnaire of sleep quality

Demographic variable	Mean $\pm$ SD^* or Median (IQR)#
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Age (years)	68 (49–73.5)#
Gender, male n (%)	18 (49)
APACHE II	16.8 (± 5.8)*
APACHE II relative risk (%)	21 (16.5–40.3)#
SOFA	11.1 $\pm$ 3.9*
BMI	28.6 (24.3–33.5)#
WCC	9.7 (8.2–12.5)#
CRP	88 (43–178)#
ICU LOS at recruitment (days)	2.3 (1.1–4.5)#
Total ICU LOS (days)	5 (2.9–8.4)#
Total hospital LOS (hours)	14.8 (9.8–27.4)#
Oxygen therapy	
Nil, n (%)	5 (13)
Standard oxygen therapy, n (%)	11 (30)
Hi-flow oxygen therapy, n (%)	15 (41)
Non-invasive ventilation, n (%)	4 (11)
Mechanical ventilation, n (%)	2 (5)

Note. APACHE II = Acute Physiological and Chronic Health Evaluation II; SOFA = Sequential Organ Failure Assessment; ICU = Intensive Care Unit; LOS = Length of Stay; BMI = body mass index; WCC = white cell count; CRP = C-reactive protein; *SD* = standard deviation; *IQR* = interquartile range; # = median and *IQR*; * = mean and standard deviation.

7.2.4.1 Patients' perceived quality of sleep

Patients' overall perception of sleep quality was low (total RCSQ $M = 47.5$, $SD 22.7$), with all sleep variables scoring less than 50 (range; 0 = no sleep – 100 = excellent sleep) (Table 2) and sleep latency (Q2) scoring the lowest ($M = 45.4$, $SD 26.9$) of the five sleep variables; 74% ($n = 14$) of female participants rated their sleep quality as poor, while 56% ($n = 10$) of male participants assessed their sleep quality as good. Female participants were found to report lower RCSQ scores across all domains, with a mean total RCSQ score of 43.2 ($SD 24$), than male participants ($M = 52$, $SD 21.1$).

Patients' self-reported mean duration of sleep was 173.4 minutes ($SD 143.3$ minutes), and they evaluated their sleep as very poor (13%, $n = 4$) to poor (63%, $n = 20$) in quality, which was considerably less than their sleep duration at home ($M 398 \pm 106.3$ minutes) (Figure 2). Patients perceived their sleep–wake pattern in the ICU to be normal (53%,

$n = 17$), with 38% ($n = 14$) of patients indicating that they could acquire enough sleep in the ICU. However, patients deemed their sleep not to be refreshing sleep (56%, $n = 18$).

Table 2

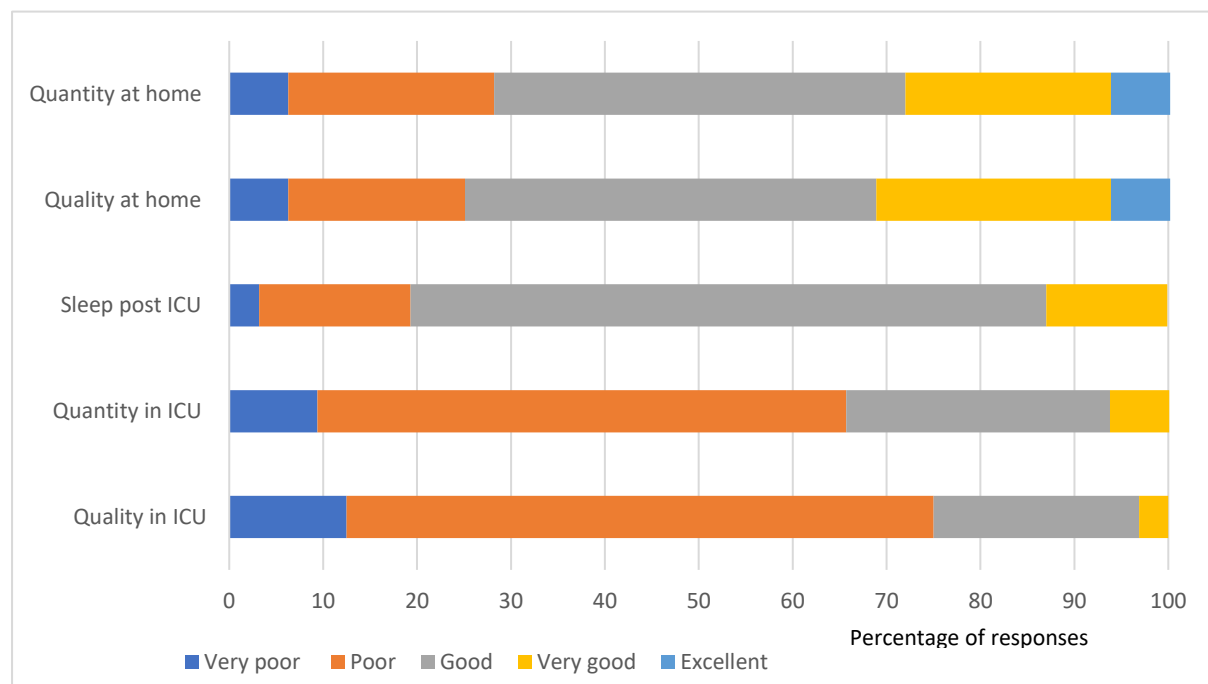
Patient-reported quality of sleep in intensive care

Sleep questionnaire measures	Mean (SD) ($N = 37$)	Range
Sleep depth (Q1) (mm)	45.7 (27.3)	9–100
Sleep latency (Q2) (mm)	45.4 (26.9)	6–100
Awakenings (Q3) (mm)	47.2 (22.3)	14–100
Returning to sleep (Q4) (mm)	49.8 (27.4)	7–100
Sleep quality (Q5) (mm)	48.9 (27.4)	5–100
Noise levels (Q6) (mm)	52 (22.7)	0–100
Overall score ^a (mm)	47.5 (22.7)	12–100

^a Average of 5 items (Q1–Q5).

Figure 2

Patients' perception of sleep quality and quantity in ICU, post-ICU and at home



7.2.4.2 Patient-reported sleep-disturbing stressors

Patients reported hunger (56%, $n = 18$) and absence of family (56%, $n = 8$) as the primary factors that affected their ability to sleep in the ICU. Noise related to loud conversations (41%, $n = 13$) and general noise (44%, $n = 14$) were frequently reported by patients (Figure 3).

Post-discharge from ICU, 81% ($n = 26$) of patients reported improved sleep, with factors related to a reduction in disturbance (38%, $n = 12$) and reduced monitoring and invasive lines (41%, $n = 13$) (Figure 4). Light exposure (25%, $n = 8$) was not noted as a major factor for sleep disturbance in intensive care but was increasingly reported post-discharge as a factor contributing to improved sleep (34%, $n = 11$).

Figure 3

Factors reported by patients (percentages) that adversely affected sleep during an intensive care admission

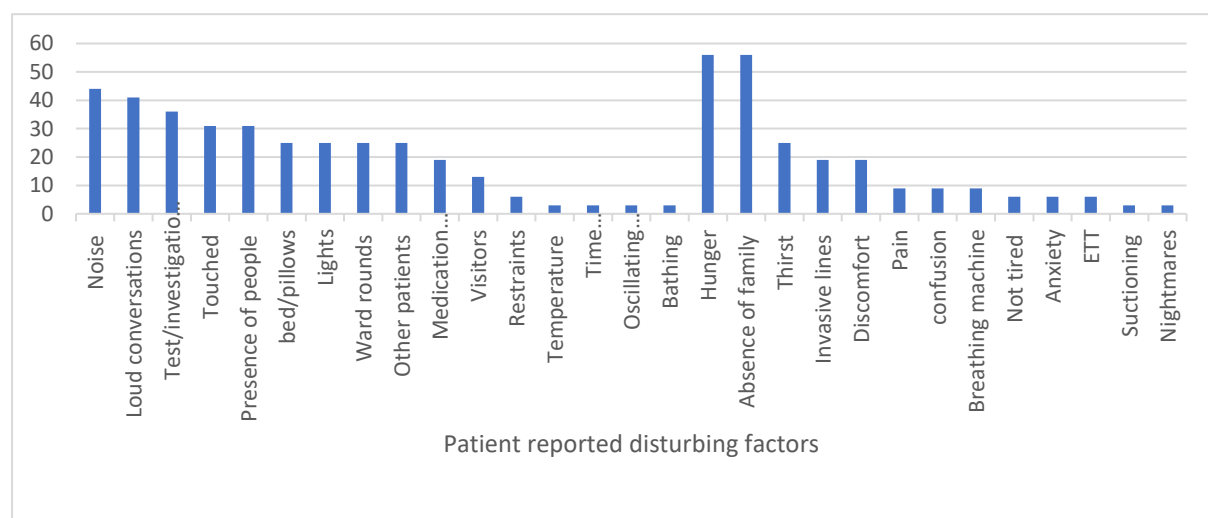
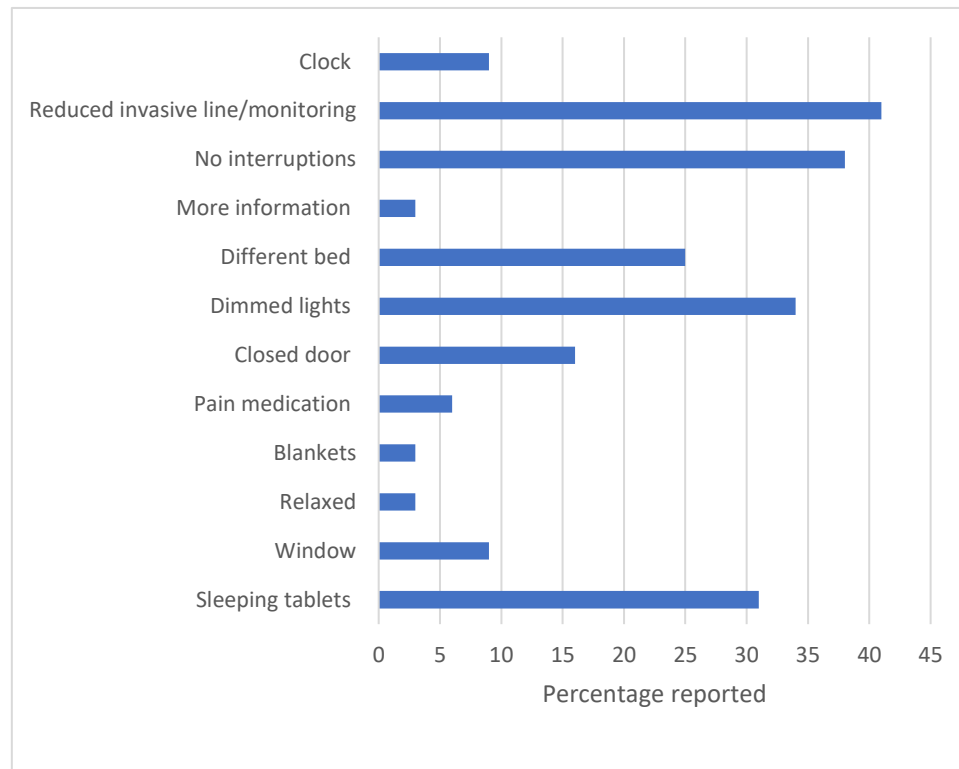


Figure 4

Factors reported in percentages identified by patients that had improved and facilitated sleep post-discharge from the intensive care



7.2.5 Discussion

Patients cared for in the ICU consistently characterise their sleep quality and quantity to be poor. Although research (Teliás & Wilcox, 2019; Tembo & Parker, 2009) suggests that sleep-disturbing factors are likely a combination of internal and external factors that contribute to poor sleep quality, patients' recollection of their ICU admission attributes sleep disturbance to external factors that form components of clinical care and the clinical environment. Patients perceive their sleep quality and quantity to be reduced both in the ICU and throughout their hospital admission.

Subjective sleep assessments performed via the RCSQ indicate sleep is sub-optimal, with patients perceiving their sleep to be poor to very poor and overall scores reported on the

five sleep scales of the RSCQ of less than 50, and reflect findings previously reported by Aitken et al. (2017) and Menear et al. (2017). Patients report an approximate 50% reduction in their night-time sleep (<3 hours) compared with at home, which is less than what is considered a TST to optimise wellbeing (Watson et al., 2015). Restricted sleep to less than 6 hours is linked to fluctuation in mental status and the onset of delirium (Weinhouse et al., 2009) and can adversely affect patient outcomes (Gabor et al., 2003; Parthasarathy & Tobin, 2009). Sleep quality was reported to improve once discharged from the ICU because of reduced monitoring and interruptions as acuity is reduced and nocturnal light exposure is curtailed.

Environmental noise levels are commonly cited as a problem in the ICU by patients and staff, with research reporting ambient noise levels ranging from 50 to 75 dB (Delaney et al., 2019; Freedman et al., 2001; Guisasola-Rabes et al., 2022; Tainter et al., 2016). Patients reported noise as a factor that affected sleep quality, making the clinical environment unfavourable for sleep, with therapeutic interactions and noise commonly acknowledged as stressors that impeded sleep. Guisasola-Rabes et al. (2022) reported that with small increases in noise level (dB), patients reported a 4-point reduction in sleep quality on the RCSQ. The pervasive nature of noise exposure is not limited to auditory effects, with non-auditory effects increasingly recognised because of their diverse implications on sleep, patient outcomes, and cognitive performance (Buxton et al., 2012).

Improved awareness and understanding of sleep-disturbing factors provide an opportunity to intervene and individualise care to support patient sleep. Research suggests that ICU nurses may lack knowledge regarding the pervasive impacts of noise and its effects on patients (Christensen, 2005; Johansson et al., 2016). As a result, strategies to mitigate the noise in the ICU setting may need to address knowledge and behaviours as previous research has indicated a reluctance of nurses to adjust alarm volumes and to reduce bedside

conversations overnight (Eliassen & Hopstock, 2011). The reported factors that negatively affect patients' sleep appear to be modifiable and potentially could be addressed with a greater focus on individualised sleep hygiene practices to develop approaches to support and prioritise sleep in the recovery process. Sleep hygiene is deemed to be behaviours that facilitate sleep and addressing behaviours that may negatively affect sleep (Riedel, 2000), with nursing staff well-positioned to assess and address patient concerns relating to sleep.

Notably, patient-reported hunger is a contributor to impaired sleep. Hunger has been attributed to an increase in metabolic expenditure (Bonnet & Arand, 1995; Spiegel et al., 1999), in which sleep plays an essential role in energy balance. Studies indicate that impaired quality of sleep, specifically characterised by a restriction in restorative sleep (SWS and REM sleep) and TST, are linked to increased feelings of hunger (Morgan & Tsai, 2015; Yang et al., 2019). Non-ventilated patients are susceptible to nutritional deficits, with Peterson et al. (2010) reporting that this patient cohort achieves less than 50% of their nutritional requirements and may go unnoticed by clinical staff. As a result, there is a need to recognise and understand factors that may affect patient sleep to establish congruence between clinical knowledge and patient needs to support an improved environment for sleep to be acquired.

Patients reported discharge from the ICU as allowing for improved sleep because of a reduction in the care interventions and environmental burden. Coordinating timely discharge of patients from ICUs would be beneficial in supporting the recovery of sleep for patients. Understanding the patients' experience and the sleep-disturbing factors from the patient perspective provides the foundation for organisations, leaders and clinicians to act and advocate for patients' needs. Given the link of sleep disturbance to adverse physiological and psychological consequences, sleep assessment must be considered as adjunct to the current comprehensive approaches to patient care in the ICU. Early documentation may provide the impetus to implement patient-specific interventions to address sleep disturbance.

7.2.5.1 Limitations

Although this study provides important insights from patients' experiences of sleep in the ICU, the study's acknowledged limitations should be considered prior in order to extrapolate the findings more broadly. The sample size within this study is small and is based on a single point in time assessment, and might have been affected by events and experiences that occurred at that time and may not depict what occurs and the experience of patients throughout their ICU admission. Nonetheless, it provides some potential insights into the experiences of patients that are conscious and able to provide consent, which is reflective of the current body of knowledge. The exclusion of patients unable to provide consent omits the experiences of patients with higher acuity and longer lengths of stay, who may be more profoundly affected by sleep disturbance. As a result, a larger cohort study conducted over a longer duration may be required to explore sleep-disturbing factors and expand on potential gender differences and the extent to which additional variables such as hunger may affect the experiences of patient sleep.

7.2.5.2 Conclusion

Sleep is essential in patient recovery, and sleep quality reported by conscious ICU patients is poor. The findings reiterate the potentially modifiable nature of many sleep-disturbing factors that could be enhanced through greater awareness of sleep and the implementation of practices that aim to reduce the noise levels experienced by patients. Improvement in sleep hygiene practices in the ICU needs to be considered, particularly among conscious patients. Increasing clinician awareness of the impact of sleep disturbance on patients physiologically and integrating consistent patient assessment associated with sleep may provide the foundations that curtail the impact of an ICU admission on a patient's ability to sleep.

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7.3 Conclusion and Linkage

Patients consistently identify factors that contribute to sleep disturbance that are favourable to modification, such as environmental noise (Elbaz et al., 2017; Freedman et al., 2001; Horsten et al., 2018). The ICU environment is inherently noisy because of the array of clinical monitoring and accompanying alarms, and frequently exceeds noise level recommendations outlined by the WHO (Delaney et al., 2017; Elliott et al., 2013; Litton et al., 2017; Xie et al., 2009). Despite the growing body of research regarding the soundscape of the ICU, little has been accomplished in reducing its impact on those within the clinical environment. Potentially, the lack of compelling evidence that suggests noise contributes to sleep disturbance reported within PSG-based studies contributes to a lack of commitment to address concerns around noise levels and how these may negatively affect sleep (Freedman et al., 2001; Gabor et al 2003).

Nonetheless, the experience of patients consistently suggests noise as a major issue within the ICU. Research attempting to abate noise has been challenged in its ability to demonstrate the capability to sustain noise reductions over time, as well as improved sleep quality as a result of noise reduction strategies beyond subjective assessments (Basner et al., 2014; Kahn et al., 1998; Nannapaneni et al., 2015). The constant exposure to increased noise can contribute to noise stress, and the lack diurnal variation may make patients more susceptible to the impacts of noise because of a loss of control over their environment. Reducing noise levels may provide an environment that may reduce patient anxiety and that is able to support rest and potentially improve the opportunity for sleep. Changing the interpretation and experience of the environment may have positive impacts on patients' subjective experience; however, it may not aid in the objective improvement in overall TST and fragmentation. Noises produces a range of adverse consequences for both patients and staff, and there is a need to address the impacts of noise in the clinical environment.

Emerging from the study are additional factors that are infrequently reported as sleep-disturbing factors such as hunger and anxiety. This highlights the complex interaction that various factors can have on individuals' ability to sleep. As a result, to better understand sleep in the clinical environment, further work is required to highlight the need to consider patient sleep in their overall plan of care and clinical assessment. Many of the factors outlined by patients suggest that with clinical assessment, intervention could be implemented to address factors that could affect sleep and provide patients with sleep hygiene practices that could support and ready them to transition into a nocturnal period readying for sleep.

Chapter 8: Discussion

8.1 Summary of the Research

Sleep is widely acknowledged as being critical in optimising individuals' sense of wellbeing and ability to function effectively throughout the day. However, in the healthcare setting, sleep is often viewed as a passive state that is readily disrupted and frequently deprioritised by healthcare providers (Burkhalter et al., 2011; Christensen, 2007; Cooper et al., 2000; Delaney et al., 2015). This is primarily observed among ICU patients, who experience atypical sleep architecture and circadian disturbance, and may continue to occur throughout the hospital admission and post-hospital discharge (Delaney et al., 2021; Gabor et al., 2001; Pisani et al., 2015; Watson et al., 2013). The implications of sleep disturbance are multifaceted and can contribute to a range of adverse physiological and psychological effects, which may hamper patient recovery (Bihari et al., 2012; Bosma & Ranieri, 2009; Frieze et al., 2009; Weinhouse et al., 2009; Xie et al., 2009).

The thesis's overarching purpose was to address the current challenge within clinical practice pertaining to identifying feasible and reliable methods to accurately assess sleep within the intensive care setting. Contemporary clinical care does not include sleep monitoring as a component of ICU care. In the absence of accurate sleep monitoring methods, the ability to understand the impact of poor quality of sleep on patients and the ability to respond to sleep disturbance are hampered. The findings suggest that ACTG may offer clinicians a feasible and accurate surrogate measure of sleep that is easily implemented and interpreted, and minimally invasive for patients (Delaney et al., 2022; Delaney et al., 2021). It is acknowledged that ACTG has a propensity to overestimate sleep and underestimate wakeful states, but presents an objective biophysiological assessment of sleep that demonstrates an acceptable level of agreement with the current gold standard of sleep monitoring: PSG (Delaney et al., 2021). The application of ACTG as a sleep monitoring

approach does not seek to diagnose formal sleep disorders, which requires the implementation of PSG, but rather to provide clinical information of sleep–wake activity across a patient admission to more objectively identify the extent of sleep disturbance experienced by patients.

Subjective approaches to sleep monitoring, such as nursing observation and patient self-reports, were found to be less accurate than biophysiological assessments (Delaney et al., 2022). Patients' ability to accurately report and quantify their sleep experience was found to be inaccurate, and may be influenced by numerous factors including effects of medication, ability to identify the lapse in time, and the frequency and duration of awakenings (Aurell & Elmqvist, 1985; Bourne et al., 2007; Gabor et al., 2003; Majer et al., 2007; Nicolás et al., 2008). Sleep documentation provided by nursing staff is frequently performed on an ad hoc basis and is subject to observer bias. Further, in cases where documentation on patient sleep is provided, it is rarely acted upon and is viewed as having limited clinical validity (Beecroft et al., 2008; Locihová et al., 2020; Louzon et al., 2022). The ability of staff to undertake frequent sleep monitoring (e.g. hourly documentation) is considered unviable and requires dedicated attention that cannot be provided in the context of ICU care. Nursing staff have numerous concurrent clinical activities inclusive of assessing, implementing and evaluating patients during their shift, along with collaborating intraprofessionally. Further, patient self-reports potentially exclude up to 40% of the ICU population, who may not have the capacity to complete survey items (Frisk & Nordström, 2003).

8.2 Clinical Environment and Improving Sleep

Noise disturbance remains a consistently reported factor that negatively affects patient sleep. The environmental factors identified within the research reiterate that noise generated as a part of clinical activities, such as speech, movement and alarms, is potentially modifiable

and could be addressed with amendments to behaviours and cultural norms within the intensive care setting in order to prioritise the importance of sleep in patient care.

8.3 ‘The Effectiveness of Noise Intervention in the ICU’

The following manuscript was manuscripts reviews the impact of noise and noise abating interventions that have been investigated in the intensive care context published April 2nd 2019 in *Current Opinion of Anesthesiology*.



The effectiveness of noise interventions in the ICU

Lori Delaney^{a,b,c}, Edward Litton^{d,e}, and Frank Van Haren^{b,f}

Purpose of review

Excessive noise has direct adverse physiological and psychological effects, and may also have indirect negative health consequences by reducing sleep quality and quantity. This review presents a synthesis of the epidemiology of noise in the ICU, and the potential interventions designed to attenuate noise and protect patients.

Recent findings

Noise increases cortisol release, oxygen consumption, and vasoconstriction. ICU noise levels are excessive throughout the 24-h cycle, irrespective of level of intervention or whether the patient is in a side room or open ward. Direct measurement suggests that noise is a substantial contributor to poor sleep quantity and quality in the ICU and is frequently recalled by survivors of critical illness as a negative experience of ICU admission. Noise abatement, environmental masking and pharmacological interventions may all reduce the impact of noise on patients. However, the sustainability of behavioural interventions remains uncertain and high-quality evidence demonstrating the benefit of any intervention on patient-centered outcomes is lacking.

Summary

Noise levels in the ICU are consistently reported to reach levels likely to have both direct and indirect adverse health consequences for both patients and staff. Noise reduction, abating the transmission of noise and pharmacological modulation of the adverse neural effects of noise are all potentially beneficial strategies, although definitive evidence of improved patient-centered outcomes is lacking.

Keywords

chronopharmacology, delirium, intensive care, noise, sleep disturbance

INTRODUCTION

Noise is an undesirable sound, which is perceived as subjectively annoying and impedes performance [1]. Noise is an insidious pollutant that is recognized as having harmful physiological and psychological effects during both sleep and wakefulness [2,3]. The individual effect of a given noise is dependent on a range of factors including noise sensitivity, coping capacity and the ability to control and regulate the sound source and environment [1].

Noise exposure results in both short-term and long-term physiological effects. Short-term effects are largely driven by the allostatic stimulation of the hypothalamus–pituitary–adrenal (HPA) axis [4,5]. Research indicates that noise levels as low as 60 dB(A), similar in volume to a standard dishwasher, can produce a 34–53% increase in plasma cortisol levels [6,7]. Endogenous catecholamines, released in response to increased acoustical intensity, remain elevated for up to 90 min after the cessation of the noise source, potentiating catabolism, oxygen consumption and vasoconstriction [8–11]. Long-term, noise pollution is associated with substantial health consequences and accounts for 24% of disability-adjusted life

years lost (DALYs), ranking second only to air pollution in pollution-associated lost DALYs [12].

The psychological effects of a single noise exposure relate to annoyance and can be sustained for 24 h after initial exposure [13,14]. Noise annoyance is characterized by feelings of bother, tiredness and irritability and potentially of sufficient intensity to impact on activities [13,15]. Noise exposure has been shown to impede complex intellectual functions, performance and memory processing [13–16]. This is a serious patient safety problem in the ICU where healthcare workers may be exposed

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KEY POINTS

- Noise is an insidious pollutant that has adverse psychological and physiological effects in patients who are asleep and who are awake.
- Excessive noise is ubiquitous in the ICU. The adverse effects are compounded by its variability and unpredictability.
- Patients frequently identify noise-related sleep disturbance as a major issue in the ICU.
- Noise-related interventions focus on three approaches: noise reduction, abating the transmission of noise and reducing adverse neural stimulation associated with noise.
- Noise abatement strategies may reduce the incidence of delirium, although the effect of noise-related interventions on patient-centered outcomes remains uncertain.

to as many as 1000 alarms per shift, leading to alarm fatigue and desensitization [16–18]. More generally, noise exposure may also reduce the capacity and accuracy in responding to unexpected events and increase the propensity for risk-taking behaviour [15,16]. As many as 500 patient deaths in 5 years are being attributed to alarm fatigue in the United States of America [18].

In the ICU, noise levels are consistently high. In a study involving 539 participants in 39 ICUs, the mean maximum sound level recorded within 1 m of the patient's head was 78 dB (decibels), similar in volume to an alarm [19]. These effects are compounded by the highly variable, diverse and unpredictable acoustical ecology of the ICU [1,19,20]. Given the ubiquitous findings of excessive noise in the ICU and the established association with a range of serious adverse health outcomes, there is an unmet need to develop strategies to reduce noise wherever possible and mitigate the adverse consequences for staff and patients.

ACOUSTICAL ECOLOGY OF THE ICU

The WHO recommends ambient noise levels for a hospital of 30 dB(A), and maximum sound peaks of 40 dB(A) at night [21]. These are universally exceeded in the ICU. Research investigating the acoustics of the ICU report mean noise levels between 50 and 65 dB(A), with peak noise levels ranging from 70 to 85 dB(A) and at times exceeding 90 dB(A) [19,20,22–25].

The result is that patients are exposed to an environment that may be nearly five times louder, with an acoustical intensity over 190 times greater

than the WHO recommendation [20]. The soundscape of the ICU is complex and exhibits fluctuations of 9.9–44 dB(A)/min [20]. These variations have a significant impact on the soundscape, as decibels is a logarithmic measure of the physical quantity of noise intensity, whereby, a sound increase of 10 dB represents a doubling in the perceived loudness of the noise. There is also little variation in maximum sound level between day and night [20,22]. As a result, between 11 and 57% of sleep arousals and awakenings have been attributed to ICU noise [23–24]. Whilst there have been a number of studies describing the effect of noise in the ICU on sleep, much less attention has been given to the effect of noise on awake patients in the ICU. Given the known adverse short-term physiological effects of noise and preexisting highly sympathetically activated and catabolic state of many patients admitted to the ICU, this should be a focus of further research.

IMPACT OF NOISE ON SLEEP

Sleep is a multidimensional physiologic process, which facilitates a range of essential functions. Patients experiencing critical illness consistently describe sleep disturbance as a major issue in the ICU and commonly attribute noise as the primary cause [25,26,27]. The adverse effects of sleep disturbance are substantial and include impaired immune function [28], anabolic and cellular repair processes [29], respiratory muscle strength and responsiveness to alterations in blood pH levels [30–32]. Further, there is an extensive range of neurocognitive implications, such as impaired clearance of degradation by-products of neural activity [33], decline in functional memory, maladaptive emotional regulation and quality of life [34].

The reported total sleep time (TST) of patients admitted to the ICU is between 7 and 9 h, although up to half of this sleep may be acquired during daylight hours, when noise levels are at their peak [22,25,35]. Although TST during critical illness may be similar to TST in healthy individuals, sleep is typically severely fragmented and of poor quality. Noise sources exceeding 30 dB(A) in patient care spaces have been shown to have adverse effects on patient's sleep cycle including both the quantity of sleep, for example, delaying sleep onset by 20 min, and the quality of sleep (less time in deep, restorative sleep) [36–38]. Sleep cycles have been shown to be highly fragmented with sleep episodes averaging 20 min, with the identification of 40 discrete sleep periods and as many as 6 awakenings per hour [25,39,32]. Fragmented sleep contributes to a phase shifting of circadian cycles and inhibits the

ability to acquire consolidated sleep. Polysomnographic studies of patients admitted to the ICU also typically reveals poor sleep quality with abnormal electroencephalographic activity and sleep architecture devoid of rapid eye movement (REM) sleep and slow wave sleep (SWS) [40,41,42⁷]. The absence of these two sleep phases are significant, as they provide the predominant restorative components of sleep, which enhance cognitive and physiological wellbeing. Recent research also suggests that the absence of electroencephalographic features of sleep such as K-complexes and sleep spindles may be associated with increase in morbidity and mortality [43].

The emerging challenge is to develop interventions that effectively reduce the impact noise on patients, support sleep and the synchrony of circadian rhythms to optimize the recovery process. The primary focus of research addressing noise levels in the ICU applies one or more of three fundamental approaches: reducing noise; abating the transmission of noise and reducing adverse neural stimulation associated with noise.

Reducing noise

An advantage of noise reduction interventions is the potential benefit for both patients and staff. Behaviour modifications, quiet time protocols and clinical design all represent interventions designed to reduce noise. Overall, the evidence that these strategies reduce noise is inconclusive. A number of studies in which bundled interventions have been introduced demonstrate significant noise reduction [44⁷,45,46] whilst others have not [47–49]. Many of these studies demonstrate considerable variability in their assessment of noise with some employing continuous noise recording, others conducting a point prevalence noise level recording and others using subjective perceptions of noise levels. Most interventions rely on staff behaviour change and have not reported whether the results observed were sustained over the long-term. Future studies will benefit from routinely including day-time monitoring, formal sleep assessment and objective environmental sound monitoring and assessing the sustainability of the intervention. Whilst reducing noise is necessary, alone, it is unlikely to be sufficient to improve sleep quality and optimise recovery.

Behaviour modifications

Konkani *et al.* [49] quantified that as much as 38% of noise generated in the ICU environment could be avoided, providing the catalyst for developing interventions to address the noise levels associated with clinician behaviours, with a view that this may translate to improved sleep quality for patients.

Behaviour modification commonly applies a multifaceted approach (Table 1), such as that implemented by Van de pol [44⁷] who reported a 10.4% decrease in noise levels over 70 dB(A), without improvement in sleep quality but with a significant reduction in delirium, and prescription of sleep-inducing medication [44⁷]. Overall, the evidence describing the effectiveness of behavioural interventions to reduce noise is inconclusive and the studies are generally limited by lack of longer term follow-up [45–50]. A description of the most common components of behaviour modifications included in published bundles is provided in Table 1.

Quiet time protocols

Behavioural modifications in the complex care environment of an ICU are challenging. Quiet time policies have been proposed as an alternative or additional approach to reduce noise. Whereby, quiet time protocols are defined as sanctioned time periods ranging between 2 and 4 h during which clinical and visitor interactions with the patient are reduced, amendment made to workflow (e.g. no ward rounds, nonurgent procedures are not scheduled) in combination with reducing conversational noise and disturbances from alarms. Boyko *et al.* [51⁷] implemented a structured ‘quiet time protocol’ (10.00 p.m. to 6.00 a.m.) involving both mechanically ventilated and nonventilated patients, but failed to demonstrate a significant reduction in the nocturnal soundscape. Similar findings have been reported in an Australian-based study [52⁷] in which poor baseline sleep quality was unaltered by the implementation of sleep guidelines aimed at reducing nocturnal noise and nocturnal quiet time. In contrast, Goeren *et al.* [53] reported a 10–15 dB

Table 1. Behaviour modification intervention bundles

Interventions
Reducing conversational noise
Minimizing nonclinical discussions at the bedside
Limiting clinical interactions
Emphasis on care clustering
Titrating alarm volumes
Monitoring alarm settings to reduce nuisance alarms
Closing patient room doors
Modifying workflow
Promoting timely response to alarms
Equipment maintenance
Footwear

reduction in noise levels through the introduction of a 2 h quiet protocol implemented at two time points (3.00 a.m. to 5.00 a.m. and 3.00 p.m. to 5.00 p.m.). Adherence to quiet time policies have also proven to be challenging in many contexts as demonstrated by Knauert *et al.* [42[■]]. The introduction of an intervention to address workflow, noise levels and clinical disruptions for a 4 h period between midnight and 4.00 a.m., produced numerous violations of the study protocol, which was subsequently revised to provide 60–120 min of reduced disturbance as a means to promote sleep [42[■]]. The implementation of a structured quiet time period that provides a reduction in noise stimulus during both the day and night provides an important opportunity to reduce noise annoyance for both staff and patients, and to evaluate the necessity of some clinical interactions and noise sources. However, the success of such an intervention is contingent on the co-operation and motivation of staff to adhere with the protocol.

Clinical design

Although consideration of the design of hospital areas is usually reserved for new structures or major renovations, there may be smaller scale changes that are feasible within an existing functioning ICU. Research conducted by Luetz *et al.* [54[■]] using clinical design features to reduce the impact of noise related to individuals, sound reverberation and conduction was able to demonstrate a significant reduction in nocturnal sound levels and events over the 50 dB threshold, albeit noise levels did not fall below the WHO recommended levels. Acoustical design considerations, such as the textiles used to absorb noise and reduce noise reverberations [54[■],55] are associated with a reduction in medications errors, improved communication, reduced length of hospital stay and subjective improvements in sleep quality [56–60]. The clinical effects and cost-effectiveness of these strategies are uncertain.

Abating the transmission of noise

Environmental masking may offer benefits in reducing the burden of noise on patients and improving sleep. Studies have focused on the potential benefits of noise abatement interventions including earplugs and noise-cancelling headphones [61,62,63[■],64–66]. These approaches avoid the challenges of controlling and regulating behaviour in the clinical environment.

Litton *et al.* [61] reported that the use of earplugs was feasible and was well tolerated by sedated and nonsedated patients in the ICU, with a mean abatement of 10 dB. In a randomized control trial

exploring the clinical benefit of using both earplugs and an eye shield, Demoule *et al.* [63[■]] demonstrated a significant reduction in prolonged awakening and increase in the duration of N3 stage sleep in patients whose earplugs were *in situ* for the entire nocturnal period. Despite these positive findings, 30% of participants did not use the earplugs, and polysomnographic data did not demonstrate an overall improvement in sleep architecture [63[■]].

Noise cancelling headphones that offer active noise control may provide an additional intervention that can mitigate noise exposure. Gallacher *et al.* [64] were able to model a 6.8 dB reduction over a 24 h period and a noted reduction in the exposure to high intensity noise source. Whilst there may be a subjective improvement in sleep using such interventions and there is some evidence that the use of abatement strategies that include earplugs may reduce the risk of delirium [62,63[■],64–67], although high-quality confirmatory studies are lacking.

Reducing adverse neural stimulation associated with noise

The majority of patients receiving mechanical ventilation in the ICU require the administration of analgesia and sedatives agents, such as benzodiazepines, opioids and propofol. Whilst these agents inhibit the responsiveness to the external environment, they also inhibit the restorative phases of sleep and impair circadian synchrony [67].

Preclinical studies suggest that dexmedetomidine, an alpha 2 agonists, may exert beneficial effects on sleep architecture, secondary to its inhibitory effects on the pons release of noradrenaline and the suppression of adrenergic inputs to the ventral lateral preoptic (VLPO) [67,68[■],69]. In a randomized control trial to ascertain the effects of Dexmedetomidine on sleep architecture, Wu *et al.* [70] revealed a small but significant improvement in N2 sleep ($P=0.048$) for nonventilated patients. In addition, increased sleep efficiency and improved subjective sleep quality were reported, although there were no measurable improvements in the restorative sleep phases: SWS and REM [70]. Noted in such studies is the similarity between Dexmedetomidine-induced spindle oscillations and those seen in non-REM sleep, highlighting the challenge in interpreting and distinguishing between the two events of sedation versus natural sleep [71[■]].

Melatonin (*N*-acetyl-5-methoxytryptamine), may also be beneficial in normalizing sleep–wake cycles in critically ill patients [72,73[■]]. Melatonin levels are reduced in patients admitted to the ICU, and demonstrate a shift in circadian synchrony

[72,73[■],74[■],75]. Supplemental administration of melatonin may enhance circadian synchrony, reduce sleep latency and decrease arousal and in turn sleep fragmentation [74[■],75]. In a recent Cochrane Review, melatonin administration in ICU was found to be associated with an increase in sleep duration, although most outcomes were subjective and the quality of the available evidence is low [76[■]]. In studies that employed objective assessment of sleep, the evidence to support the administration of melatonin remains inconclusive [73[■],74[■]]. In response, a number of randomized control trials are underway including ProMEDIC [77]. Future trials may also need to consider whether the background noise level also adversely impacts on the effectiveness of the intervention.

CONCLUSION

Noise levels in the ICU are consistently reported to reach levels likely to have direct and indirect adverse health consequences for both patients and staff. Although current evidence does not conclusively demonstrate a causal link between noise reduction and improvement in patient-centered outcomes, studies suggest that bundled behavioural interventions may reduce noise levels, whilst noise abatement strategies may reduce adverse patient outcomes including delirium. Future interventions to address noise and its impact on patients will likely require a multifaceted approach incorporating noise reduction, abatement and mitigation of the adverse consequences.

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Conflicts of interest

There are no conflicts of interest.

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Papers of particular interest, published within the annual period of review, have been highlighted as:

- of special interest
- of outstanding interest

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8.4 Further Research

The findings within this thesis add to the body of knowledge relating to the complex challenges encountered in monitoring sleep and addressing sleep-disturbing factors.

Emerging from the work presented is a range of future research areas to support the promotion and awareness of the impacts of sleep disturbance in the intensive care setting.

The findings presented within this thesis indicate that further research is required to fully understand the impact of sleep disturbance and its contribution to patient recovery. Sleep is a physiological requirement that supports the haemostatic function of hormones and immunological responses, and aids in promoting wellbeing. The contribution of sleep in the care and management of ICU patients is frequently deprioritised in favour of technologically advanced monitoring systems and accompanying alarms. The lack of recognition of its value in patient care and overall recovery may be compounded by the lack of scholarly attention in both undergraduate and postgraduate degree programs. Undergraduate programs in both nursing and medicine fall prey to issues with crowded curricula due to the exponential increase in healthcare information (Dalley et al., 2008). Therefore, healthcare organisations may need to bridge this gap within their services and establish education and clinical practice processes that highlight the significant contribution sleep plays in the overall recovery and wellbeing of patients. Addressing potential knowledge deficits and areas for improvement may first provide the foundations for implementing practice changes and sleep assessment into contemporary practices, thereby potentially reducing the perpetuation of practices that do not support patients' needs for sleep and its role in the context of patient care. As a result, research needs to be undertaken to ascertain the level of knowledge of clinicians regarding sleep and current practices, and evaluate the impact of educational interventions on clinical practice and culture.

The inability for clinicians to effectively and accurately monitor sleep in the clinical setting has been a long-reported barrier in understanding and optimising sleep within the ICU. With the evolution of wearable technology and advancement in sleep monitoring equipment such as motion accelerometers, emerging research findings suggest that these may have a potential role in the monitoring of intensive care patients' sleep, along with monitoring the circadian patterns of patients discharged from the ICU. Further research exploring the broader implementation of motion accelerometers in the monitoring and assessment of sleep within a multi-site study over a prolonged duration would aid in identifying whether sleep profiles alter over the course of an admission and highlight future potential of identifying the impact of sleep disturbance. Expanding the research would enable further understanding of the characteristics of ICUs and patient cohorts to identify which patient groups may benefit from motion accelerometer-based monitoring. ACTG is an accepted assessment of sleep–wake activities in non-laboratory settings, and the findings presented with this thesis suggest that this may provide clinicians with a much needed accurate, feasible, objective biophysiological assessment (de Zambotti et al., 2019). Compared with PSG, it is cost effective, less complex in its initiation and interpretation, and minimally invasive for patients. Further research is required to fully explore the potential of ACTG in its ability to assess sleep–wake activity among ICU patients as the findings reported indicate a trade-off between sensitivity and specificity in ACTG monitoring and ACTG is unable to distinguish between motionless wakeful states and sleep states. As a result, the patient cohort that may benefit from ACTG monitoring is likely to be patients that are not heavily sedated. The current data reported by the ANZICS indicate a decrease in patient admissions requiring mechanical ventilation, resulting in an increase in patients more susceptible to the impacts of the ICU environment and sleep disturbance, and this patient cohort may need further exploration in larger multi-site studies.

The physiological implications linked to sleep disturbance and critical illness are not fully elucidated. Emerging is the potential for bidirectional relationships between sleep and delirium, and sleep and pain, in addition to the impact of physiological changes involving inflammatory markers and whether these are important contributing factors in sleep disturbance during critical illness. There is growing research that highlights the similar neurobiological features of delirium and sleep, in particular, whether inflammatory markers such as C-reactive protein and white cell count are related to increased sleep disturbance, and more specifically if interleukins are a contributing factor. The need for sleep appears to have a beneficial effect in clearing by-products of brain metabolism, and whether ICU patients are more susceptible to this accumulation warrants further clinical research.

The clinical environment is widely considered a contributing factor to poor quality of sleep, with patients reporting noise as a major factor in poor quality of sleep. Developing sleep bundles and interventions to curtail the negative impact of the clinical environment remain important areas for clinical research. Reported research is limited in its ability to demonstrate prolonged effects in practices to reduce the impact of noise and how this may in turn affect sleep, and as a result, more rigorous research is likely needed. Findings exploring the impact of noise abatement interventions such as ear plugs suggest that these might have a role in reducing incidences of delirium, and further research understanding the relationship among delirium, sleep and patient outcomes is required.

Critical consideration is needed around ICU environment design features and whether this can be optimised to mitigate the negative effects reported by patients and provide an environment in which rest and sleep may be more achievable. Clinical design features can potentially alter the way individuals behave and engage in the environment. Given nurses' proximity to patients and their potential capacity to support sleep, there is opportunity for meaningful contributions around future designs of clinical areas and the implementation of

design amendments that may provide a cost-effective approach to mitigate the negative effects of the environment. Although the financial burden of developing new hospitals and ICUs may be a limiting factor, opportunities to encourage design and use of textiles for improved care and patient outcomes, and that consider intensive care to extend from invasive life preservation to survivorship and recovery, need to be seized.

8.5 Limitations

The limitations of each study are presented within the individual study manuscripts. Sleep is a complex physiological process, and within this research, sleep was monitored over a 24-hour duration. This monitoring period acknowledges the sleep–wake activities of ICU patients, who potentially acquire as much as 50% of their sleep during daylight hours, and provides information on the features of sleep quality and quantity among ICU patients, who may remain a patient with the ICU for days, weeks or months. Monitoring sleep over an extended duration may provide information related to the emergence of recovery sleep or ongoing deterioration of sleep quality. There exist some thoughts that patients may acclimate to their environment and sleep may improve; however, in the absence of ongoing sleep monitoring, these concerns around sleep cannot be addressed.

Challenges with maintaining ongoing 24-hour sleep monitoring are noted with works published in this thesis. In particular, PSG monitoring is not intended for this duration of study, and PSG electrodes will be displaced and result in losses in data with ongoing clinical care of patients.

8.6 Final Conclusion

The provision of intensive care has been able to integrate a variety of advance monitoring techniques to support patients and has contributed to improved survival outcomes. Despite the advancements in care and improved understanding of physiological responses, sleep remains a biological process that is not well understood or considered in the context of

intensive care. The need for sleep is an essential physiological requirement that is fundamental to support optimal wellbeing, but is poorly considered and integrated into the care of patients in the intensive care setting. Identifying a method that is feasible for implementation, such as motion accelerometers, is an important clinical development to enhance awareness of the contribution of sleep in overall patient care and recovery. The ability to accurately and objectively monitor sleep provides the foundations to identify the baseline sleep profile of patients and to effectively identify those experiencing circadian disturbances. Interventions that seek to improve sleep can then be effectively monitored and evaluated, and potentially operationalised as standard clinical practices.

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Appendices

Appendix A: Publications/Presentation During Candidature

Peer Reviewed Publications

Delaney, L. J., Litton, E., Huang, H.-C.,C., Lopez, V., & Van Haren, F. (2022). The accuracy of simple, feasible alternatives to polysomnography for assessing sleep in intensive care: An observational study. *Australian Critical Care*.

<http://doi.org/10.1016/j.aucc.2022.02.004>

Delaney, L. J., Litton, E., & Van Haren. (2021). The nexus between sleep disturbance and delirium among intensive care patients. *Critical Care Clinics of North America*.

<https://doi.org/10.1016/j.cnc.2021.01.001>

Delaney, L. J., Litton, E., Melehan, K. L., Huang, H.-C. C., Lopez, V., & Van Haren, F.

(2021). The feasibility and reliability of actigraphy to monitor sleep in intensive care patients: An observational study. *Critical Care*, 25, Article 42.

<https://doi.org/10.1186/s13054-020-03447-8>

Delaney, L. J., Litton, E., & Van Haren, F. (2019). The effectiveness of noise interventions in the ICU. *Current Opinion in Anesthesiology*, 32(2), 144–149.

<https://doi.org/10.1097/ACO.0000000000000708>

Delaney, L. J., Currie, M. J., Huang, H.-C. C., & Van Haren, F. (2018). “They can rest at home”: An observational study of patients’ quality of sleep in an Australian hospital. *BMC Health Services Research*, 18, Article 524. <https://doi.org/10.1186/s12913-018-3201-z>

Delaney, L. J., Currie, M. J., Huang, H.-C. C., Litton, E., Wibrow, B., Lopez, V., & Van Haren, F. (2018). Investigating the application of motion accelerometers as a sleep monitoring technique and the clinical burden of the intensive care environment on

sleep quality: Study protocol for a prospective observational study in Australia. *BMJ Open*, 8(1).

Delaney, L. J., Currie, M. J., Huang, H.-C. C., Lopez, V., Litton, E., & Van Haren, F.

(2017). The nocturnal acoustical intensity of the intensive care environment: An observational study. *Journal of Intensive Care*, 5, Article 41.

<https://doi.org/10.1186/s40560-017-0237-9>

Delaney, L. (2017). When two worlds collide: Patient centred care in a nocturnal healthcare environment. *Quality in Primary Health Care*, 1(1), 1–2.

Delaney, L. J. (2016). The role of sleep in patient recovery. *Australian Nursing and Midwifery Journal*, 23(7), 26–29.

Delaney, L. J., Van Haren, F., & Lopez, V. (2015). Sleeping on a problem: The impact of sleep disturbance on intensive care patients-a clinical review. *Annals of Intensive Care*, 5(1), Article 3. <https://doi.org/10.1186/s13613-015-0043-2>

Delaney, L. J., Haren, F. V., Currie, M., Huang, H.-C. C., & Lopez, V. (2015). Sleep monitoring techniques within intensive care. *International Journal of Nursing and Clinical Practice*, 2, Article 114. <https://doi.org/10.15344/2394-4978/2015/114>

Delaney, L. J. (2014). Behavioral modification of healthcare professionals in an adult critical care unit to reduce nocturnal noise: An evidence-based implementation project, *JBIM Database of Systematic Reviews and Implementation Reports*, 12(7), 505–520. [doi:10.11124/jbisrir-2014-1647](https://doi.org/10.11124/jbisrir-2014-1647)

External Consultations

NSW Therapeutic Advisory Group Inc. (2021). *Getting it right for sleep at night: Guidance for promoting sleep and reducing harm from inappropriate pharmacologic management of sleep disturbance and insomnia in hospitalised patients.*

https://www.nswtag.org.au/wp-content/uploads/2021/12/1.-Guidance_Getting-it-right-for-sleep-at-night_21Dec2021.pdf

Conference Abstracts

Delaney, Lori J. (2014). Behavioural modification of healthcare professional in an adult critical care unit to reduce nocturnal noise: An evidence-based implementation project. *JBIC Evidence Synthesis*, 12(7), 505–520. <https://doi.org/10.11124/jbisrir-2014-1647>

Delaney, Lori J. (2014). Patients quality of sleep at Canberra Hospital. *International Journal of Evidence Based Healthcare*, 12(3), 186–187.
<https://doi.org/10.1097/01.XEB.0000455172.49326.a0>

Delaney, L., Parke, J., Robinson, R., Da Fonte, N., & Lopez, V. (2014). What hath night to do with sleep; noise levels in ICU—Preliminary findings. *Australian Critical Care*, 27(1), 52. <https://doi.org/10.1016/j.aucc.2013.10.030>

Conference Presentations

Delaney, L. J., Litton, E., Melehan, K. L., Huang, H.-C. C., Lopez, V., & Van Haren F. (2020). *The feasibility and reliability of actigraphy to monitor sleep in intensive care: An observational study*. The Inaugural Herston Health Precinct Symposium 2020, Brisbane, QLD.

Delaney, Lori J., Park, J., Da Fone, N., Richardson, R., & Currie M. (2014). *Patients' quality of sleep at Canberra Hospital*. Canberra Health Annual Research Meeting, Canberra, ACT.

- Best poster presentation
- Best student presentation

Delaney L. J. (2014). *Behavioural modification of healthcare professional in an adult critical care unit to reduce nocturnal noise*. Ninth Biennial Joanna Briggs Institute International Colloquium, Singapore.

- Poster presentation finalist

Delaney, L., Parke, J., Robinson, R., Da Fonte, N., & Lopez, V. (2014). *What hath night to do with sleep; noise levels in ICU—Preliminary findings*. Ninth Biennial Joanna Briggs Institute International Colloquium, Singapore.

Delaney, Lori J. (2014). *Patients quality of sleep at Canberra Hospital*. Ninth Biennial Joanna Briggs Institute International Colloquium, Singapore.

Delaney, L., Parke, J., Robinson, R., Da Fonte, N., & Lopez, V. (2014). *What hath night to do with sleep; noise levels in ICU—Preliminary findings*. Australia and New Zealand Intensive Care Conference, Hobart, TAS.

Appendix B: Permissions to Reproduce Publications

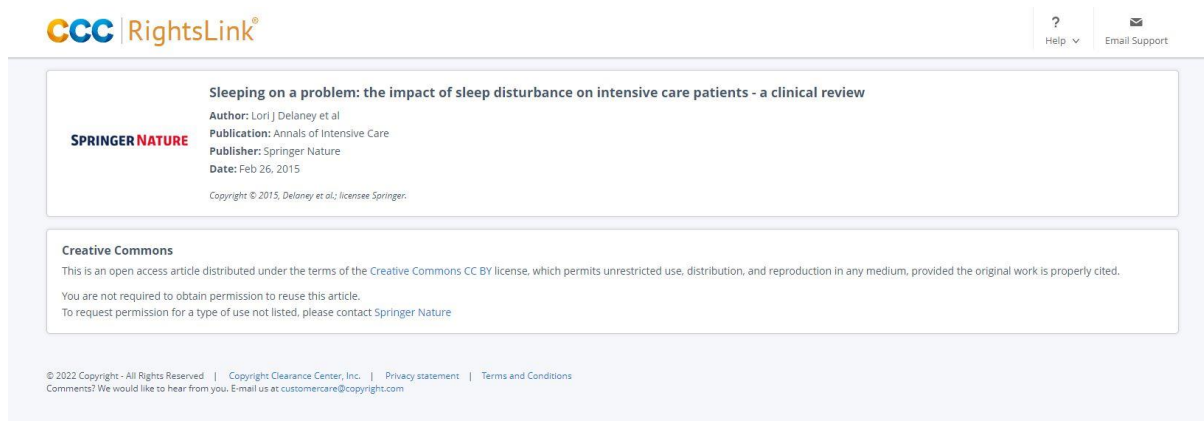
Delaney, L. J., Currie, M. J., Huang, H.-C. C., & Van Haren, F. (2018). “They can rest at home”: An observational study of patients’ quality of sleep in an Australian hospital. *BMC Health Services Research*, 18, Article 524. <https://doi.org/10.1186/s12913-018-3201-z> (Incorporated into Chapter 1)

The screenshot shows the Springer Nature RightsLink interface. At the top left is the 'CCC | RightsLink' logo. At the top right are links for 'Help' and 'Email Support'. The main content area displays the article title '“They can rest at home”: an observational study of patients’ quality of sleep in an Australian hospital' in a light blue box. Below the title, the author 'Lori J. Delaney et al' is listed, followed by the publication 'BMC Health Services Research', the publisher 'Springer Nature', and the date 'Jul 5, 2018'. A copyright notice 'Copyright © 2018, The Author(s)' is at the bottom of this section. Below this, a 'Creative Commons' section states that the article is distributed under a CC BY license, allowing unrestricted use with proper citation. At the very bottom, a small footer contains copyright information for 2022, a privacy statement, and terms and conditions.

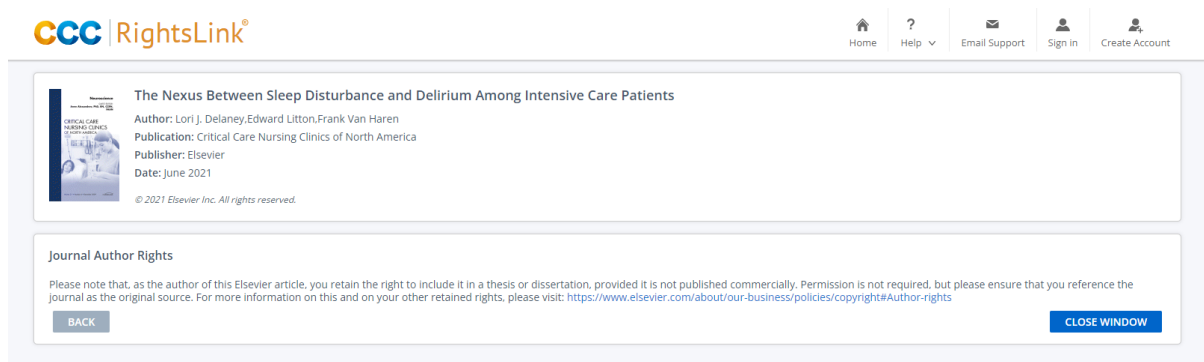
Delaney, L. J., Currie, M. J., Huang, H.-C. C., Lopez, V., Litton, E., & Van Haren, F. (2017). The nocturnal acoustical intensity of the intensive care environment: an observational study. *Journal of Intensive Care*, 5, Article 41. <https://doi.org/10.1186/s40560-017-0237-9> (Incorporated into Chapter 1)

The screenshot shows the Springer Nature RightsLink interface for a different article. The top navigation bar is identical to the previous screenshot. The main content area displays the article title 'The nocturnal acoustical intensity of the intensive care environment: an observational study' in a light blue box. Below the title, the author 'Lori J. Delaney et al' is listed, followed by the publication 'Journal of Intensive Care', the publisher 'Springer Nature', and the date 'Jul 11, 2017'. A copyright notice 'Copyright © 2017, The Author(s)' is at the bottom of this section. Below this, a 'Creative Commons' section states that the article is distributed under a CC BY license, allowing unrestricted use with proper citation. At the very bottom, a small footer contains copyright information for 2022, a privacy statement, and terms and conditions.

Delaney, L. J., Van Haren, F., & Lopez, V. (2015). Sleeping on a problem: The impact of sleep disturbance on intensive care patients—A clinical review. *Annals of Intensive Care*, 5, Article 3. <https://doi.org/10.1186/s13613-015-0043-2> **(Incorporated into Chapter 2)**



Delaney, L. J., Litton, E., & Van Haren, F. (2021). The nexus between sleep disturbance and delirium among intensive care patients. *Critical Care Nursing Clinics*, 33(2), 155–171. **(Incorporated into Chapter 2)**



Delaney, L., Van Haren, F., Currie, M., Huang, H.-C. C., & Lopez, V. (2015). Sleep monitoring techniques within intensive care. *International Journal of Nursing & Clinical Practices*, 2, Article 114. <http://dx.doi.org/10.15344/2394-4978/2015/114> **(Incorporated into Chapter 3)**

RE: Request to include publication in thesis

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Best regards,

Delaney, L. J., Litton, E., Melehan, K. L., Huang, H.-C. C., Lopez, V., & Van Haren, F.

(2021). The feasibility and reliability of actigraphy to monitor sleep in intensive care patients: An observational study. *Critical Care*, 25, Article 42. (**Incorporated into Chapter 5**)

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The feasibility and reliability of actigraphy to monitor sleep in intensive care patients: an observational study

Author: L. J. Delaney et al
Publication: Critical Care
Publisher: Springer Nature
Date: Jan 29, 2021
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Delaney, L. J., Litton, E., Huang, H.-C. C., Lopez, V., & van Haren, F. M. (2022). The accuracy of simple, feasible alternatives to polysomnography for assessing sleep in intensive care: An observational study. *Australian Critical Care*. Advance online publication. **(Incorporated into Chapter 6)**

The effectiveness of noise interventions in the ICU

Author: Lori Delaney, Edward Litton, and Frank Van Haren
Publication: Current Opinion in Anesthesiology
Publisher: Wolters Kluwer Health, Inc.
Date: Apr 1, 2019
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BACK **CLOSE WINDOW**

Delaney, L. J., Litton, E. & van Haren, F. M. (2022). The effectiveness of noise interventions in the ICU. *Current Opinion in Anesthesiology*. **(Incorporated into Chapter 8)**

Appendix C: Patient Sleep Interview Form



A survey of the factors affecting sleep quality and experience of hospitalised patients

Patient Sleep Interview Form

Action: Introduce yourself to the Ward Manager /Nurse in Charge, and note any restricted areas and patients not to be interviewed.

Background: Hello my name is ...xxxxx... Can I talk to you about how you have been sleeping whilst in hospital? This will take approximately 10-15 minutes of your time.

We are investigating how well our patients sleep when they are in our wards at night. Our aim is to improve the sleep of our patients at the Canberra Hospital.

We are therefore collecting sleep information from our patients through a series of both interviews, and ward observations across the hospital. Our patients' comments, thoughts and ideas will help us build a picture of what are the main sleep issues, and will help us to shape and improve our patients' sleep in our hospital.

Interviews are being conducted on a voluntary basis and you do not have to participate. You can also stop the interview at any time you want to. Personal details and all of your comments will remain anonymous. I will be taking notes during this interview. You will not be identified by name in any report that is subsequently produced.

Setup information

Date: _____ Time (✓): ☐ Morning ☐ Afternoon ☐ Evening

Interviewed by: _____

Gender (✓): ☐ Male ☐ Female Age: _____ Years

Ward: _____ Room/Bed No.: _____

Number of days in hospital so far? _____

1

Adapted from Flood, D. (2012). Sleep Study. Imperial College Healthcare NHS

Usual sleep at HOME

1. What time do you normally:
 - a. Go to bed? _____
 - b. Get to sleep? _____
 - c. How many hours on average, per night, do you think you sleep at home? _____

2. Do you consider your normal night's sleep to be restful? ☐ Yes ☐ No

3. What helps you get to, and stay asleep (medication, meditation, alcohol, nightly routine)?

Sleep in HOSPITAL

4. How would you rate your sleep experience (✓)? (i.e. poor, fair, good) [use patient's words]?

☐ very poor ☐ poor ☐ fair ☐ good ☐ very good

- 4.a. How many hours per night do you think you sleep in the hospital? _____

- 4.b. What time do you aim to be asleep? _____

5. What has disturbed your sleep in hospital? ...wait for answer. If no answer, then offer prompts such as – light, heat, noise, smells, other patients, clinical care, hospital day to day business, bed, mattress.(If No, go to Q8.)

6. What do you think might avoid sleep disturbance in the hospital? What would improve your overall sleep experience in hospital?

7. Have you spoken to any health professional or other members of staff, or patients on the ward about your sleep. If yes, who?

8. Have you been taking any tablets to help you sleep? (✓) ☐ No ☐ Yes (If Yes)

Sleeping tablets? (Y/N). _____

9. General comments.

Thank you for participating in this interview.

Appendix D: Staff Self-Report



CANBERRA HOSPITAL
AND HEALTH SERVICES

A survey of the factors affecting sleep quality and experience of hospitalised patients

Staff Self Report Form

Background: We are investigating how well our patients sleep when they are on our wards at night, with the aim of improving patient sleep at Canberra Hospital.

We are therefore collecting sleep information from staff through self reports and ward observations across the hospital. Our staffs' comments, thoughts and ideas will help us build a picture of the main sleep issues, and will help us to shape and improve sleep in our wards.

Self reports are being conducted on a purely voluntary basis and you do not have to participate. You can also cease completing the self report at any time you want to. Personal details and all of your comments will remain anonymous, and you will not be identified by name in any report that is subsequently produced.

Set up information

Date: _____ Time (✓) ☐ Morning ☐ Afternoon ☐ Evening

Staff (RN/EN/AIN): _____ Ward: _____

How many nights do you work per month? _____

Sleep in the hospital

1. How would you rate the overall patients' sleep on this ward? (✓)

☐ Very poor ☐ Poor ☐ Fair ☐ Good ☐ Very good

2. What do you think disturbs patients' sleep?

3. What are your comments about noise on this ward?

4a. Do you think that the amount of light overnight in this ward impacts on patient sleep? (✓)
☐ Yes ☐ No

4b. What are your comments about light on this ward?

5. What are your comments about temperature on this ward?

6. What are your comments about smells on this ward?

7. List the top three factors that you believe could contribute to improved patient sleep on this ward?

2

Adapted from Flood, D. (2012). Sleep study. Imperial College Healthcare NHS

Thank you for participating in this interview

Appendix E: Environmental Sleep Observation Form



CANBERRA HOSPITAL
AND HEALTH SERVICES

A survey of the factors affecting sleep quality and experience of hospitalised patients

Environmental Sleep Observation Form (ESOF)

Date: _____

Time: From _____ To _____

Observer: (✓) ☐ Ward Nurse ☐ Research Assistant

Ward: _____

ENVIRONMENTAL MEASURES

(Measures - document readings from the handheld monitor)

Locations	Light 20 to 20,000 lux	Noise 35 to 130 db	Temperature 20c to 200c	Humidity 25% to 95%
Corridor				
Single room ward				
2-bed room ward				
4-bed room ward				
6-bed room ward				
Nursing station				



SMELLS:

Do you notice any offensive odours in the locations you are observing?

No offensive smell (✓) ☐

	Odour intensity						Do you think the odour would affect patient sleep?		
	Very weak	Weak	Distinct	Strong	Very strong	Intolerable	Yes	No	Don't know
Toilet	☐	☐	☐	☐	☐	☐	☐	☐	☐
Food	☐	☐	☐	☐	☐	☐	☐	☐	☐
Perfume	☐	☐	☐	☐	☐	☐	☐	☐	☐
Gases	☐	☐	☐	☐	☐	☐	☐	☐	☐
Vomit	☐	☐	☐	☐	☐	☐	☐	☐	☐
Chemical	☐	☐	☐	☐	☐	☐	☐	☐	☐
Disinfectants	☐	☐	☐	☐	☐	☐	☐	☐	☐
No offensive smells	☐	☐	☐	☐	☐	☐	☐	☐	☐
Others	☐	☐	☐	☐	☐	☐	☐	☐	☐

Are there any other smells that are not contained within this list? ☐ No ☐ Yes

If YES, can you describe these?

Do you think the odour would affect patient sleep (✓)

☐ Yes ☐ No ☐ Don't know

NOISE:

What were the main noise problems [potentially disturbing sleep] during your observation? Tick all the boxes that apply. Also in the same boxes, please enter the number of incidences of that item.

e.g.

Alarm
✓ 4

Alarms	Staff	Telephones	Mobile Phones	Groups of people	Equipment
--------	-------	------------	---------------	------------------	-----------

Printers	TVs	Pumps	Admissions	Transfers	Doorbells
----------	-----	-------	------------	-----------	-----------

Bins	Bleeps	Shoes	Snoring	Drip stand	Bed movement
------	--------	-------	---------	------------	--------------

Air vents	Shredders	Toilet flushing	Wash basins	Trolleys	Curtains	Crockery
-----------	-----------	-----------------	-------------	----------	----------	----------

Radios	Doors	Sluice machines	Humidified oxygen	Outside noises	Mattress	Visitors
--------	-------	-----------------	-------------------	----------------	----------	----------

Are there any other noises you heard other than those listed above (✓)? ☐ No ☐ Yes

If YES, what are they?

What would be your recommendations for reducing noise in this ward?

3

Adapted from Flood, D. (2012). Sleep study. Imperial College Healthcare NHS

OTHER COMMENTS:

If there are any other issues that you notice disturbing sleep, or generally have any comments related to your observations on this ward, please comment on the following:

1. Comments for contact (Nurse in charge), reference special ward conditions during the observation.

2. Comments for any recommendations on improving sleep on this ward.

3. Any other comments.

Thank you for participating in this observation.

Appendix F: Supplementary File to Accompany ‘The Nocturnal Acoustical Intensity of the Intensive Care Environment: An Observational Study’

Table S1

Sound level change and loudness ratio

	Psychoacoustics	Volume	Acoustical intensity
Equation	$\Delta L = 10 \cdot \log_2 \chi = 32.22 \cdot \log_{(2)}$	$\chi = 10^{\frac{\Delta L}{32.22}} = 2^{\frac{\Delta L}{10}}$	$Z = 10^{\frac{\Delta L}{10}}$
Outcome	Level change $\Delta L_{\text{loud}} = 22.85$	4.87 times louder	192.75 times greater

Appendix G: Human Research Ethics Approval

Appendix 7: Human Research Ethics Approval



ACT
Government
Health

ACT Health
Research Ethics and Governance Office
Human Research Ethics Committee

Assistant Professor Lori Delaney
Building 10, Office B26.B
Faculty of Health
Disciplines of Nursing and Midwifery
University of Canberra
University Dr
Bruce ACT 2617

Dear Assistant Professor Delaney

ETH.5.16.071

The ACT Health Human Research Ethics Committee considered the proposed:

An investigation of sleep monitoring techniques and the impact of the clinical environment on Intensive Care patients sleep at its meeting of 6 June 2016.

I am pleased to inform you that, following further correspondence, your application has been approved.

Approval includes:

- HREC Application
- Participant Information and Consent Form – Interventional Study Version dated 29 September 2015, revised July 2016
- Person Responsible Information and Consent Form – Interventional Study Version dated 29 September 2015
- Richards Campbell Sleep Questionnaire (RCSQ)
- Karolinska Sleepiness Scale
- ICU Research Team approval
- L Delaney – CV and GCP
- V Lopez – CV and GCP
- C Huang – CV and GCP

I confirm that the ACT Health Human Research Ethics Committee is constituted according to the National Statement on Ethical Conduct in Human Research 2007 and is certified for single review of multi-centre clinical trials. ACT Health HREC operates in compliance with applicable regulatory requirements and the International Conference on Harmonization Guidelines on Good Clinical Practice.

I attach for your records an Outcome of Consideration of Protocol form.

Please note: this letter gives approval for ACT Health sites only. Please ensure appropriate approvals are in place at non-ACT Health sites.

Yours sincerely



Louise Morauta PSM PhD
Chair
ACT Health Human Research Ethics Committee
7 July 2016

ACT HEALTH HUMAN RESEARCH ETHICS COMMITTEE

Outcome of Consideration of Protocol

Submission No: ETH.5.16.071 **Date of Approval:** 7 July 2016

Project Title: An investigation of sleep monitoring techniques and the impact of the clinical environment on Intensive Care patients sleep

Submitted by: Assistant Professor Lori Delaney

Your project was considered by the ACT Health Human Research Ethics Committee and Approved for a period of 5 years from 7 July 2016 to 7 July 2021

First Annual Review due: 15 June 2017

Conditions of Approval:

- At regular periods, and not less than annually, Principal Investigators are to provide reports on matters including:
 - adverse affects on participants
 - Serious Adverse Events as they occur on site
 - SUSAR/Line Listing reports
 - unforeseen events that could affect the continued ethical acceptability of the project
 - proposed changes in the protocol
 - updates of the investigator brochures
 - continued compliance with approved consent procedures and updates of consent documentation
 - Data Safety Monitoring Board Reports (where applicable)
 - security of records
 - updated insurance coverage
 - compliance with other approved procedures.
- All published reports are to carry an acknowledgement stating:
 - Approved by ACT Health Human Research Ethics Committee on 7 July 2016



Louise Morauta PSM PhD
Chair
ACT Health Human Research Ethics Committee
7 July 2016

Appendix H: Richards Campbell Sleep Questionnaire (RCSQ)

Appendix 8: Richards Campbell Sleep Questionnaire

Richards Campbell Sleep Questionnaire (RCSQ)

Code Number _____	Date _____
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Each of these questions is answered by placing an "X" on the answer line. Place your "X" **anywhere** on the line that you feel **best** describes your sleep last night. The following are examples of the type of questions you are to answer.

EXAMPLE A

Right now I feel:

Very Sleepy **X** _____ Not sleepy at all

If you were very sleepy, you would place an "X" as is shown at the beginning of the line next to the words "**Very Sleepy.**"

EXAMPLE B

Right now I feel:

Very Sleepy _____ **X** _____ Not sleepy at all

If you were somewhat sleepy, you would place an "X" near the center of the line. Mark the answer line near the center to indicate the answer "**Somewhat Sleepy.**"

EXAMPLE C

Right now I feel:

Very Sleepy _____ **X** Not sleepy at all

If you were not sleepy at all, you would place an "X" at the end of the line next to the words "**Not Sleepy At All.**"

Please turn to next page

You are now ready to begin to answer the questions. Place your "X" **anywhere** on the answer line that you feel **best** describes your sleep last night.

1. My sleep last night was:

Deep Sleep _____ **Light Sleep**

2. Last night, the first time I got to sleep, I:

Fell Asleep _____ **Just Never Could**
Almost Immediately **Fall Asleep**

3. Last night I was:

Awake _____ **Awake All**
Very Little **Night Long**

4. Last night, when I woke up or was awakened, I:

Got Back To _____ **Couldn't Get Back**
Sleep Immediately **To Sleep**

5. I would describe my sleep last night as:

A Good _____ **A Bad Night's**
Night's Sleep **Sleep**

Optional Noise Item:

6. I would describe the noise level last night as:

Very Quiet _____ **Very Noisy**

Appendix I: Karolinska Sleepiness Scale



Karolinska Sleepiness Scale

Here are some descriptors about how alert or sleepy you might be feeling right now.

Please read them carefully and CIRCLE the number that best corresponds to the statement describing how you feel at the moment.

1. Extremely alert
2. Very alert
3. Alert
4. Rather alert
5. Neither alert nor sleepy
6. Some signs of sleepiness
7. Sleepy, but no difficulty remaining awake
8. Sleepy, some effort to keep alert
9. Extremely sleepy, fighting sleep

Appendix J: Little Sleep Questionnaire

Sleep quality in the intensive care unit

1. Time of Interview (prior to hospital discharge):
☐ 24 hrs. ☐ 48 hrs. ☐ 72 hrs. ☐ Other.
2. Source of Interview:
☐ in-person

Section 1 Assessment of Orientation

- What is the... Year, season, month?
☐ Correct / ☐ Incorrect
- Where are we... Hospital, City, Country?
☐ Correct / ☐ Incorrect

If the patient is oriented AND willing to participate proceed to Section 2 – ICU

Sleep Quality Survey If patient is NOT oriented please re-evaluate in 24 hours and complete questionnaire if oriented.

Section 2 ICU Sleep Quality Survey

1. Do you remember being in the Intensive Care Unit?
☐ Yes / ☐ No

2. What do you remember? (*check ALL that apply*)

☐ Family	☐ Faces	☐ Darkness	☐ Feeling confused
☐ Alarms	☐ Breathing tube	☐ Clock	☐ Feeling down
☐ Voices	☐ Suctioning	☐ Tube in nose	☐ Feeling anxious/scared
☐ Dreams	☐ Lights	☐ Discomfort	☐ Ward rounds
☐ Pain	☐ Panic	☐ Restrained/confined	☐ Hallucinations
☐ Nightmares	☐ Feeling people might hurt you	☐ Feeling like you might die	☐

☐ Other: _____

3. Please classify the overall quality of your sleep at *home* (before hospital).

☐ Very Poor. ☐ Poor. ☐ Good. ☐ Very good. ☐ Excellent.

4. Please classify the overall quantity of your sleep at *home* (before hospital).

☐ Very Poor. ☐ Poor. ☐ Good. ☐ Very good. ☐ Excellent.

How many hours of sleep, on average, did you get a night?

5. Please classify the overall quality of your sleep *during your ICU stay*.

☐ Very Poor. ☐ Poor. ☐ Good. ☐ Very good. ☐ Excellent.

6. Please classify the overall quantity of your sleep *during your ICU stay*.

☐ Very Poor. ☐ Poor. ☐ Good. ☐ Very good. ☐ Excellent.

How many hours of sleep, on average, did you get a night?

7. Do you remember having a normal sleep/wake cycle?

☐ Yes. ☐ No. (*awake during the day, asleep at night*)

8. Do you feel like you got *enough* sleep in the ICU?

☐ Yes. ☐ No. ☐ Unsure.

a) If yes, was it refreshing sleep? ☐ Yes. ☐ No

If No, continue to 8 b)

b) If no, please check all the factors that led to poor sleep in the ICU.

☐ Pain	☐ Nightmares/hallucinations	☐ Anxiety	☐ Team rounding
☐ Lights	☐ Temperature (too cold/hot)	☐ Thirsty/dry mouth	☐ Medication administration
☐ Confusion	☐ Bed/pillow	☐ Bathing	☐ Discomfort in position
☐ Visitors	☐ People in room	☐ Tests/X-rays	☐ Noise (staff, alarms, TV)
☐ Other patient	☐ Time disorientation	☐ Endotracheal tube	☐ Restrained/confined
☐ Suctioning	☐ Loud talking	☐ Breathing machine	☐ Absence of partner
☐ Not tired	☐ Sleep disorder	☐ Touch/move you	☐ Procedures/measurements
☐ Lines	☐ Bed in/de-flation	☐ Hungry	☐ Tubes (nose/rectal/bladder)

☐ Other: _____

c) If unsure, please explain:

9. Please rate the overall quality of your sleep *since leaving the ICU*.

☐ Very Poor. ☐ Poor. ☐ Good. ☐ Very good. ☐ Excellent.

10. Have you slept *better* since leaving the ICU?

☐ Yes. ☐ No.

If yes, check all that you feel contributed to this:

☐ Noise	☐ Light	☐ Interruptions	☐ Pain
☐ Comfort	☐ Care	☐ Privacy	☐ Anxiety
☐ Fear of Death	☐ Ambulation	☐ Tubes/Lines	☐ Other:

11. What factors do you believe would have improved sleep in the ICU?

☐ Sleeping pill	☐ Eye mask/blindfold	☐ Personal pillow/keepsake
☐ Ear plugs	☐ White noise	☐ No unnecessary interruptions
☐ Window in room (if none)	☐ Closing door/blinds at night	☐ Removal of monitors/alarms
☐ Relaxation techniques	☐ Dimmed lights	☐ Music therapy
☐ More blankets	☐ Different bed	☐ Clock in the room
☐ Pain medication	☐ More info about your health	☐ Other:

12. Additional Comments or Remarks
