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ORIGINAL RESEARCH

Multidimensional Sleep Health and Sleep Environment Factors in Individuals with Cancer Undergoing Outpatient Chemotherapy: An Exploratory Cross-Sectional Analysis

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Purpose: Sleep problems are common amongst individuals with cancer receiving chemotherapy and are associated with poorer health outcomes. Considerable research to date has investigated specific sleep domains or symptomology, with little attention given to overall sleep health, which is more closely associated with overall health. This exploratory cross-sectional study aimed to characterize multidimensional sleep health in individuals with cancer reporting sleep complaints whilst undergoing chemotherapy, with exploratory examination of environmental associations.

Patients and Methods: Twenty-three participants were included in this exploratory cross-sectional analysis. Participants were diagnosed with cancer within the last 6 months, undergoing outpatient chemotherapy at time of study entry and reported poor sleep quality and/or insomnia symptoms per the Pittsburgh Sleep Quality Index and Insomnia Severity Index. Multidimensional sleep health (duration, continuity, timing, regularity, rhythmicity, sleepiness/alertness, quality) and sleep environmental factors were assessed using sleep questionnaires, wrist-worn actigraphy and a temperature/light data logger. Linear regressions models were used to explore the association between sleep health and sleep environment factors.

Results: Examination of multidimensional sleep health indicated that poor sleep quality (87%) and variable sleep timing (61%) were the most prevalent sleep complaints amongst our sample. Mean sleep health score = 3.17 (± 1.83 SD) suggests that on average, three sleep complaints were experienced by the current sample. There were no significant associations between sleep health (domain and overall) and sleep environment factors.

Conclusion: Sleep quality and sleep timing were the primary concerns observed amongst our sample. Future investigations should be adequately powered and longitudinally designed to observe changes in sleep health trajectories and temporal relationships over the course of active treatment. Nevertheless, our preliminary findings provide the foundation for future research exploring sleep health amongst cancer populations and highlight that improving sleep quality and timing should be prioritized amongst individuals undergoing chemotherapy.

Keywords: oncology, supportive care, sleep disturbance

Introduction

Sleep problems, such as poor self-reported sleep quality, difficulties initiating and/or maintaining sleep and excessive daytime sleepiness are common amongst individuals with cancer receiving chemotherapy treatment and are associated with greater symptom burden[1] and poorer health-related quality of life[2–4] Studies show that sleep problems, most commonly reported as sleep disturbances and symptoms of insomnia, are experienced by approximately 60% of individuals with cancer.[5] Poor sleep is linked with greater levels of fatigue,[6,7] pain,[4] cognitive dysfunction,[8] anxiety and depressive symptoms.[4,9] It is therefore imperative that sleep problems are effectively managed.

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"Sleep health", a term used to describe the multidimensional pattern of sleep-wakefulness, offers a holistic framework to understand sleep.[10] Sleep health can be viewed along a continuum and includes key sleep dimensions that are strongly associated with health outcomes, including sleep regularity, subjective satisfaction, appropriate timing, adequate duration, high sleep efficiency and sustained alertness during the day.[10,11] Sleep health takes into consideration unique individual, social and environmental factors.[10] Novel methods, such as RU-SATED[11,12] and the multidimensional sleep health framework[13–16] utilize subjective and objective data to identify sleep domains of interest. Compared to traditional sleep measures which focus on individual symptoms and sleep disorders, assessing sleep health has several advantages. First, sleep health dimensions can be characterized and adapted to the individual's unique context. Second, sleep health avoids dichotomizing "good sleep" and "poor sleep". Third, sleep health assessments can inform the design of personalized sleep interventions.[10,11] A multidimensional sleep health framework is particularly relevant for individuals undergoing chemotherapy, as treatment-related disruptions to circadian rhythms, fatigue and sleep-wake behaviors can differentially impact sleep duration, continuity, timing, and regularity, necessitating a comprehensive sleep assessment. Moreover, the multidimensional nature of sleep health enables nuanced evaluation of environmental influences on sleep and supports the development of targeted interventions within outpatient settings cancer care.

The sleep environment, comprising various social and physical components, has been shown to influence sleep.[17–19] Social environmental factors include the perceived safety of the sleep environment, social and familial connections, whereas physical environmental factors include ambient temperature, light, air quality and noise.[17] Shorter sleep duration, symptoms of insomnia and circadian disruption are associated with unfavorable social environmental factors, including social fragmentation and reduced safety of the sleep environment (ie community violence).[17] Similarly, physical environmental factors can negatively impact sleep. Increased air and noise pollution is associated with poorer sleep quality, reduced sleep duration and efficiency and incidence of sleep-disorders such as sleep-apnea.[17] Meanwhile, greater exposure to light at night and warmer temperatures is associated with increased sleep latency, poorer sleep quality, reduced sleep efficiency and duration, as well as sleep-wake and circadian rhythm disorders.[17,20] Whilst sleep environment factors specifically have not been explored amongst individuals with cancer undergoing outpatient chemotherapy, it may be possible that there is a treatment–environment interaction. Treatment-related side effects such as vasomotor symptoms may influence thermal comfort and ambient temperature preferences, whereas nausea may influence comfort and sleeping position, whilst fatigue may be associated with daytime napping[21] and reduced daytime light exposure, dampening circadian rhythmicity and sleep propensity. Light exposure and ambient temperature are modifiable factors for most individuals, and when optimized can positively influence sleep.[20] Therefore, environmental factors are an important consideration when examining sleep health.

To the authors' knowledge, only one study to date has explored multidimensional sleep health in individuals with cancer. Price et al[22] examined actigraphy-derived multidimensional sleep health (sleep duration, maintenance, timing, and regularity) in 68 breast cancer survivors, compared to 1042 controls. Sleep health was suboptimal in both groups, with breast cancer survivors within 5 years of diagnosis experiencing shorter total sleep time.[22] However, Price et al[22] focused exclusively on cancer survivors and excluded individuals undergoing active treatment, limiting generalizability to those undergoing chemotherapy, where treatment-related side effects such as fatigue, nocturia, pain[23] and other related side effects may uniquely disrupt multiple dimensions of sleep health. To date, no study has explored sleep health in individuals with cancer receiving treatment, particularly chemotherapy, which has well-established detrimental effects on sleep. Considering the association between poor sleep and chemotherapy,[3,4] as well as its impact on symptom burden[1] and quality of life,[4] there is a need to comprehensively characterize sleep health in individuals with cancer and explore its potential relationship with contextual factors, such as the sleep environment.

The relationship between multidimensional sleep health and the environmental factors such as light and electronic device use has been explored in adolescents.[24] Despite being limited to self-reported measures, Gauthier-Gagné et al[24] found that greater light exposure during the morning was associated with longer sleep duration, whereas greater evening light exposure and electronic device use was associated with later sleep onset and offset times, shorter sleep duration and lower sleep regularity Despite the well-established influence of environmental conditions on sleep, its influence on sleep health in cancer patients receiving chemotherapy has not been investigated.

To our knowledge, this study is the first to investigate multidimensional sleep health in individuals with cancer reporting sleep complaints whilst undergoing chemotherapy and explore its association with sleep environment factors.

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Materials and Methods

Ethics Statement

This study was approved by the Human Research Ethics Committee at St John of God Subiaco (#1907) and Edith Cowan University (2022–03777-CRUICKSHANK). All testing procedures were conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained by all participants prior to the commencement of study procedures.

Study Design

This was an exploratory cross-sectional study investigating multidimensional sleep health amongst individuals with cancer reporting sleep complaints whilst undergoing chemotherapy. Due to the exploratory nature of the work and limited existing evidence in this field, the study was designed to generate preliminary insights and inform future adequately powered longitudinal investigations, rather than draw definitive causal conclusions. The analysis uses baseline data captured from the LightTherapyCa trial, prior to randomization (ACTRN12622001035718). The aim of the LightTherapyCa trial was to evaluate the therapeutic effects of green-blue light therapy in combination with sleep health guidelines, compared to sleep health guidelines alone, on sleep disturbances in individuals with cancer undergoing chemotherapy treatment. The sample included in the analyses represents a subgroup of participants with poor self-perceived sleep quality and/or subthreshold insomnia symptoms. This study adhered to Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement (see Supplementary File 1).

Setting

Participants were recruited between February 2023 and November 2024 from St John of God Subiaco and Murdoch, ICON Cancer Centre Midland and Oncology West/Joondalup Health Campus in metropolitan Perth, Western Australia. Participants were referred through the support of consultant medical oncologists, nursing staff in the chemotherapy day units and self-referral via study flyers at the recruitment sites.

Participants

Twenty-three participants were included in this exploratory cross-sectional analysis (see Figure 1). Inclusion criteria for the study were as follows: 1) Patients who have received a cancer diagnosis within the last 6 months and are receiving or about to receive neoadjuvant or adjuvant chemotherapy for cancer (with or without other therapies, including immunotherapy) and with no or minimal underlying symptoms from their cancer, 2) patients capable of providing written and informed consent, 3) patients with an Eastern Cooperative Oncology Group (ECOG) performance status of 0–1, 4) a score of ≥5 on the Pittsburgh Sleep Quality

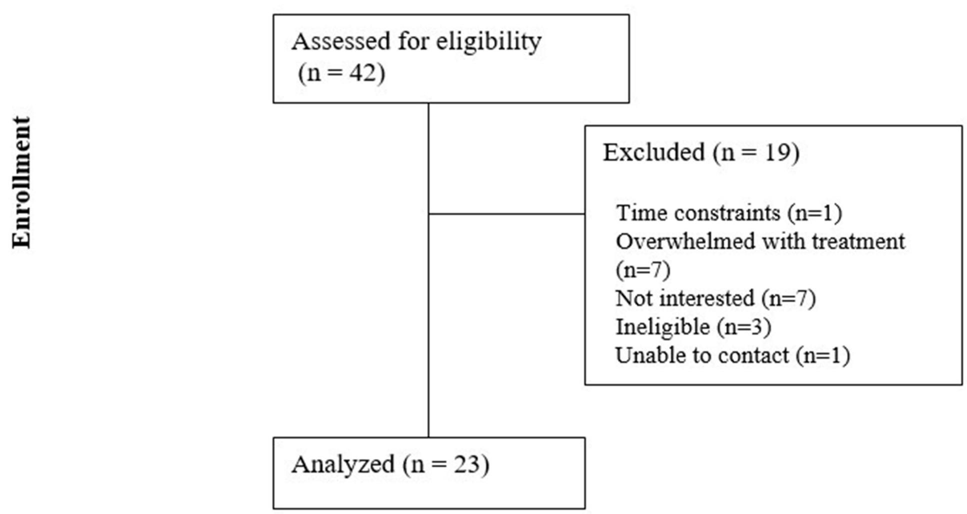

Figure 1 Participant flow diagram.

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Index ([PSQI] indicative of self-perceived poor sleep quality) and/or a score of ≥8 on the Insomnia Severity Index ([ISI] indicative of subthreshold insomnia symptoms).[25] The exclusion criteria includes: 1) Individuals with a visual abnormality that may interfere with the green-blue light therapy (cataracts, narrow-angle glaucoma, photosensitivity), 2) intention to undertake night shift work and/or trans meridian travel during the study or within 4 weeks leading up to the study, 3) a confirmed diagnosis of sleep apnea, sleep-wake, and circadian rhythm disorders.

Measures

Sleep-Wake Behavior

The consensus sleep diary (CSD) and wrist-worn actigraphy (GT3X, ActiGraph, Pensacola, FL USA) were utilized to capture participants sleep-wake behavior over the 7-night assessment period. The Epworth Sleepiness Scale (ESS) and Pittsburgh Sleep Quality Index were also completed during this period.

The CSD is a fifteen-item standardized self-report sleep diary that assesses subjective sleep parameters,[26] including habitual sleep-wake patterns (eg time of getting into and out of bed), time taken to fall asleep, time taken to fall asleep, sleep duration, sleep continuity, perceived quality of sleep and other sleep habits.[26] The CSD was used to confirm the sleep-wake parameters captured through wrist-worn actigraphy.

Wrist-worn actigraphy is a portable, objective measure of habitual sleep-wake activity, in which an accelerometer is used to measure arm movements and provide estimates of sleep-wake parameters.[27] Participants were instructed to wear the monitor on their non-dominant wrist 30 minutes before falling asleep and for 30 minutes post-awakening. Using the Cole-Kripke algorithm to identify sleep and wake periods, data was captured in 60-second epochs with a low pass extension filter applied. Sleep-wake parameters captured throughout the 7-night period include total sleep time, sleep efficiency, sleep onset latency, time in bed, time of awakening, wake after sleep onset (WASO), number of awakenings and the sleep fragmentation index. Actigraphy data were considered valid if participants provided a minimum of three nights of data. This criterion was chosen to ensure sufficient data for reliable sleep measurement. Compliance with this criterion was assessed by counting the number of participants who met the required number of nights.

The ESS is an eight item self-administered questionnaire widely used within sleep medicine research to assess daytime somnolence (license number 123899).[28] Eight situations are listed in which an individual must rate their chances of falling asleep using a 4-point Likert scale. Scores range between 0 and 24, with a score greater than ten indicative of excessive daytime sleepiness.[28] Although yet to be validated in cancer populations,[25] previous evidence in a mixed sample of cancer survivors and non-cancer controls suggests a Cronbach alpha value of 0.82,[29] demonstrating good internal consistency.

The PSQI is a nineteen-item self-report questionnaire that assesses the previous month's sleep quality across seven domains including subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medication and daytime dysfunction.[30] Each item is scored using a 0–3 interval scale, which contributes to seven component scores and a global score between 0 and 21. A global score greater than 5 is indicative of poorer subjective sleep quality. The PSQI has been validated for use in individuals with cancer.[25] As the global PSQI score includes other sleep domains,[31] a single item from the PSQI was used to assess sleep quality; this item queried "During the past month, how would you rate your sleep quality overall?", which participants rated on a 4-point Likert scale.

Sleep Environment Measures

Sleep environment was characterized using a combination of subjective and objective measures, including the Sleep Environment Questionnaire (SEQ) and HOBO device (Pendant Temperature/Light Data Logger UA-002-64K).

The SEQ is a seven-item self-report questionnaire that assesses behavioral and environmental factors that influence sleep.[32] The SEQ includes seven items directly relating to the sleep environment (including the type of environment, number of people who sleep in the bedroom and perceived safety in bedroom), eight items representing ambient sleep disruptive factors (ASDF) (including environmental factors that may disrupt sleep) and five items representing dysfunctional sleep behaviors (DSB) (including behavioral activities that may affect subsequent sleep onset or quality).[32] The seven items relating to sleep environment are not included in the scoring of the SEQ but will be added to participant descriptives. The SEQ is yet to be used or validated in individuals with cancer.

The HOBO device (Pendant Temperature/Light Data Logger UA-002-64K) was used to assess the ambient temperature and light intensity of the participants designated sleep environment. The HOBO device specifications are as follows: ambient temperature measurement range (−20°–70° C (−4° to 158° F)) and accuracy (± 0.53° from 0° to 50°C ± 0.95°F from 32° to 122°F)), light measurement range 0–320,000 lux (0–30,000 lumens/ft2) and device accuracy is designed for measurement of relative light levels.[33] Participants were instructed to place the data logger within proximity to their sleep environment, specifically their bedside table Participants were instructed to have the device standing upright and free from obstruction for the duration of the assessment period to ensure relevant measurements. The logger was set to record air temperature and light intensity in one-minute increments throughout the night, providing detailed and continuous data; these measurements were aligned to the actigraphy-defined sleep periods, Temperatures were logged in degrees Celsius (°C), and light intensity was measured in Lux (lx).

Data Analyses

Multidimensional Sleep Health

The multidimensional sleep health framework utilized by Turner et al[31] was used to assess multidimensional sleep health. The framework combines actigraphy-derived variables, the ESS and a single item from the PSQI to generate seven domains of sleep health (duration, continuity, timing, regularity, rhythmicity, sleepiness/alertness and quality). The multidimensional sleep health framework has not been used amongst cancer populations, although it has been used in older adults[34] and individuals with multiple sclerosis.[14,31] Based upon our teams prior research, the below cut-off ranges have been used to define the extreme categories for each domain.[31]

Duration: Lowest and highest sixth of the sample.

Continuity: Highest third of WASO values in the sample.

Timing: A sleep mid-point less than 2:01am or greater than 4:00am.

Regularity: Highest third of standard deviation in wake time values in the sample.

Rhythmicity: Lowest third of percentage values, representing the probability of being asleep or awake at the same time 24 hours apart, in the sample.

Sleepiness/alertness: A score of ≥10 on the ESS.

Quality: A participant response of "fairly bad" or "very bad" on the PSQI item.

Statistical Analyses

Descriptive data, including mean, standard deviation, minimum and maximum were calculated for all sleep health and sleep environmental factors. Linear regressions were performed to establish associations between continuous sleep health variables and sleep environment measures. Ordinal models were performed for ordered categorical sleep health variables (sleep health and quality) and sleep environment measures. Age and sex were added as covariate variables to each model. The models consisted of the following formula:

$$\textit{Sleep health factor} \sim \textit{Sleep environment factor} + \textit{Age} + \textit{Sex}$$

The standardized coefficient (standardized β) or odds ratio (OR) was reported for each model, along with confidence intervals (CI). False discovery rate (FDR) corrections using the Benjamini/Hochberg method were performed on p-values. All data and statistical analyses were conducted using Python (version 3.9.7). Statistical significance was set at $p < 0.05$.

A sensitivity power analysis indicated that with a sample of n=23, the study achieved 80% power to detect associations with effect size (f2) of at least 0.379. This indicates the study was powered to detect large effect but may have been underpowered to detect small-to-medium associations.

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Results

The demographic information, including age, sex, cancer type and stage, ethnicity, marital status, education level, employment status, consumption of alcohol and smoking status is provided in (Table 1). There were more females

Table 1 Participant Demographic Information

	Mean ± SD or Count (Percentage)
Age	54.14 ± 11.96
Sex	
Male	5 (22%)
Female	18 (78%)
Cancer type	
Breast	14 (61%)
Rectal	3 (13%)
Lung	2 (9%)
Pancreatic	1 (4%)
Bladder	1 (4%)
Gastric	1 (4%)
Ovarian	1 (4%)
Cancer stage	
I	2 (9%)
II	12 (52%)
III	7 (30%)
IV	1 (4%)
Unknown	1 (4%)
Chemotherapy	
Neoadjuvant	14 (61%)
Adjuvant	9 (39%)
Prescription sleep aid use	
Yes	4 (17%)
No	19 (83%)
Ethnicity	
White/Caucasian	19 (83%)
Asian	2 (9%)
Mixed race	1 (4%)
Unknown	1 (4%)

(*Continued*)

Table 1 (Continued).

	Mean ± SD or Count (Percentage)
Marital status	
Married	18 (78%)
De facto/living together	3 (13%)
Single	1 (4%)
Divorced/separated	1 (4%)
Education level	
Bachelor's degree or higher degree	16 (70%)
High school (Year 12 or lower)	4 (17%)
Trade, certificate or diploma	3 (13%)
Employment status	
Full-time	7 (30%)
Part-time	3 (13%)
Retired	6 (26%)
Not working	3 (13%)
On leave (including medical and maternity)	4 (17%)
Consumes alcohol	
Yes	13 (57%)
No	10 (43%)
Smoking	
Has never smoked	17 (74%)
Has previously smoked	6 (26%)

Abbreviations: SD, standard deviation; ±, plus-or-minus.

(78%) than males (22%), most participants were diagnosed with stage II (52%) disease, breast cancer was the most common type (61%) and most of the participants received neoadjuvant chemotherapy (61%). Prescription sleep aids were used by a small portion of the sample (17%), which included zolpidem and temazepam. Participants were mainly Caucasian (83%), married (78%) and had obtained a bachelor's degree or higher degree (70%). Employment status varied, most participants were non-smokers (74%) and consumed alcoholic beverages (57%). The distribution of valid nights across participants for actigraphy compliance is as follows; 1 participant had three nights (4.3%), 1 participant had six nights (4.3%) and 21 participants had seven nights (91.3%).

Sleep Health Composite Score

Table 2 shows descriptive data for sleep health and sleep environment factors. Sleep duration was marginally less than the recommended range of 7–9 hours per night, with an average of 6 hours and 57 minutes. Examination of sleep continuity showed that participants had an average of 58 minutes of wake after sleep onset each night and sleep timing showed that most people were of a morning chronotype, with the average midsleep point being 3:44 am. Inspection of

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Table 2 Sleep Health and Environment Scores

	Mean	Std	Min	Max
Duration (mins)	417.46	53.06	282.86	506.86
Continuity (mins)	57.91	29.54	25.29	143.14
Timing (hrs)	3.74	6.27	0.53	23.60
Regularity (hrs)	0.87	0.40	0.33	1.88
Rhythmicity (%)	54.22	11.62	3.51	63.50
Sleepiness	7.74	4.06	2.00	18.00
Quality				
Very good	0 (0%)			
Fairly good	3 (13%)			
Fairly bad	14 (61%)			
Very bad	6 (26%)			
Sleep Health	3.17	1.83	0.00	7.00
ASDF	16.65	6.12	9.00	34.00
DSB	1.30	1.18	0.00	4.00
Temperature (°C)	23.09	2.81	16.00	28.00
Light exposure (mins)	9.87	11.11	0.00	38.00

Abbreviations: Std, standard deviation; Min, minimum; Max, maximum.

sleep regularity showed that the standard deviation in wake times was 0.87 hours. The probability of participants being awake or asleep 24 hrs apart was 54%, as shown by the sleep rhythmicity score. Average sleepiness scores, measured by the ESS, were below the threshold of 10. Eighty seven percent of the sample rated their sleep quality as fairly bad (61%) or very bad (26%). The mean sleep heath score for this sample was 3.17 (± 1.83 SD); scores ranged from 0 to 7, with a higher score indicative of more non-optimal sleep health dimensions.

ASDF and DSB Scores

The average ASDF score of 16.65 indicates that disruptive sleep environment factors are not common for participants. The low DSB value (1.3) indicates that sleep disturbing behaviors are also not common amongst the participants. High temperatures were recorded during the sleeping periods of participants; on average the ambient temperature of the room was 23°C when sleeping. Light exposure during the sleeping periods was low, with only 10 min of light exposure above 10 lux recorded.

Figure 2 shows the number of participants that had extreme sleep health factors. These extreme ranges have been described in the above methods but indicate that sleep quality and timing are the biggest issues for this sample of participants.

Associations Between Sleep Health Domains and Sleep Environment

Sleep environment factors, including self-reported environmental factors and objectively measured light and temperature metrics, had no significant associations with sleep health or any of the sleep health factors (Supplementary Table 1).

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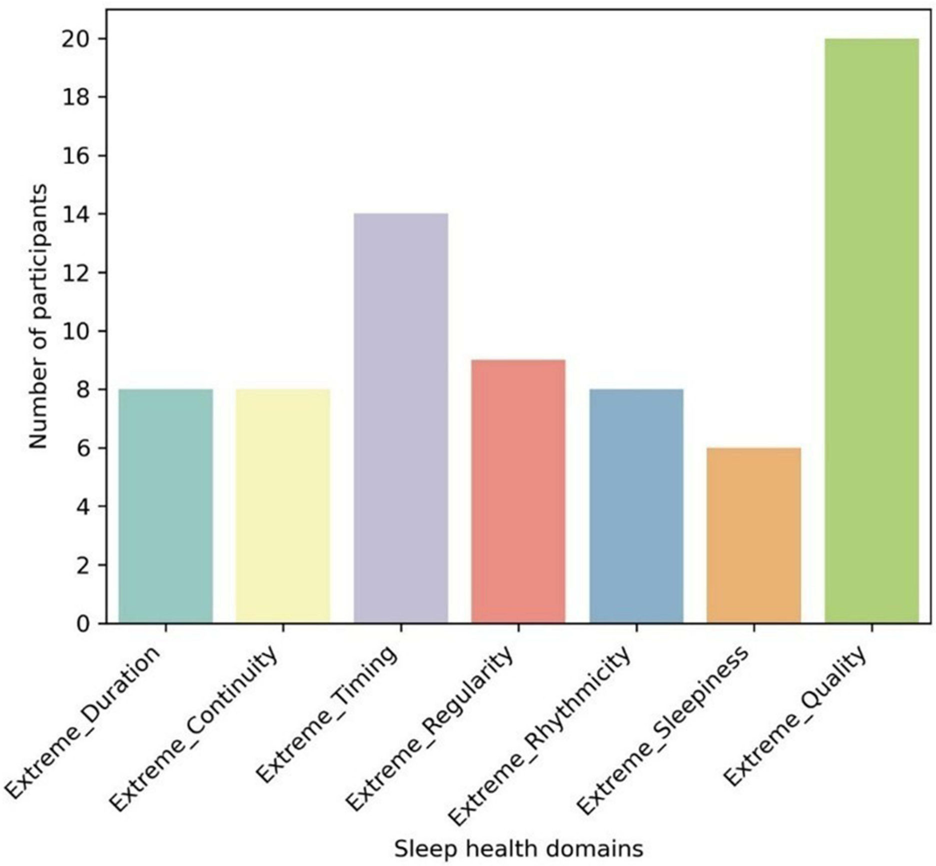

Figure 2 Proportion of participants that meet the cut-offs for the extreme categories in each sleep health domain.

Discussion

To our knowledge, this study is the first to comprehensively characterize multidimensional sleep health in individuals with cancer reporting sleep complaints whilst undergoing outpatient chemotherapy. Importantly, this work provides a detailed descriptive characterization of multidimensional sleep health amongst this population, with poor sleep quality and extreme variability in sleep timing identified as the primary concerns. Exploratory analyses showed no significant associations between sleep health (overall and domain specific) and sleep environment factors. These findings should be interpreted cautiously, as the absence of significant associations may reflect limited statistical power, rather than a true lack of meaningful relationships. Nevertheless, our study provides preliminary insights into multidimensional sleep health and its relationship with sleep environment factors amongst this population, which warrants further investigation by adequately powered and designed studies.

Poor sleep quality and extreme variability in sleep timing were identified as the most prevalent sleep health concerns in this community. Poor subjective sleep quality, rated as fairly bad or very bad, was reported by 87% of participants, consistent with previous findings in individuals receiving chemotherapy.[35] Although the average sleep midpoint (03:44) fell within the expected range of 02:00 to 04:00,[10] 61% of participants demonstrated extreme sleep timing, with midpoints ranging from 00:33 to 23:36 (standard deviation ±6.27 hours), indicating high variability. This high variability may be attributable to individual factors, such as irregular sleep schedules, including earlier and later sleep onset times, as well as the elevated WASO. Sleep duration averaged 6 hours and 57 minutes, falling marginally below the recommended 7 to 9 hours for healthy adults,[36] while sleep continuity was also compromised, with a mean WASO of 58 minutes, exceeding the suggested limit of 20 to 30 minutes.[37] Individual, disease- and treatment-related factors were reported in the CSD as reasons for nighttime awakenings, including corticosteroid medications, nocturia, family disturbance (ie bedpartner, children and pets), excessive daytime napping, fatigue, rumination, vasomotor symptoms, coughing, dyspnea, headache and pain. These reasons may partially explain the elevated WASO observed in our sample. Although 39% met the threshold for extreme sleep regularity, the average variability in daily wake times remained

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relatively modest at 0.87 hours, within the acceptable range of less than 60 minutes.[10] Other domains, such as sleep rhythmicity (affected in 54%) and daytime sleepiness (mean ESS score: 7.74; normative range <10;[28]), appeared less severely impacted. The mean sleep health score (ranging from 0–7, with a higher score indicative of more suboptimal sleep health domains) of 3.17 (± 1.83 SD) suggests that most participants experienced suboptimal sleep health in at least three domains. These findings underscore the importance of exploring domain-specific sleep health issues, which may inform the development of tailored interventions to improve overall sleep health in individuals undergoing outpatient cancer treatment.

The influence of environmental factors (social and physical components) on sleep health is well documented.[17–19] During sleep periods, ambient sleep environment temperatures ranged 16°- 28°C (mean=23.09°C) amongst our sample. Although there were no significant associations between temperature and sleep health (overall and domain specific), other factors including local climate acclimatization,[38] personal temperature preferences,[39] temperature device measurement accuracy, ambient temperature interaction with sleepwear, bedding and air circulation[40] may influence thermal comfort and sleep differently than our temperature findings suggest. Nighttime light exposure above 10 lux ranged from 0–38 minutes amongst our sample, with a mean of 9.87 minutes (± 11.11 minutes SD) above 10 lux recorded. Consensus-based recommendations suggest that evening light exposure be limited to <10 lux and nighttime light exposure during sleep limited to <1 lux or as dark as possible,[41] which is consistent with our findings of lower nighttime light exposure. Through self-report via the SEQ, ambient sleep disruptive factors and dysfunctional sleep behaviors appeared to be minimally disruptive to sleep. Although our study showed no significant associations between overall and domain-specific sleep health and sleep environment factors, these findings are likely attributable to a lack of statistical power, and should be viewed as preliminary findings warranting further investigation. Nevertheless, this exploratory study utilized a holistic approach to characterising multidimensional sleep health and explore associations and sleep environment factors, which intends to be foundational and hypothesis-generating for future research.

This study has several limitations that should be considered when evaluating its findings. First, eligible participants were required to have poor self-perceived sleep quality and/or experience subthreshold insomnia symptoms. Second, the sample included multiple cancer types and stages, resulting in greater heterogeneity. This may have introduced sample biasing, limiting the generalizability of our findings to the wider cancer community receiving chemotherapy. Third, the linear regression models used in this study only included age and sex as covariates. These variables were chosen due to their well-established influence on sleep[42] and to avoid overcomplicating the interpretation of the regression results. While disease and treatment related variables (cancer type, stage, chemotherapy regimen, prescription sleep aid use) are likely to have a greater influence on sleep, the exclusion of these variables should be acknowledged as a significant limitation. Fourth, the data presented is cross-sectional; this may lead to potential bias and not account for the changes in sleep domains over time. Furthermore, the recruitment period between February 2023 and November 2024 covered multiple seasons, which may represent an unmeasured confounder. Fifth, the small sample size may have decreased the ability to achieve statistical significance or observe any stronger associations. Whilst sensitivity analyses suggest that our sample was adequately powered to detect large associations, our sample was likely underpowered to detect small-to-medium associations.

Despite these limitations, these findings may have potential clinical implications by drawing attention to specific sleep health dimensions, particularly poor sleep quality and irregular sleep timing, that may be relevant to target for future investigations. From a behavioral perspective, the results suggest that interventions aimed at supporting more consistent sleep-wake schedules and managing daytime and nighttime behaviors to optimize sleep may warrant further exploration in this clinical population. From an environmental perspective, the findings indicate that modifiable environmental factors such as light exposure, temperature and thermal comfort in home settings should be considered in the design of future studies. The results also suggest a possible role for education programs on sleep health for family members and carers who may influence daily routines, behaviors and the home sleep environment. Together, these preliminary insights provide a basis for future, adequately powered studies to examine behavioral and environmental interventions aimed at improving multidimensional sleep health in individuals undergoing cancer treatment.

Conclusion

This exploratory study characterized multidimensional sleep health amongst individuals with cancer reporting sleep complaints whilst undergoing chemotherapy and explored its association with sleep environment factors. Importantly, our findings suggest that the multidimensional sleep health framework can be used to comprehensively and holistically assess sleep, which has important clinical implications for patient education around screening for sleep health concerns and informing the development of targeted interventions. Future research should be adequately powered and longitudinally designed to observe sleep health trajectories across chemotherapy cycles. The inclusion of individuals with cancer without sleep complaints, alongside bedpartners as a comparator, is needed to confirm and build upon the present findings. Nevertheless, our findings provide the foundation for future research, with important clinical implications for informing targeted sleep interventions.

Data Sharing Statement

The data that supports the findings of this study are available from the corresponding author upon reasonable request.

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Author Contributions

Sam Adams: Conceptualization; methodology; investigation; writing – original draft, review and editing. Timothy D Clay: Investigation; writing – review and editing. Arman Hasani: Investigation; writing – review and editing. Mitchell Turner: Conceptualization; methodology; formal analysis; writing – original draft, review and editing. Travis Cruickshank: Conceptualization; methodology; writing – original draft, review and editing. Mitchell Turner and Travis Cruickshank contributed equally to this work and should be considered joint senior authors. All authors have given their final approval of the version to be published, have agreed to the journal to which the article is submitted, and agree to be accountable for all aspects of work.

Disclosure

Dr Timothy Clay reports personal fees from Specialised Therapeutics, Roche, MSD, The Limbic, Takeda, Merck/Pfizer, Ipsen, Astra Zeneca/Daiichi Sankyo, Janssen; and personal fees and other support from Boehringer Ingelheim, Daiichi Sankyo, and Bayer, outside the submitted work. The authors report no other conflicts of interest in this work.

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