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Does evidence support "banking/extending sleep" by shift workers to mitigate fatigue, and/or to improve health, safety, or performance? A systematic review☆,☆☆

P. Daniel Patterson, PhD, NRP [a,b,*], Joshua D. Ghen, BS, NRP [a,b], Samuel F. Antoon, BS, NRP [a,b], Christian Martin-Gill, MD, MPH [a], Francis X. Guyette, MD, MS [a], Patricia M. Weiss, MLIS [c], Rose L. Turner, MLIS [c], Daniel J. Buysse, MD [d]

[a] University of Pittsburgh, School of Medicine, Department of Emergency Medicine, 3600 Forbes Avenue, Iroquois Bldg., Suite 400A, Pittsburgh, PA 15261, USA
[b] University of Pittsburgh, Department of Rehabilitation Science & Technology, Program in Emergency Medicine, 230 McKee Place, Pittsburgh, PA 15261, USA
[c] University of Pittsburgh, Health Sciences Library System, 200 Scaife Hall, 3550 Terrace Street, Pittsburgh, PA 15261, USA
[d] University of Pittsburgh, School of Medicine, Department of Psychiatry, 3811 O'Hara Street, Pittsburgh, PA 15213, USA

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ABSTRACT

Background: Sleep deprivation is common in shift work occupations, including safety-sensitive occupations. While extending sleep prior to scheduled shifts (i.e., "banking sleep") may be an intuitive strategy for fatigue mitigation, the evidence behind this strategy is unclear.
Methods: We performed a systematic review of literature retrieved in searches of four databases. We examined agreement between two independent screeners, abstracted key findings, reviewed and synthesized findings, and evaluated the quality of evidence using the Grading of Recommendations, Assessment, Development, and Evaluation (GRADE) methodology. The Cochrane Collaboration's risk of bias tool was used to evaluate bias of individual studies. We reported findings as prescribed by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement.
Results: Of the 3007 records screened, five met inclusion criteria. The inter-rater agreement for inclusion/exclusion was high ($\kappa = 0.87$). One study addressed patient safety outcomes. Four studies assessed the impact of banking sleep on performance, five assessed measures of acute fatigue, and three evaluated banking sleep on indicators of health. All five studies presented a very serious risk of bias and the quality of evidence was very low. Given these caveats, the findings, in aggregate, support banking sleep as a strategy to improve indicators of performance and acute fatigue.
Conclusions: This systematic review identifies gaps in research of shift workers on the efficacy of banking sleep as a fatigue risk management strategy. The available evidence supports banking sleep prior to shiftwork as a strategy for improved patient safety, performance, and reducing acute fatigue.

Background

Shift work refers to periods of scheduled work that occur outside traditional daylight work hours of 9 am to 5 pm, and can involve evening or night shifts, early morning shifts, and/or rotating shifts.[1–3] The duration, rotation, and timing of shifts, as well as the speed of rotation, inter-shift recovery time, and number of successive shifts, differ by occupation and industry.[4] One-fifth of US working adults work non-daylight shifts.[5] Compared to traditional day work schedules, shift work is associated with an elevated risk of poor health[6] and increased risk to safety.[7] Despite the dangers, "shift work is here to stay."[8]

Sleep is "*a reversible behavioral state of perceptual disengagement from, and unresponsiveness to, the environment. It is typically accompanied by postural recumbence, behavioral quiescence, closed eyes, and other indicators commonly associated with sleeping.*"[9] Professional organizations in sleep medicine, such as the National Sleep Foundation, American Academy of Sleep Medicine, and the Sleep Research Society recommend adults obtain seven to 9 hours of sleep each night (or

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* Corresponding author at: University of Pittsburgh, School of Medicine, Department of Emergency Medicine, Iroquois Bldg., Suite 400A, Pittsburgh, PA 15261, USA.
E-mail address: pdp3@pitt.edu. (P.D. Patterson).

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every 24-hour period). Most U.S. adult workers report 7 hours of sleep per night,[10] however, roughly one-third report inadequate sleep of less than 7 hours per night over the previous 30-days.[11] Shift workers regularly obtain less sleep than non-shift workers,[12] and their sleep quality is often poorer.[12] Sleep problems, such as sleep apnea, insomnia, trouble falling asleep, and inadequate sleep are also common among shift workers.[12] The negative effects of inadequate sleep that are often attributed to shift work include, yet are not limited to, disruptions in glucose/insulin balance,[13] interference with normal fluctuations in blood pressure and heart rate,[14] greater risk of developing hypertension,[15,16] worse mood,[17] impaired performance,[18] and increased risk of negative safety outcomes at work.[10]

Improving sleep and reducing the threats to safety posed by inadequate sleep and fatigue are priorities for shift work occupations, especially for those that operate in high-risk environments.[19] Caffeine and naps are often promoted as evidence-based strategies for fatigue mitigation.[20–22] Banking sleep refers to extending time in bed prior to a period of anticipated sleep loss, or for purposes of addressing accumulated sleep debt.[23,24] Extending the main nocturnal sleep period over a series of days improves performance, alertness, and indicators of sleep health (eg, daytime sleepiness) in diverse groups.[23,25–27] Previous studies have also examined sleep banking in relation to mood and performance[25,28]; diet and lifestyle[29]; the potentially harmful effects of long duration sleep[30]; and determining optimal sleep duration.[31]

Banking sleep before scheduled shifts or before a series of shifts is a potentially pragmatic strategy to combat the negative effects of shift work.[23] Despite the face validity and perceived practicality of this strategy, few experimental research studies have tested this strategy in occupational groups that work in shifts.[32] Furthermore, there are no known systematic reviews of the evidence connected to sleep banking. A review of the experimental evidence will fill this gap in knowledge and spur additional research on fatigue mitigation strategies that are sensible or feasible for shift workers.

While a review of the evidence would be informative to all shift worker occupations, we contextualized our search with Emergency Medical Services (EMS) clinicians as our population of interest. EMS clinicians are a unique subset of shift workers that may benefit from a sleep banking intervention before and/or between scheduled shifts. Half of EMS shift workers obtain less than 6 hours of sleep per 24-hour period.[33] Approximately half report inadequate recovery between shifts,[34] greater than one third report excessive daytime sleepiness,[35] and greater than half report poor sleep quality and fatigue.[33,36,37] Large numbers of EMS personnel work 12- or 24-hour shifts,[34,36–39] and many work multiple jobs and/or work overtime hours.[40,41] Complex multi-modal interventions that require a substantial time commitment, and those that have been tailored to aviation, trucking, or other professions may not be effective or well-received by EMS clinicians or other shift workers in safety-sensitive occupations where work is unpredictable. A simple, single component intervention that promotes EMS personnel banking sleep before and/or between scheduled shifts may have positive impacts on multiple outcomes. Because the evidence behind banking sleep from the shift worker perspective is not well-described,[32] the overarching question for this study is: "In EMS personnel and related shift worker groups, does banking sleep mitigate fatigue, fatigue-related risks, and/or improve sleep?" (PROSPERO 2017: CRD42017079396).

Methods

Overview and study design

Three co-investigators formulated the research question that guided this systematic review a priori. The question was framed in the P.I.C.O. format, which specifies the population, intervention, comparison, and outcomes of interest.[42,43] Our population of interest was specified as: EMS personnel or similar worker groups, defined as shift workers whose job activity requires multiple episodes of intense concentration and attention to detail per shift, with serious adverse consequences potentially resulting from a lapse in concentration. The intervention of interest was banking sleep prior to work shifts with anticipated sleep loss. Our intended focus was on extending the main sleep period; we excluded studies that focused on napping before or during shift work. The comparison of interest was banking sleep versus habitual/normal sleep patterns. The primary outcomes of interest were indicators of personnel safety and patient safety. Secondary outcomes included indicators of personnel performance, acute fatigue, indicators of sleep (specifically sleep latency), health status, turnover and job satisfaction, stress and burnout. All elements of our P.I.C.O. research question were registered with PROSPERO, an international database of prospectively registered systematic reviews and meta-analyses (PROSPERO 2017: CRD42017079396). We began with searches of four bibliographic databases: PubMed/Medline, the Cumulative Index to Nursing and Allied Health Literature (CINAHL), Scopus, and PsycINFO. All searches included literature published and added to these databases from January 1, 1980 to December 7, 2017. We selected these databases based on the cross-disciplinary nature of fatigue mitigation in shift worker occupations. These databases are also similar to those chosen for recent systematic reviews dedicated to fatigue in the workplace.[44] We focused our search on experimental study designs (eg, randomized controlled trials, crossover trials, and quasi-experimental trials) and tests of banking sleep, i.e., extending the sleep opportunity between or before scheduled shifts for shift workers.

Our population of interest was EMS personnel and related shift worker groups. However, we included studies with non-shift worker study samples if the protocol tested was judged similar to protocols tested with shift workers. Specifically, we looked for protocols that tested habitual sleep versus sleep banking followed by a period of sleep deprivation similar to shift work. The comparison of interest was outcomes measured during the sleep deprivation (shift work like) period stratified by habitual versus sleep banking. We labeled research with non-shift worker groups as "analog data." Our procedures for literature screening are described in detail below as prescribed in the PRISMA diagram.[45] We used the Cochrane Collaboration's Risk of Bias tool to assess bias of each study that met criteria for inclusion,[46] and we used the Grading of Recommendations, Assessment, Development and Evaluation (GRADE) framework to review and rate the quality of evidence.[47,48]

Literature search methods

Appendix A contains the details of our search strategy for four databases, including search terms.

Data collection and selection of studies

Screening

Two co-investigators were trained to independently screen titles and abstracts and identify relevant publications and research. We used DistillerSR by Evidence Partners (Ottawa, Ontario, Canada) to maintain and screen records. Screeners excluded records believed to be book chapters, conference abstracts, newsletters, dissertations, or theses. A third co-investigator adjudicated disagreements using inclusion/exclusion criteria: a) the study describes the population of interest; b) the study describes sleep banking versus habitual sleep as the primary comparison of interest; and c) the title and/or abstract describes one or more outcomes of interest. The Kappa statistic was used to determine agreement between screeners.[49]

Full-text review

Two co-investigators reviewed full-text articles and worked independently to abstract key information. This key information included study design, participant characteristics, intervention characteristics, comparisons, outcome measures, and key findings (Appendix B). Any disagreements in data abstractions were resolved by discussion. Investigators searched the bibliographies of retained literature to identify relevant research. All potentially relevant research was reviewed in full-text format against the study's inclusion and exclusion criteria.

Risk of bias assessment

Three co-investigators examined the retained studies for risk of bias with the Cochrane Collaboration's Risk of Bias tool for experimental studies.[46] The Cochrane tool is commonly used for the assessment of risk of bias. The tool allows for evaluation of bias across six domains: selection bias (i.e., sequence generation and allocation concealment); performance bias (i.e., blinding of participants and personnel); detection bias (i.e., blinding of outcome assessment); attrition bias (i.e., incomplete outcome data); reporting bias (i.e., selective reporting); and other bias (i.e., other sources of bias not addressed in other domains). All disagreements regarding the assessment of bias were handled by discussion.

Types of interventions

We searched the literature for experimental and intervention studies that used banking sleep as a strategy to mitigate fatigue, fatigue related risk, and/or improve sleep. We excluded observational research that did not report on the impact of banking sleep prior to shift work or prior to a period of sleep deprivation similar to shift work.

Participants

We retained studies that involved shift workers 18 years of age and older. Studies that involved non-shift worker groups were retained, and labeled "analog data," if the protocol tested was judged similar to exposure to shift work like conditions following a period of sleep banking vs. habitual sleep. Disagreements were addressed with discussion.

Outcome measures

We selected outcomes that overlap with those reported in recent fatigue-related systematic reviews addressing shift workers analogous to our target population.[50] The primary outcomes of interest were personnel safety and patient safety. Secondary outcomes of interest included direct measures or indicators of personnel performance, acute fatigue, sleep latency, health status, turnover and job satisfaction, and stress and burnout. We evaluated the impact of the intervention on sleep latency, often described as the "duration of time between when lights are turned off (lights out), until the time when the individual falls asleep as evidenced by Electroencephalography (EEG)."[51] Decreased sleep latency suggests a greater drive for sleep. Sleep latency is a key component of the Multiple Sleep Latency Test (MSLT) and Maintenance of Wakefulness Test (MTW), two standard tests for assessing sleepiness in sleep medicine. Sleep latency and the MSLT and MWT have also been linked to assessment of fitness for duty of shift workers, in the context of alertness and performance.[52] Previous research suggests that banking sleep duration leads to normalizing (improving) sleep latency and reducing daytime sleepiness.[53] Given this link, we report on the impact of sleep banking on sleep latency.

Statistical analysis

We assessed the favorability of study findings for each outcome of interest and reported these findings in table format. Three senior co-investigators used a system for classifying the findings of a single study, linked to each outcome, as favorable, unfavorable, mixed/inconclusive, or no impact.[44,54] Favorable was used when findings favored the intervention. Unfavorable was used when findings did not favor the intervention. Mixed/inconclusive was used when findings showed both positive and negative impacts on outcomes with multiple components (eg, a composite or index measure) or when reported findings were insufficient to draw a conclusion. No impact was used when the findings showed no statistical and/or clinically meaningful impact on outcomes.

Three senior co-investigators adhered to the GRADE framework to summarize and rate the quality of retained research (evidence).[47,48] Investigators have been trained to use GRADE and have prior experience applying framework towards evidence evaluation and development of evidence-based guidelines.[44,55] Investigators used GRADE and the GRADEPro software (www.gradepro.org) to evaluate the quality of evidence. The software guides investigators through a process of assessing the evidence with multiple studies grouped by outcome. The assessments for each outcome include evaluation of study design, risk of bias, inconsistency, indirectness, imprecision, and other considerations.[47] Separate publications provide detailed explanations for each component and directions for quality assessment using GRADE.[47,56–63]

Results

The search strategy yielded n = 3007 unique records, from which n = 41 duplicates were removed (Fig. 1). Two co-investigators independently screened n = 2966 records with titles and abstracts. The inter-rater agreement for inclusion/exclusion was high (Kappa = 0.87). Screeners identified 10 records that met inclusion criteria based on title and abstract alone. Conflicts between screeners were identified for three records. Thirty records were identified during bibliography searches as potentially relevant and 43 were selected for full-text review. Five experimental studies (six total articles) were judged relevant to the study's PICO question, and their key findings abstracted into table format (Appendix B).[23,64,65] Thirty-seven articles were excluded following full-text review with explanations for their exclusion reported in the Population, Intervention, Comparison, Outcome (PICO) format (See Appendix C).[43,66,67] The most common reason for exclusion was the study did not report on the comparison of interest. See Appendix D for a risk of bias form completed for each of the retained studies.

Description of interventions

Kubo and associates enrolled shift workers at an electric company in a three-week experiment that began with a baseline week of habitual sleep followed by the intervention, which was isolated to the weekend.[64] Twenty-five participants remained in bed ≥8 hours during the intervention weekend (Friday, Saturday, and Sunday). Rupp and associates completed a randomized, experimental study design with 24 individuals to determine the impact of banking sleep on performance during a period of sleep restriction and subsequently during a period of recovery.[23] Participants were civilian and active duty military men and women randomized to the intervention condition, spending 10 hours in bed for 7 days, whereas participants in the control condition followed a habitual sleep schedule. Similar to previous research,[21] we considered the military men and women to be shift workers.

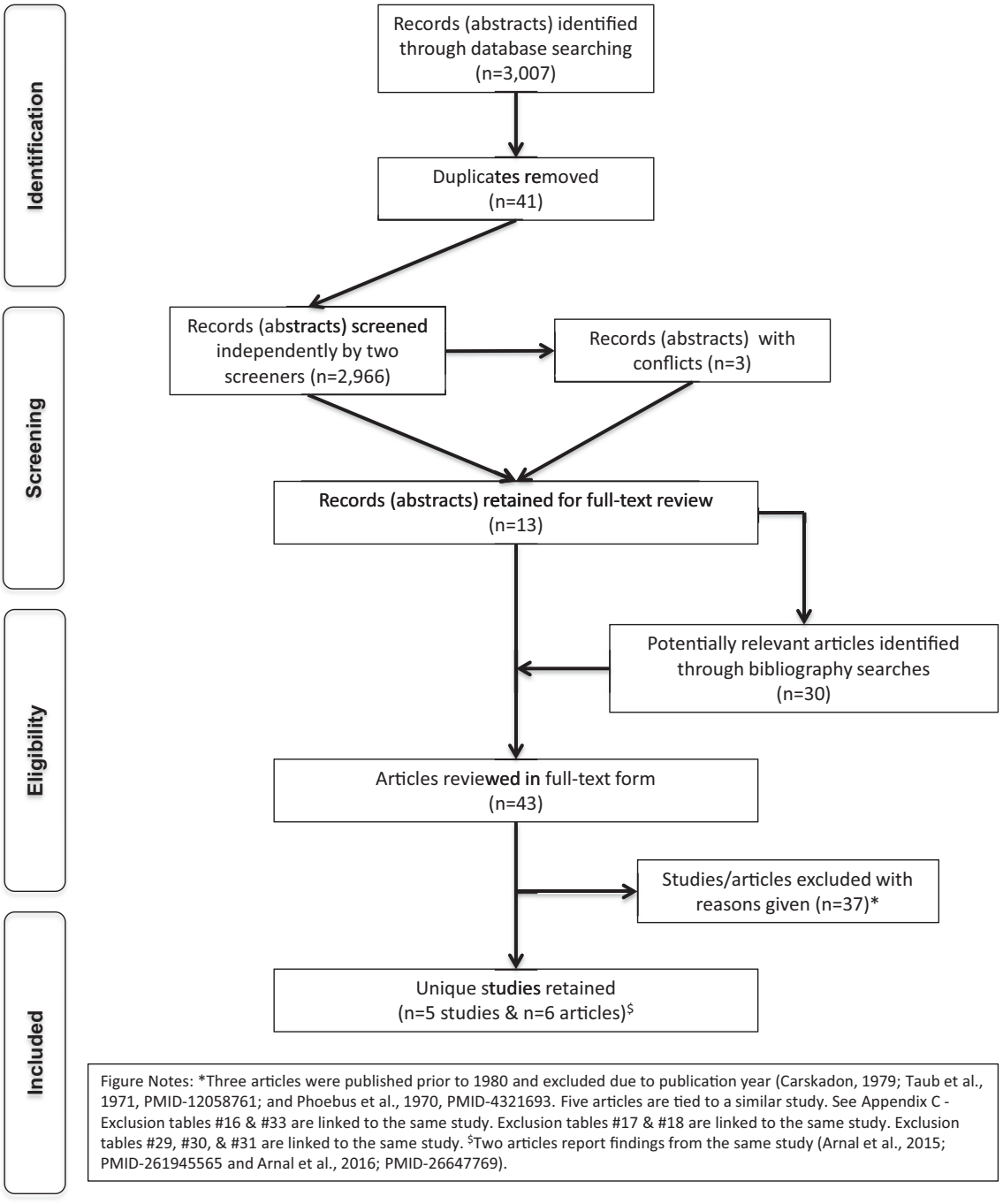

Fig. 1. PRISMA diagram.

Yeung and colleagues recruited shift workers in Australia (occupation/industry not specified) to participate in a within-subject, before-after quasi-experimental study design with 16 participants.[65] The intervention followed a baseline period of habitual sleep that lasted 7 days. During the intervention, participants were asked to increase their bedtime to 10 hours prior to the start of a shift. The intent was to provide participants the opportunity to have 8 hours of time in bed.

Howard and colleagues explored the impact of sleep deprivation versus sleep extension among 12 anesthesiologists prior to a simulated surgery.[70] In a randomized crossover design, participants completed one of two possible conditions prior to simulated surgery. The first condition was sleeping normally (habitual) for three nights followed by a night of total sleep deprivation (25 hours) immediately before the simulated surgery (mean sleep hours over 4 nights were 5.4, SD 0.68). The second condition involved four nights of extended sleep prior to simulated surgery (mean sleep hours 9.1, SD 0.68). Investigators hypothesized that performance during the anesthetic case would be worse following sleep deprivation than following four nights of extended sleep.

Analog data

Arnal and colleagues' protocol with 14 healthy young men (non-shift workers),[68,69] was judged similar to the protocol of Rupp and associates[23] and included in this systematic review as analog data. Fourteen volunteers were randomized to six nights of extended time in bed (~10 hours) or habitual time in bed (≥8 hours). This was followed by a baseline wake period (0700–0000) and total sleep deprivation from 0000 to 2100. Participants then completed one night of recovery sleep (2100–0700). In this crossover design, participants assigned to extended sleep crossed over to the habitual sleep and vice versa when testing was conducted.

Primary outcome

Howard and associates assessed indicators of patient safety (i.e., clinical tasks (i.e., machine check, equipment faults, management of induction, and detection/correction of abnormal clinical events), vigilance probes, tasks analysis and psychological workload assessment, and behavioral assessment of sleep behaviors.[70] No differences between the sleep extension and habitual sleep group were reported for machine checks, equipment faults, management of induction, and detection/correction of abnormal clinical events. Vigilance probes consisted of 1) a machine notification of potential problem (a red light on the machine); 2) a sudden 0 reading in the patient's arterial blood pressure; and 3) an erratic, sudden fluctuation in patient blood pressure or heart rate for 10 to 30 seconds. These probes occurred at random for a total of 27 times during the simulation. Mean response time to the third probe was longer among participants in the habitual sleep group vs. the sleep extension group. Observer rated workload did not differ by group status. We judged these findings as favorable using the classification system established by Bolster and Rourke and used previously in related research (Table 1).[44,54]

Secondary outcomes (personnel performance)

Four studies assessed the impact of banking sleep on personnel performance (Table 1). Kubo and associates assessed reaction time and lapses with the 10-minute psychomotor vigilance test (PVT) on the Monday and Thursday post intervention.[64] Reaction time and lapses improved on the Monday post intervention, but worsened on Thursday. We judged these findings as mixed/inconclusive.

In the study by Rupp and associates, a seven-day extended vs. habitual time in bed intervention period was followed by a seven-day period of sleep restriction to 4 hours per night, then a five-day period of recovery sleep.[23] Reaction time and lapses were measured with the five-minute PVT during the sleep restriction and recovery periods. Performance deteriorated in both groups; however, performance of participants in the habitual (control) condition was worse in terms of PVT lapses during the sleep restriction and recovery periods compared to participants in the intervention group. We judged these findings as favorable towards the intervention of banking sleep and its impact on personnel performance (Table 1).

Howard and colleagues reported on two measures that we classified as personnel performance.[70] These included the 10-minute PVT and the probed recall memory (PRM), both measured prior to initiation of the simulation, mid-simulation, and on completion of the simulation. Fewer lapses occurred among those in the sleep extension group vs. the habitual sleep group. Performance on the PRM measure was worse, and response times for selected measures within the performance probe measurement were longer among participants in the habitual sleep group vs. those in the sleep extension group. We judged these findings as favorable towards sleep banking.

Table 1
Synthesis of findings of the impact of 'banking sleep' on outcomes: Findings are classified as favorable, unfavorable, mixed/inconclusive, or no impact.

Author, Year	Distiller RefID# PMID#	Study Design & Study Population	Primary Outcomes		Secondary Outcomes					
			Personnel Safety	Patient Safety[%]	Personnel Performance[#]	Acute Fatigue[*]	Sleep Latency	Health Status[&]	Turnover & Job Satisfaction	Stress/ Burnout
Yeung et al., 2011	RefID-2527 PMID-20882266	Before-after quasi-experimental Shift worker occupation not specified	–	–	–	Favorable	No Impact	–	–	–
Kubo et al., 2011	RefID-1256 PMID-21475780	Before-after quasi-experimental Electric company employees	–	–	Mixed/ Inconclusive	No Impact	–	No Impact	–	–
Rupp et al., 2009	RefID-1984 PMID-19294951	Randomized trial Civilian and active military	–	–	Favorable	No Impact	Favorable	–	–	–
Howard et al., 2003	RefID-n/a PMID-12766642	Randomized crossover design Anesthesiology residents	–	Favorable	Favorable	Favorable	–	Favorable	–	
Arnal et al., 2015; & Arnal et al., 2016	RefID-149 PMID-26194565	Randomized crossover study design			Favorable	Favorable	Favorable	Mixed/ Inconclusive		
Analog Data	RefID-148 PMID-26647769	Healthy men & women (non-shift workers)								

NOTE. Favorable implies the study's findings favor the intervention. Unfavorable implies the study's findings do not favor the intervention. Mixed/inconclusive implies the study's findings showed both positive and negative impacts of the intervention on multiple outcomes. No impact implies the study's findings showed no statistical or clinically meaningful impact on outcomes.
[%]Includes measures of quality of care or observer ratings of safety related behavior/events.
[#]Includes external objective and subjective ratings of performance. Measures of psychomotor vigilance included.
[*]Includes acute states of fatigue, sleepiness, or alertness.
[&]Includes general wellness or well-being measures and measures of psychological health.

Participants in the Arnal et al.,[68] study completed two 6-day periods of extended sleep and extended time in bed and habitual sleep. Participants experienced 24 hours of continuous awakening. Performance measures with the 10-minute PVT were assessed at select time intervals and findings show that participants in the habitual group experienced significantly more lapses during select time points of sleep deprivation and during recovery. In addition, PVT speed was worse among the habitual group during the recovery period than among the sleep extension group. We judged these findings as favorable towards sleep banking.

Secondary outcomes (acute fatigue)

Yeung and associates used the Karolinska Sleepiness Scale (KSS) to evaluate sleepiness 4 hours after waking, 4 hours before bedtime, and immediately before bedtime.[65] During the intervention phase, participants reported less sleepiness ($P < .05$) immediately before bedtime. We classified these findings as favorable towards the intervention of advancing sleep time for purposes of banking sleep immediately prior to shift work (Table 1).

Kubo and associates measured fatigue symptoms with a 25-item survey on Monday and Thursdays following the weekend intervention of extended sleep.[64] Investigators reported no significant differences in subjective fatigue when comparing measurements taken after the weekend of extended sleep versus a weekend of habitual sleep. We classified these findings as no impact (Table 1).

Rupp and associates used the Stanford Sleepiness Scale (SSS) to evaluate sleepiness during the sleep restriction and recovery phases.[23] Measures were taken hourly from 0800 to 1800 daily, but these hourly measures were collapsed into one measure per day for analysis. Aggregated, daily sleepiness measures did not differ between the intervention and habitual (control) groups. We classified these findings as no impact (Table 1).

Howard and colleagues used blinded observers to rate participant alertness.[70] Observers reported a significantly higher mean rating of alertness among participants in the sleep extension group vs. the habitual group.[70] Observers also detected a higher frequency of sleeping episodes during the simulation among participants in the habitual sleep group vs. the sleep extension group. Authors noted that three participants were recorded sleeping more than 10 minutes during the simulation. We classified these findings as favorable towards sleep banking (Table 1).

Arnal and colleagues examined "micro-sleeps," defined as 3–14 second epochs of stage 1, 2, or 3 sleep preceded by a period of wakefulness ≥15 seconds.[68] Findings show that the sleep banking group experienced fewer micro-sleeps than participants in the habitual sleep group. We judged these findings as favorable towards sleep banking.

Secondary outcomes (sleep latency)

Yeung and associates reported no impact of their intervention on sleep latency.[65] Rupp and colleagues showed that banking sleep for one week prior to a week of sleep restriction had a positive impact on sleep latency by normalizing time to sleep onset.[23] The impact was limited to the initial one to two days when sleep was restricted (See Fig. 2 in a separate publication[23]). There was no evidence of intervention benefit during the period of recovery. We classified these findings as favorable towards the intervention (Table 1).

Secondary outcomes (health status)

Three studies examined indicators of health status. One study assessed blood pressure and evaluated the impact of banking sleep on systolic and diastolic blood pressure.[64] Blood pressure on Monday and Thursday following three nights of extended sleep did not differ from blood pressure among participants with habitual sleep.[64] We classified these findings as no impact (Table 1). Howard and associates used the Profile of Mood States (POMS) to assess mood at different time points during the simulated experiment.[70] The POMS is a widely used indicator of psychological health and wellbeing.[71] Howard and associates reported the total mood disturbance score, which was significantly worse during the experiment in the habitual sleep group vs. the sleep extension group.[70] We classified these findings as favorable towards the sleep banking/extension. Data from Arnal and colleagues' study of 14 healthy men showed that six nights of sleep extension prior to 24 hours of awakening did not alter the decrease in concentration of testosterone and cortisol observed in the control condition of habitual sleep.[69] However, plasma concentrations of prolactin were higher in the sleep extension condition following 24 hours of awakening versus the habitual condition. While prolactin levels have been associated with various components of reproductive and sexual health, diabetes, and other medical conditions,[72,73] the Arnal and colleagues did not compare the net effect of differences in prolactin levels with a baseline in the population. Therefore, we judged the effects on health status as mixed/inconclusive.

None of the retained studies reported findings germane to two secondary outcomes: turnover and job satisfaction, and stress/burnout (Table 1).

Quality of evidence

We determined that all five studies presented a very serious risk of bias. Two studies[64,65] were non-randomized before-after study designs, and the method of randomization in three studies[23,68–70] was not well described (Appendix D). No study had adequate allocation concealment or blinding. We found limitations of incomplete outcome data in two studies and selective reporting in one study, though this represented a minority of the data. We downgraded for indirectness of evidence for all outcomes. This was due to differences in study populations, outcome measures, and interventions as well as small sample sizes in all the studies. We viewed the quality of the evidence as very poor for patient safety, personnel performance, for acute fatigue, for sleep latency, and for improvement in health status (See Table 2 and Appendix D). We found no evidence for the outcome of personnel safety or secondary outcomes of turnover and job satisfaction or stress/burnout.

Discussion

Summary of main results

Limited evidence from experimental studies shows that banking sleep prior to sleep loss can improve personnel performance, acute fatigue, and sleep latency for shift workers like EMS personnel. The evidence that banking sleep can contribute to improvements in patient safety is also limited. Banking sleep prior to a shift or series of shifts may lead to improved reaction time and a reduction in lapses on the PVT during or following a period of sleep restriction analogous to shift work. Three of five studies demonstrated that banking sleep reduced indicators of acute fatigue and sleepiness. The discrepancy between subjective and objective measures of acute fatigue shown in previous research[74] suggests that the impact of sleep banking on acute fatigue or sleepiness may be greater (more favorable) than represented in these studies. Two studies showed that banking sleep might have a positive impact on sleep latency during waking hours following a brief period of sleep restriction. In aggregate, this review shows mixed findings across studies and important gaps in the literature. Additional studies with diverse groups of shift workers could improve our understanding of the impact of sleep banking on

Table 2
GRADE Evidence Profile Table

Certainty assessment							Impact/Effect	Certainty	Importance
№ of studies	Study design	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations			
Patient Safety (Multiple measures germane to patient safety)									
1	Experimental Study Design	very serious [i]	not serious	serious [d]	very serious [e]	none	Pooled Effect Not Estimable. Findings from one study (Howard et al., 2003 were judged favorable). [Sample Size = 12] [e]	⊕◯◯◯ VERY LOW	CRITICAL
Personnel Performance (reaction time and lapses as measured by PVT)									
4	Experimental Study Designs [a]	very serious [b]	serious [c]	very serious [d]	very serious [e]	none	Pooled Effect Not Estimable. Findings from one study (Kubo et al., 2011; PMID-21475780) were judged mixed/inconclusive. Findings from three studies (Rupp et al., 2009; PMID-19294951; Howard et al., 2003; PMID-12766642; Arnal et al., 2015; PMID-26194565) were judged favorable. [Median Sample Size = 19] [e]	⊕◯◯◯ VERY LOW	CRITICAL
Acute Fatigue (sleepiness, alertness, and fatigue survey measures)									
5	Experimental Study Designs [f]	very serious [b]	serious [c]	very serious [d]	very serious [e]	none	Pooled Effect Not Estimable. Findings from three studies (Yeung et al., 2011; PMID-20882266; Howard et al., 2003; PMID-12766642; Arnal et al., 2015; PMID-26194565) were judged favorable. Findings from two studies (Kubo et al., 2011; PMID-21475780; and Rupp et al., 2009; PMID-19294951) were judged no impact. [Median Sample Size = 16] [e]	⊕◯◯◯ VERY LOW	IMPORTANT
Sleep (sleep latency)									
2	Experimental Study Designs [h]	very serious [b]	not serious	very serious [d]	very serious [e]	none	Pooled Effect Not Estimable. Findings from one study (Yeung et al., 2011; PMID-20882266) were judged no impact. Findings from one study (Rupp et al., 2009; PMID-19294951) were judged favorable. [Median Sample Size = 20] [e]	⊕◯◯◯ VERY LOW	IMPORTANT
Indicators of health status (ambulatory blood pressure, mood states, testosterone, cortisol, prolactin)									
3	Experimental Study Designs [g]	very serious [b]	not serious	very serious [d]	very serious [e]	none	Pooled Effect Not Estimable. Findings from one study (Kubo et al., 2011; PMID-21475780) were judged no impact. Findings from one study (Howard et al., 2003; PMID-12766642) were judged favorable. Findings from one study (Arnal et al., 2016; PMID-26647769) were judged mixed/inconclusive. [Sample Size = 14][e]	⊕◯◯◯ VERY LOW	IMPORTANT

NOTE.
a. Four studies: (Kubo et al., 2011; PMID-21475780; Rupp et al., 2009; PMID-19294951; Howard et al., 2003; PMID-12766642; Arnal et al., 2015; PMID-26194565).
b. Non-randomized experimental study design.
c. Findings inconsistent between studies.
d. Non-EMS shift workers.
e. Small sample size: Below optimal information size (Guyatt et al., 2011; PMID-21839614).
f. Five studies: (Yeung et al., 2011; PMID-20882266; Kubo et al., 2011; PMID-21475780; Rupp et al., 2009; PMID-19294951; Howard et al., 2003; PMID-12766642; Arnal et al., 2015/2016; PMID-26194565/26647769).
g. Three studies: (Kubo et al., 2011; PMID-21475780; Howard et al., 2003; PMID-12766642; Arnal et al., 2015/2016; PMID-26194565/26647769).
h. Two studies: (Yeung et al., 2011; PMID-20882266; Rupp et al., 2009; PMID-19294951).
i. Method of randomization not described.

important outcomes that were not adequately addressed in the studies we reviewed, eg, safety, job satisfaction, burnout, and stress.

Inclusion/exclusion of published studies

Our inclusion/exclusion decisions were motivated by relevance to EMS shift workers and related shift worker groups. We carefully examined the study protocol to identify exposure to habitual sleep versus sleep banking/extension followed by a period of shift work-like sleep deprivation. We included studies that assessed shift workers who are challenged by temporal irregularity and disruption of the sleep–wake cycle. We excluded a number of studies with healthy volunteers who were not shift workers, and who did not undergo experimental procedures simulating shift work. Restricting our analysis to shift workers, and to selected sleep extension protocols with healthy volunteers, limited bias due to indirectness.[61] Notably, we found no studies directly involving EMS shift workers, our population of interest. Studies of sleep banking in samples of college students, athletes, and other populations—which we did not include–support the hypothesis that extending sleep duration can improve neurobehavioral outcomes. These data may be indirectly relevant to EMS clinicians and other shift workers.[25,28,75]

We included analog data from one study involving healthy volunteers exposed to simulated shift work.[68,69] The study's protocol was similar to the other studies retained in this systematic review. However, we excluded a number of other potentially analog studies with healthy volunteers and athletes because the data did not include our comparison of interest[53,76] (that the outcomes be measured during a shift work like period and stratified by habitual versus sleep banking, which was to occur immediately prior to shift work like conditions). We also excluded studies because a comparison group was not reported.[31] Consistent with our study, lack of reporting on the primary comparison of interest is the most common reason for exclusion in systematic reviews.[67]

We excluded potentially relevant studies based on the study protocol. Specifically, several studies did not include a period of exposure to shift work-like sleep deprivation following sleep banking/extension versus habitual sleep. For example, the study by Horne and colleagues included a habitual sleep and sleep extension group/exposure.[26] However, the protocol did not include a period of sleep deprivation analogous to shift work immediately following exposure to habitual sleep or sleep extension (banking). We excluded the study by Mah and colleagues based on study design.[25] Participants in this study spent 5–7 weeks in the sleep extension phase of the protocol. Five to seven weeks is extensive, and not at all common or potentially feasible for many shift workers, including our population of interest, EMS clinicians. In addition, the protocol did not include a period of sleep deprivation – similar to shift work – immediately following exposure to sleep extension or habitual sleep. We also excluded a study[77] by Howard and colleagues that preceded a separate study that was included in this systematic review.[70] We excluded the earlier study because the protocol did not include sleep banking prior to exposure to shift work-like sleep deprivation. The protocol was therefore not similar to those retained in this systematic review and the comparison of interest was not presented.

Quality of evidence

The quality of evidence assessment was based on judgment informed by the GRADE methodology (Table 2).[48] Lack of randomization or incomplete descriptions of randomization procedures and allocation concealment limited our ability to accurately assess risk of bias and study quality for some studies. Complete concealment of the intervention (banking sleep) is not feasible. Our approach to downgrading based on risk of bias was primarily focused on the limited information about the study's execution and procedures, and/or lack of randomization. The sample sizes for all studies were small, which impacted confidence in precision.[59] Overall, we determined the research retained in this systematic review presented a very serious risk of bias (Table 2). Largely for this reason, our assessments demonstrate a very low quality of evidence.

Agreement and disagreement with other systematic reviews

Our review examines the evidence behind a fatigue mitigation strategy that may be implemented by the individual shift worker on a voluntary basis or could be incorporated into an employer-sponsored fatigue risk management program. Our findings are complementary to recent reviews that highlight other strategies for fatigue mitigation. For example, one recent systematic review examined the impact of napping/sleeping during shift work on performance and related outcomes.[22] Many strategies, like napping during a shift, requires the presence of corresponding policies, dedicated time, and a location suitable for napping, any of which may not be available or feasible in many organizations that employ shift workers. Other recent reviews examined the evidence related to shift duration,[78] providing access to fatigue countermeasures like caffeine,[21] and education and training of a workforce.[79] Our review adds to this literature and to the discussion of diverse strategies that may be used at home or in the workplace to mitigate fatigue.

Lessons learned

We found qualified evidence that sleep banking has a positive impact on performance, acute fatigue, and sleep latency. However, we identified important limitations that may guide future research. The first and most notable limitation is the lack of a standard definition or description of 'banking sleep.' To the best of our knowledge, there is no agreed upon description or expert consensus standard definition for banking sleep. The descriptions of interventions in the retained studies differ, but overlap in considering 'sleep banking' as part of the main sleep period. Specific studies defined sleep banking as ≥8 hours[64,65] or 10 hours in bed.[23] Those in the scientific community concerned with fatigue-mitigation of shift workers should establish a standard definition of banking sleep in order to help investigators focus the design of future studies and to reduce confusion when interpreting and comparing findings. Such a definition should also specify whether sleep banking should refer only to the major sleep period, or to all sleep obtained in a 24-hour period, including napping.

Banking sleep may be difficult to distinguish from, and may even be identical with, recovery sleep after a series of shifts or between shifts. Although some of the studies reviewed here clearly distinguished sleep banking from recovery sleep,[23] others focused only on the former.[64] Clarifying the difference between banking and recovery sleep may be complicated by the absence of an agreed upon standard description or definition for either term.[34,80,81] Complications may also emerge when trying to describe sleep banking in reference to repaying "sleep debt" that has accumulated over a period of time.

An important consideration for future research is whether napping should be considered a variant of sleep banking. Naps are "sleep periods at least 50% shorter than an individual's average nocturnal sleep length,"[82,83] but they may range from as little as 8 minutes to several hours.[22,83] Naps may be "prophylactic," i.e., adding sleep to the main sleep period in order to "accumulate an adequate amount of sleep,"[83] or "operational," intended to improve alertness, reduce sleepiness, or mitigate fatigue during work hours.[22] Both shift workers and investigators are likely to conceptualize napping separately from the main sleep period. Prophylactic

napping was not allowed in one of the studies retained in this review because of the belief that napping would have a negative impact on the participant's ability to sleep longer (and spend more time in bed) during the main sleep period.[65] The combination of napping studies with studies of extending the main sleep period may complicate interpretation and synthesis of published research. Our findings reveal an obvious gap in the literature and a fair amount of ambiguity regarding sleep strategies and how they are or are not operationalized. Future studies that test different types of sleep strategies are needed, and these studies should clearly define the inclusion/exclusion of napping as part of a sleep strategy. Future studies should also consider testing multiple study arms that include prophylactic naps, operational naps, and banking sleep, either alone or in combination.

The total number of studies that involved shift workers and banking sleep was small. Our finding a small number of relevant studies, however, is similar to the findings of other recent systematic reviews of shift workers.[21,22,78,79,84–86] Notwithstanding our qualified conclusions, this review points to a substantial gap in experimental studies and evidence germane to sleep strategies for shift workers to improve sleep health and mitigate the effects of fatigue. Observational studies provide important insights[87]; yet lack the important components of experimental designs such as a comparison group and controls for potential confounding factors. Experimental sleep intervention studies in shift worker populations are technically and pragmatically challenging. Powering such studies for important outcomes, like safety events, will require large numbers of participants and a substantial investment in terms of time and funding. Given these requirements, it is unlikely that the gaps identified in this systematic review will be filled quickly. Future studies may need to focus on novel outcomes and rely on small samples of targeted populations.

Given these challenges, studies in non-shift worker populations also need consideration. The intent of focused searches and synthesis of evidence specific to shift workers is to exclude information that the targeted population may consider "indirect" and isolate the evidence most applicable to their situation.[61] However, this systematic review, and other similar reviews,[21,22,78,79,84–86] find studies of non-shift worker groups are abundant and may offer important insights for those concerned with the health and wellbeing of shift workers. Future systematic reviews, we believe, should continue to collate the evidence involving shift worker groups to provide the targeted population with as much "direct evidence" as possible. However, parallel efforts may be needed that combine data from non-shift worker groups, as we have done, and synthesize the evidence from a much larger pool of studies.

Limitations

As with any systematic review, ours has several potential limitations: databases selected for searches, criteria for included/excluded studies, and consistency in screening judgments. We addressed these potential limitations by searching multiple databases; using the PICO and GRADE frameworks to define the research question; and requiring rigorous training and reliability, supplemented by consensus judgments. Consistency in judgment during the screening process is a common concern for systematic reviews.[88] We addressed this by first training our screeners to apply study inclusion and exclusion criteria in all cases. We also instructed screeners to err on the side of caution and retain a record when application of study criteria was unclear. Second, we examined inter-rater agreement with the Kappa statistic. The inter-rater agreement was high (kappa = 0.87). Third, we took a random sample of 100 records from the initial pool and examined the percentage of agreement between screeners and the principal investigator. Findings show 100 percent agreement among the two screeners and principal investigator.

We also took steps to reduce error during the data abstraction process by having a second co-investigator verify the data abstraction of key findings performed by the first co-investigator to review the study.[89] Finally, we addressed concerns germane to application of the GRADE framework and judgments of evidence quality by requiring consensus in judgment among three senior co-investigators.

Non-experimental studies were excluded from this review because our interest was in the effects of banking sleep. We are less able to ascribe causality with observational data that results from cross sectional surveys and other designs that generate correlational data. Notably, our exclusion of observational data is similar to other systematic reviews with a focus on synthesizing the best available evidence on specific sleep-fatigue mitigation strategies.[22,83] Future studies may include observational data, which we acknowledge may help to further the conversation about banking sleep and its impact on or association with select outcomes.

Our research question was narrowly focused on banking sleep immediately prior to exposure to shift work periods when sleep restriction and deprivation are common. This narrow focus limited the total number of studies retained and synthesized. Future studies may need to expand the research question in terms of the population, intervention, and comparisons of interest. Future studies may wish to consider "interventions" that involve both pre-emptive and post-hoc applications of banking/extending sleep. Data from a more diverse pool of studies may add to our findings and clarify the previously discussed uncertainty in defining sleep banking and recovery sleep. Synthesis of these data will be a challenge without a clear description of the sleep/wake and work patterns of study participants. This level of detail is important given known inter-individual differences in habitual sleep need regardless of sleep opportunity.[90] Future studies should also consider including "gray literature" such as conference proceedings, reports, dissertations, theses, and other non-peer-reviewed publications.

Conclusions

In this systematic review, the evidence provided qualified support for the conclusion that banking sleep prior to shiftwork improves patient safety, personnel performance, acute fatigue, and sleep latency. The effect of banking sleep on health status was inconclusive. The quality of evidence was judged very low, mostly due to bias and lack of randomized clinical trials conducted in operational shift workers. This systematic review identifies knowledge gaps involving shift workers on the efficacy of banking sleep as a fatigue risk management strategy. We advocate for research that explores the timing, duration, feasibility and acceptability of sleep banking on shift worker outcomes, with a specific focus on patient and worker safety outcomes.

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Disclosure statement

The authors report no conflicts of interest.

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None.

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