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REVIEW ARTICLE

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US research needs related to fatigue, sleep, and working hours among oil and gas extraction workers

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Abstract

Background: During 2003–2013, 1189 US oil and gas extraction (OGE) workers died while working, resulting in an average annual workplace fatality rate seven times that for all US workers. OGE work commonly involves long hours, shiftwork, irregular schedules, and long commutes, but effects of these factors on fatigue, occupational injury, and illness in OGE are largely unknown.

Methods: A scoping review of relevant OGE research during 2000–2019 was completed and supplemented by input from a NIOSH-sponsored Forum.

Results: Seventy-eight papers were identified; 76% reported only offshore research. Five themes for research needs emerged: build knowledge about the impacts of fatigue; explore interactions between on- and off-the-job risk factors; identify and evaluate interventions; assess effectiveness of technology; and increase the diffusion of fatigue risk management information.

Conclusions: Further collaboration between researchers and OGE operators and contractors can lead to action-oriented recommendations to mitigate the effects of fatigue, inadequate sleep, and shiftwork.

KEYWORDS

alertness, offshore, onshore, petroleum, research needs, scoping review, shiftwork, sleepiness

1 | BACKGROUND

The contributions of sleep, fatigue, shiftwork, and working hours to occupational injury and illness in the United States (US) oil and gas extraction (OGE) industry, as well as the effectiveness of interventions to mitigate their effects, are largely unknown. To gain a thorough understanding of the state of the science on this topic, the authors conducted a scoping review of current literature and summarized the findings. The results of the review were combined with input gathered from a NIOSH-sponsored forum to propose research that will lead to strategies to protect workers from adverse effects of fatigue, inadequate sleep, shiftwork, and long working hours within this critical high-risk industry.

This manuscript is part of a series of papers developed following the NIOSH Working Hours, Sleep and Fatigue Forum in September 2019. The purpose of this series is to identify the research gaps/needs around working hours, sleep, and fatigue that are specific to industry sectors and vulnerable working populations in the US Collectively, the papers provide overviews of the current state of research, identify health and safety risks, highlight effective interventions, and suggest future research directions.

In the United States, crude oil production more than doubled and natural gas production increased by 38% between 2010 and 2018 such that by 2018, the US was the world's leading oil and natural-gas producing country.[1,2] Although the level of attention given to offshore oil rig disasters may lead to the perception that most OGE activity occurs offshore, in fact more than two-thirds of the world's oil and about 85% of the US's oil and over 96% of its natural gas is produced onshore.[3,4] In 2018, the US OGE workforce was composed of 471,471 workers employed by a handful of major international oil and gas operators and approximately 9000 independent oil and gas producers that develop and operate properties[5] (North American Industrial Classification System [NAICS] 211), contractors who drill oil and gas wells (NAICS 213111), and a large number of other support contractors who provide a wide range of services to bring new wells into production and service existing wells (NAICS 213112).[6]

Despite increases in US production in recent years, the OGE worker fatality rate decreased significantly between 2003 and 2013 (29.0 and 19.1 per 100,000 workers, respectively). Nonetheless, the average annual rate for the OGE workforce was approximately seven times that for all US workers during the same time period.[7] One possible explanation for the comparatively high rate in OGE is an elevated motor vehicle fatality rate compared to all US workers (7.6 vs. 0.9 per 100,000). Falling asleep at the wheel has been identified in crash reports as a contributing factor to the high rate in OGE.[8]

The nature and organization of work in the OGE industry has been shown to predispose workers to adverse safety and health outcomes as a result of fatigue, which is the body's drive for restorative sleep and rest in response to short- or long-term sleep loss and disruption of the circadian rhythms that regulate the sleep-wake cycle.[9] Predisposition to fatigue may vary by age, sex, marital and socioeconomic status, personality traits, and chronotype (i.e., the preference for activity and tendency to be sleepy or alert based on time of day).[10] Workplace factors that may exacerbate fatigue include prolonged physical or mental exertion, task monotony, job stress, long commuting time, and work environment features such as lighting and noise.[10,11] An estimated 15%–20% of motor vehicle crashes in the general population have been attributed to fatigue,[12] and fatigue is estimated to be a factor in 13% of all work injuries.[13] Fatigue is associated with reduced alertness, declines in performance, sleepiness, and increased risk-taking behavior, all of which contribute to risk of serious incidents and injuries.[11,13–15]

OGE work is also characterized by long work hours, overtime work, and shiftwork. Long work hours and overtime work have been associated with declines in performance, poorer perceived general health, increased injury rates, and increased mortality.[16,17] In 2018, US workers in private industry worked 34.5 h per week on average, but oil and gas operator employees (34% of the OGE workforce) worked 42.4 h per week on average[18] and workers engaged in drilling and oil and gas support activities (66% of the OGE workforce) worked 48.8 h.[19] Many subgroups of OGE workers (e.g., operator field staff, drilling contractors, some support contractors, and offshore workers) work 12-h shifts, for 2 consecutive weeks or longer, generally followed by 2 weeks off work.[20,21] Moreover, while some workers work fixed day or night shifts during this 2-week work block, many work swing shifts, which begin with seven-night shifts followed by seven-day shifts (or the reverse) or rotating shifts, where the same daily schedule is worked through the work block but the shift type may change from one work block to the next.[22,23] Changing of shift schedules and unpredictable “on-call” or “call-out” status can result in circadian disruptions and impair sleep.[24,25]

The OGE work environment may further increase the potential for adverse outcomes related to fatigue, shiftwork, and long work hours. Economic forces that drive the industry are cyclical and unpredictable. Rapid increases in activity or unexpected events during drilling and completion of new wells may lead to understaffing, which in turn leads to increased overtime and extended work blocks. Oil and gas operators rely heavily on companies which are contracted to conduct drilling, well servicing, and transportation. These companies are often independent contractors and/or have few employees. They may support multiple operators at the same time, exacerbating the potential for competing work demands, small profit margins, long work hours, and insufficient rest time. Transportation contractors are also often paid by the load. Onshore and offshore OGE workers are often exposed to a wide range of physical and chemical hazards, including extreme weather conditions and working at heights, around large and heavy moving equipment, and around potentially flammable and toxic gases, vapors and particulates.

Many onshore worksites are remote, requiring workers to drive long distances before, during, and after shifts on rural roads which often lack safety features.[26] Long commutes (50 or more miles/80 or more kilometers one way)[27] further extend work days. Offshore workers may also have long commutes, using multiple modes of transport, between their residence and the locations from which they are transported to rigs and offshore platforms.[7,28] Once they reach these locations, their time awake can be extended further by helicopter flight delays due to inclement weather.[29] Remote sites, onshore and offshore, have created a need for short- or long-term accommodations nearby where workers can eat, rest, and sleep while off duty. Conditions in these accommodations may not necessarily support adequate sleep, nutrition, exercise and overall health.[21]

Coverage of OGE workers in the US by federal work hours regulations is limited. The Occupational Safety and Health Administration has no maximum work hour regulations for private industry that cover OGE workers on the worksite or the road. The transport of oil and gas after extraction is covered by federal hours-of-service (HOS) regulations that set maximum driving hours and duty hours during a work shift or over several shifts, require breaks during a shift, and require a minimum number of off-duty hours between shifts.[30] However, heavy vehicles specifically designed for the oilfield are exempt from compliance with HOS regulations.[30] Further, HOS regulations cover only vehicles weighing 10,000 pounds or more inclusive of any unit being towed; they do not apply to light-duty vehicles, which are widely used in the OGE industry. Other federal legislation and regulations in the US address fatigue and HOS for other workers involved in the transport of oil and gas: rail workers[31] and pipeline control room workers.[32]

Research suggests that the HOS approach alone does not adequately manage fatigue. Individuals do not experience fatigue uniformly, and HOS regulations do not consider the point in the individual's circadian cycle when work is taking place, nor do they address sleep quantity or quality outside work hours.[11,14] A more comprehensive approach is a fatigue risk management system (FRMS), which is integrated into other occupational safety and health (OSH) management systems. A FRMS is data-driven, fosters continuous improvement, requires that companies and workers share responsibility and control over fatigue risk management (FRM), and employs many elements—policies, risk management, evidence-based scheduling, technology, training, reporting, incident investigation, and auditing.[11,14,33]

US federal aviation regulations require commercial carriers to implement a FRMS,[34] but no other industry has similar requirements. After the Texas City, Texas refinery explosion in 2005, petrochemical industry stakeholders developed a voluntary standard which calls for the use of a comprehensive FRMS.[35] FRMS components as defined in the standard include balance between workload and staffing, shift scheduling, fatigue training, sleep disorder management, environment and workplace design, and monitoring of fatigue and fitness for duty. This standard was designed for operations in which workers travel to and from work each day. Operations in which workers are housed on or near the site have unique challenges that are not addressed by this standard. Other FRM resources have been developed by the International Petroleum Industry Environmental Conservation Association (IPIECA) and International Association of Oil & Gas Producers (IOGP), an organization composed primarily of large companies.[36,37] However, these organizations have limited reach in the US beyond their member companies, and FRM recommendations for the well site and the road were not integrated until the recent publication of joint IPIECA/OGP guidance and supplementary materials.[36,38] For these reasons, additional guidance is needed for the US, particularly for onshore operations.

Several characteristics of the OGE industry support the need for broadly reviewing research findings to date pertaining to fatigue, sleep, and working hours, along with identifying needs for research on these topics. OGE operations are global and highly variable. They are governed by different country- or region-specific regulatory regimes, with gaps in regulation addressed by industry-led guidance. As noted earlier, work shifts are characterized by long hours, many consecutive days of work, irregularity, and unpredictability. Work takes place both onshore and offshore. The remoteness of OGE worksites results in long commutes, thus adding risks of fatigued driving to risks posed by shiftwork and the OGE work environment.

The primary focus of this paper is identification of research needs for the US, but the global nature of the industry supports inclusion of papers from all world regions, as many companies operate throughout the world and employ standardized policies. This paper assesses OGE-specific research on fatigue and sleep by categorizing papers by geographic area, research type, and the independent and outcome variables examined. By identifying topics that have received the greatest attention from researchers to date, it also suggests areas where more work is needed to inform the development of evidence-based strategies to protect OGE workers in the United States from health and safety risks associated with fatigue, poor sleep, and long work hours.

2 | METHODS

A scoping review was conducted to identify scientific and grey literature published worldwide on fatigue, sleep, shift work, and working hours for OGE workers.[39–41] Grey literature was important to include because it is often the source of information about working, living, and sleeping conditions within the industry. In contrast with a systematic review, which is typically used to summarize the quality of scientific evidence in support of a specific intervention, a scoping review may be more appropriate for mapping the concepts that underly a broader body of research, summarizing what is known, and identifying research gaps.[39,40] Further, a scoping review does not necessarily assess the quality of existing research, nor does it adhere strictly to an a priori list of inclusion criteria.[39,41] This scoping review was guided by the following research questions:

- What recent research has been done globally to characterize fatigue, sleep, and working hours among OGE workers (onshore and offshore) and their safety and health impacts?
- What are the research gaps?
- How can this information be applied to the US OGE workforce?

Librarians at the Centers for Disease Control and Prevention (CDC) conducted a literature search on January 15, 2020. To help ensure relevance and timeliness, only papers published in English (not just the abstract) from 2000 forward were included. Animal studies were excluded. The search strategy allowed for numerous variants and truncations of search terms. To be included, papers had to contain: (1) an OGE-specific descriptor: oil and gas, crude oil, natural gas, offshore, drilling, petroleum, hydraulic fracturing, unconventional gas, or unconventional oil AND (2) one or more terms related to shift work, work hours, and fatigue: fatigue, sleep, sleep deprivation, sleep disorder, night work, alertness, long work hours, drowsy, circadian, driver fatigue, asleep, asleep at the wheel, shift, shiftwork, overtime, night work, overnight, hours of work, extended work shifts, long work hours, work schedule tolerance, on-call, and commuting. CDC librarians searched the following databases: Medline, Embase, PsychInfo, CINAHL, Scopus, NIOSHTIC-2, and OnePetro (a repository of papers presented by industry professionals at conferences convened by the Society of Petroleum Engineers and other groups). Duplicates were identified using the automated EndNote function and removed.

An iterative screening process was used to make a final determination of the fit of each article to this study. First, two study authors (KHH and SGP) independently reviewed all titles and abstracts to determine relevance. A paper was included if it met any of these pre-determined criteria:

> The study population included workers engaged in oil and gas extraction either onshore or offshore

AND

Fatigue, sleep, shift work, or long working hours was an independent variable and the outcome of interest was any type of health or safety outcome, including physical or mental exhaustion

OR

Fatigue, sleep, shift work, or long working hours was an outcome of interest

OR

The paper reported the development or evaluation of an intervention whose goal was to reduce fatigue, fatigue risk factors, or fatigue-related safety and health outcomes

Several exclusions were applied:

- Grey literature that provided only an informational overview of a fatigue-related topic.
- Conference abstracts that reported research also reported in a full-length paper by the same authors.

After independently reviewing titles and abstracts, the two authors met to review the inclusion determination for each abstract and discuss disagreements. Disagreements were resolved by re-reviewing full papers and inclusion criteria. Abstract-only citations were retained if both reviewers agreed there was enough information to confirm they fit the inclusion criteria. Abstract screening procedures are depicted in Figure 1.

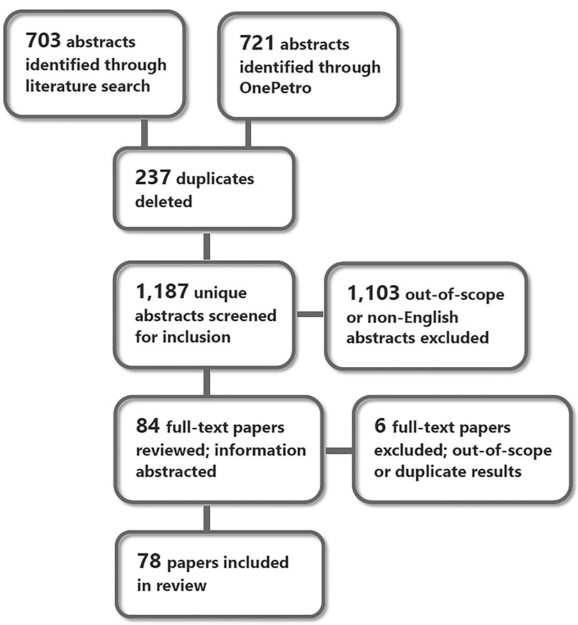

FIGURE 1 Abstract screening procedures for scoping review

Next, the authors independently reviewed all full-text papers deemed to be in scope, populating a table with pertinent information: study population, peer review (Y/N), geographic area, work location (offshore/onshore/onshore [remote], research type (etiologic, intervention development or description, intervention evaluation, systematic review, or non-research), measures used, independent variables, outcomes of interest, key findings, and stated research needs. This step also included independent coding of each paper by the two authors to one or more thematic areas, which were refined as the review proceeded.[42] These thematic areas were the basis for organizing and reporting the key findings and research needs.

The determination of research needs was further informed by input from attendees at an OGE-focused session at the 2019 Working Hours, Sleep, & Fatigue Forum: Meeting the Needs of American Workers and Employers, as well as content of an extended abstract prepared in advance of that forum.[43]

3 | RESULTS

Table 1 summarizes the characteristics of the 78 papers included in the final scoping review. The majority of papers were peer-reviewed (64%). The majority of the non-peer-reviewed papers were retrieved from OnePetro. Abstracts from OnePetro conference papers were peer-reviewed, but the full conference papers were not.

As Table 1 shows, 76% of the papers focused on offshore OGE operations and 55% reported research from the North Sea region. Nearly three-fourths of the papers reported the results of etiologic research, with only 16 papers describing an intervention or reporting the results of an intervention evaluation (10.3% each). Moreover, only 5 of the 14 papers that described or evaluated interventions were peer-reviewed. Intervention descriptions addressed topics such as FRM, training, and risk assessment. Intervention evaluations reported assessments of FRMS as a tool to prevent motor vehicle crashes, the effects of schedule changes on shift workers, and the effectiveness of bright light and melatonin in facilitating adaptation to shiftwork.

Although a few of the studies developed original scales, the majority used previously validated scales to measure constructs such as subjective sleepiness and sleep quality, health complaints, workload, personality traits, and locus of control (e.g., the Karolinska Sleepiness Scale, Pittsburgh Sleep Quality Index, General Questionnaire for Psychological and Social Factors at Work [QPS Nordic], and Eysenck Personality Questionnaire). Other papers employed subjective and objective measures such as personal interviews, worker observation, sleep diaries, actigraphy, reaction-time tests, and biological samples (data not shown).

3.1 | Independent variable: Shiftwork

Research findings from papers where shiftwork was an independent variable for other outcomes of interest are summarized by thematic area in Table 2 below. The greatest number of papers addressed

TABLE 1 Characteristics of literature included in the scoping review (n = 78)[a]

	Number	Percentage
Year		
2015–2019	34	44
2010–2014	23	30
2005–2009	13	17
2000–2004	8	10
Peer-reviewed?		
Yes	50	64
No	23	30
Unknown	5	6
Geographic area[b]		
North Sea (United Kingdom, Norway, Netherlands)	43	55
North America	6	8
Middle East	5	6
Russia	5	6
Brazil	4	5
China	4	5
Global	6	8
Other/unknown	6	8
Work location[c]		
Offshore	59	76
Onshore (remote)[d]	8	10
Onshore (non-remote)	5	6
Combination	6	8
Not applicable	1	1
Research type[e]		
Etiologic research	58	74
Intervention research		
Development or description	8	10
Evaluation	8	10
Systematic review	3	4
Non-research	2	3

[a]Due to rounding, not all column totals sum to 100.
[b]Sums to 79 because one paper covered both the North Sea and China.
[c]Sums to 79 because one paper covered offshore and onshore (remote).
[d]Locations where access is primarily fly in/fly out.
[e]Sums to 79 because one paper combined etiologic research and intervention evaluation.

biological or psychosocial adaptation to shiftwork (n = 20), followed by adverse mental health outcomes (n = 19). Overall, shiftwork affected workers' sleep negatively, but its effects on worker health and safety were less consistent. Of note, no papers meeting the inclusion criteria examined the effects of long hours of work independent of shiftwork.

3.2 | Dependent variables: Fatigue and sleepiness

Research findings from papers where fatigue and sleepiness are outcomes of interest, with other characteristics as independent variables, are summarized by thematic area in Table 3 below. The greatest number of papers in this group (n = 32) assessed the relationship between fatigue and sleepiness and shiftwork-related variables (comparisons between shift types or within work blocks).

3.3 | Independent variables: Fatigue and sleepiness

Ten papers differed from those presented in Table 3 in that fatigue and sleepiness were independent variables, with adverse safety consequences as outcomes of interest (Table 4).

3.4 | Suggested research methodologies

Many of the papers reviewed also suggested directions for future research (Table 5). Thirteen papers noted the need to identify and evaluate interventions to mitigate adverse effects of shiftwork and fatigue. Eleven papers cited the need to move beyond cross-sectional research designs to develop longitudinal studies that would assess longer-term health and safety effects of shiftwork and fatigue. Other needs related to research design and methodology were studies using objective measures (eight papers) and studies assessing discrepancies between objective and subjective measures (six papers). Eight papers noted the importance of including factors related to the work environment (e.g., safety culture, employment arrangements) as potential contributors to fatigue and shiftwork-related outcomes.

4 | CONCLUSIONS

The scoping review yielded several key insights regarding gaps in OGE shiftwork and fatigue research in general, and for the US OGE industry in particular. For more than three-fourths of the 78 papers reviewed, the study population was exclusively offshore workers (Table 1), although offshore production accounted for only 29% of global output in 2015.[3] Further, few papers focused on U.S. OGE operations, with more than half reporting research conducted in the North Sea. US offshore and remote OGE workers often work in swing shifts (usually night shifts for 1 week then day shifts for 1 week), while European workers rarely work swing shifts; given these differences in shiftwork schedules and differing regulatory environments, results from European research may not be directly generalizable to the US OGE industry.

TABLE 2 Key findings from OGE research with shiftwork as an independent variable

Outcomes of interest	Key findings
Adaptation/re-adaptation to shiftwork (biological or psychosocial) [20 papers]	Within work blocks: • Offshore swing-shift workers adapted to night shift, but individual variations in re-adaptation after transition to day shift[44,45] • Offshore workers adapted to night shift within a week whether on fixed or swing shift, but re-adaptation to day shift was not complete until the 4-week off-work period.[46] • Offshore workers generally adapted to night work within 1–2 weeks, but re-adaptation back to day work was slower.[22,45] • Poor circadian adaptation for offshore night and swing-shift workers, compared to day workers[47] • For offshore swing-shift workers, treatment with bright light and melatonin may facilitate adaptation to night work and re-adaptation back to normal day rhythm following the night-work period.[48,49] • Higher functional status at middle of 30-day work block at remote onshore sites[50] • Remote onshore shift workers who adapted better had greater flexibility, locus of control, and problem-solving options.[51] • Significantly better psychosocial adaptation to shiftwork for workers in remote onshore locations in south Russia vs. north[52] • Adaptation to swing shift was more difficult than adaptation to day or night shift. First week of work: higher sleep efficiency for day than night or swing shift; and better sleep quality for swing than day or night shift. Across 2-week work block: greater total sleep time for day and night than swing shift; sleep efficiency higher for day than night and swing shifts; change from night to day work for swing shift affected sleep negatively.[53] Comparing periods on and off work: • Generally, longer sleep duration and better sleep quality during nonwork periods (pre- and post-offshore work) than during offshore work blocks[21,54–56] • Offshore workers needed about 3 days to re-adapt after returning home.[57] • Offshore workers who worked overtime did not get compensatory sleep during the 2 weeks off work[55] • Offshore workers on night shift before returning home had higher levels of sleepiness at home than those who had been on day shift;[58] home re-adaptation after work block: no significant sleep-related differences between shift types[53] • Offshore workers reported "pre-boarding stress syndrome" (anxiety, sleep problems, bad mood) in days just before going back to the rig;[54,57,59] pre-offshore sleepiness levels predicted adaptation to offshore work.[59] • Offshore workers with shiftwork disorder (SWD) did not re-adapt at home as well as those without SWD.[60]
Adverse mental health outcomes (e.g., stress, impaired cognitive functioning, disrupted family and social life) [19 papers]	Social and family life: • Across studies, results on effects of shiftwork on family and social life are inconsistent and do not allow general conclusions to be drawn.[22] • Shiftwork-specific internal locus of control negatively associated with reported problems with social and family life; workers on 7 days/7 nights swing shift reported higher levels of problems with social/domestic family life due to shiftwork than offshore day workers[61] • Increased difficulty participating in normal home and community life with increased length of time offshore[57] • Interference of shiftwork with home life independently associated with mental distress[62] Mental health: • Stress: o Offshore workers on 7 nights/7 days swing shift had abnormal cortisol levels in the days after transition back to working day shifts.[46] o Positive correlation between cortisol levels and shiftwork among offshore workers[63] o Offshore rotations of more than 2 weeks led to greater stress and boredom.[64] o Shiftwork-related factors less strongly related to stress than were safety and environmental factors[65]

(Continues)

TABLE 2 (Continued)

Outcomes of interest	Key findings
	o Onshore: compared to day-shift workers, workers on other shifts reported significantly greater exposure to physical stressors, lower levels of skill discretion and job control, lower social support from supervisors, and less favorable safety perceptions; offshore: workers on non-day shifts reported higher exposure to physical environment stressors and lower job control than day-shift workers.[66] • Psychological symptoms: o For onshore and offshore workers, no differences in anxiety and depression by shift schedule; onshore, higher neuroticism for swing-shift workers than day workers[67] o More factors associated with mental distress for offshore than onshore workers (job control, job demands, leadership quality, role clarity)[67] o Incidence of a wide range of psychological symptoms significantly higher for shift workers than those working a fixed day shift[68] o Offshore shift/night workers reported significantly more feelings of sadness than day-shift workers.[47] o Univariate associations between mental distress and (1) shift schedules (day vs. at least some night work) and (2) shiftwork locus of control[62] o Individuals with shiftwork disorder reported significantly lower scores on coping.[60] • Functional status: o Pronounced decline in working capacity of all onshore employees as shift block progressed, with drivers showing the most pronounced effects[69] o For day-shift workers working 30-day shift block in a remote onshore area, impaired functional status for 42% at beginning, 33% at middle, and 43% at end of work block[50] o Self-reported difficulty concentrating during night shift[64]
Adverse safety outcomes (injuries, incidents, safety-related errors or violations, reduced situational awareness) (12 papers)	Shift type: • Studies on the relationship between shiftwork and safety yield inconsistent results, precluding drawing general conclusions[22] • Changing from 3 to 4 weeks at home between shift blocks did not affect probability of an incident leading to minor or major physical injury upon return to work.[70] • Higher rates of occupational injury for night-shift workers vs. day-shift workers[45,71] • Action errors and violations increased significantly with the number of overtime hours per shift.[72] • Offshore employees who had a "nomadic" status and the least regular shift rotations had a *lower* risk of incident involvement.[73] Other shiftwork-related variables: • On an offshore drilling rig, accidents occurred disproportionately near shift "handovers."[57] • Mixed results: Significantly increased probability of a worker experiencing an injury-producing incident as on-shift number of days increased, but only for minor incidents requiring first-aid treatment;[70] injury incidence *decreased* as on-shift days increased (first 4 weeks of work block) and lower relative risk of injury regardless of time offshore (4, 8, 16, or 24 weeks).[74] • No significant differences between shift pattern and levels of situation awareness (SA) among offshore workers,[75] but workers with low SA levels reported more unsafe behaviors and previous work accidents.[75,76] • Errors in situation awareness identified in 135 of 332 incidents (41%) on an offshore oil rig[77]

TABLE 2 (Continued)

Outcomes of interest	Key findings
Adverse health effects (e.g., insomnia, shiftwork disorder, occupational exposures relevant for cancer) (11 papers)	Insomnia: • Compared to day workers, shift/night workers reported significantly more habitual difficulty in falling asleep.[47] • Insomnia worsened significantly during 2 weeks of offshore work, but no differences between day and swing shifts.[78] • Overall, significantly more complaints of insomnia at the end than at the start of the work block; for swing shift, insomnia significantly worse at end than at start, compared to day shift.[79] • No difference in reported insomnia for workers with and without shiftwork disorder[60] General/other health problems: • Offshore night work is a risk factor for health problems, based on a systematic review.[45] • The body of evidence on effects of shiftwork on physical health shows inconsistent results and does not allow general conclusions to be drawn.[22] • Compared to day workers, all types of shift workers were more likely to report frequent cancer-relevant occupational exposures. Night workers were more likely to report frequent exposure to oil vapor, exhaust fumes, chemical vapor, and solvent vapor. Results may reflect different distribution of work tasks between day and night shifts.[80] • For offshore workers, BMI increased with age and years of exposure to an alternating day-night shift.[81] • 72% of shift workers were overweight or obese; 40% had total cholesterol levels at 200 mg/dl or above.[82]
Subjective health complaints (8 papers)	• Few studies, no longitudinal studies, and mixed results that preclude drawing meaningful conclusions[22] • Significantly more subjective health complaints among offshore workers with shiftwork disorder (SWD) compared to those without SWD[60,78,79] • Fatigue due to shiftwork cited as a primary factor affecting health in the offshore environment[83] • For offshore shift workers, no significant differences in subjective health complaints at beginning and end of a 2-week work block[78,79] • For offshore workers, shiftwork schedules were indirectly associated with safety climate through sleep problems, but not health complaints.[84] • No significant changes in subjective health complaints among offshore workers one year after transition from fixed shift to swing shift[46]

Nearly three-fourths of the papers reviewed reported etiologic research, with most of the remainder describing an intervention or evaluating it. Virtually all the etiologic research was cross-sectional. Research that employed repeated measures were limited to short time periods such as a 2-week work block and in some cases, non-work periods before or after work blocks. Not surprisingly, a number of papers stated that longitudinal research is needed to better ascertain long-term health and safety consequences of shiftwork and fatigue, although this would undoubtedly pose considerable methodological and logistical challenges. The papers that described or evaluated an intervention were limited to a few topics, primarily FRM as a crash-prevention strategy, bright lights and melatonin to facilitate adaptation to shiftwork, fatigue or shiftwork training, and schedule changes. Notably absent were rigorous evaluations of FRM and studies assessing the use of technology to identify fatigue- or shiftwork-related performance declines.

In addition, few studies focused on the relationships of shiftwork and fatigue with motor vehicle crashes, which in the US are the leading cause of work-related fatalities for OGE workers.[8] Two non-US intervention evaluations reported that FRMS was effective in reducing crashes, but neither was peer-reviewed and both lacked detail about methodology or analysis.[102,104] The long driving and air commutes typical of OGE work are also largely unexamined in the scientific literature as a risk factor for fatigue-related crashes. The US definition of a work-related crash excludes those that occur while commuting,[106] so no national data on commuting-related crashes exist. However, guidance developed by industry experts reflects an understanding of the interrelationships between shiftwork, fatigue, and commuting, offering strategies for using FRM principles to mitigate crash risks at work and while commuting.[36,107,108]

Except for a few North Sea studies that compared sleep quality and duration for offshore workers who worked overtime compared to standard 12-h shifts,[55,56,95] our review identified no research among OGE workers that examined the effects of long hours of work independent of shiftwork. It appears that most offshore OGE workers are working at least 12-h shifts, therefore long hours of

TABLE 3 Key findings from OGE research with fatigue or sleep characteristics as outcomes of interest

Independent variables	Key findings
Shiftwork (32 papers)	Differences in sleepiness: Between shift types: *Objective measures* • No mean differences in reaction times for day shift versus night shift workers at end of work block[85] or between day, night, and swing-shift workers[58] • For offshore swing-shift workers, bright light improved sleep slightly for workers during their week of night shifts, based on sleep diaries and actigraphy.[48] • Greater heart-rate variability for swing-shift vs. non-swing-shift workers and for night-shift vs. day-shift workers[86] • Few correlations between objective and subjective measures of fatigue for the same OGE shift workers[20] *Subjective measures* • No significant differences in overall sleepiness between day, night, and swing-shift workers[58] Within work blocks: *Objective measures* • Worsening of sleep parameters with return to day work after 7 days on night shift, but gradual improvement during that week[87] • Mixed results based on reaction-time tests: overall, 57% of workers were fatigued at beginning of 2-week work block, 88% at end (but higher % of fatigue at beginning of work block for those with 2 weeks on/1 week off);[88] objective fatigue remained stable over the course of 2-week offshore day shifts;[29,85,89] faster reaction time at the end of the 2-week work block for all shift types (day, night, swing);[58] no declines in reaction time on the day swing-shift workers changed from night to day shifts.[46] *Subjective measures* • Daily subjective post-shift fatigue scores increased significantly over the course of 2-week offshore shifts[29,89] and from pre-shift to post-shift within the same day;[29] self-reported fatigue greatest at days 10 and 11[90] • During 2-week offshore day shifts, post-shift fatigue scores increased with days on shift and chronic sleep loss[29] • Gradual improvement in subjective fatigue measures during the night-work portion of a swing shift; increase in subjective sleepiness with return to day work after 7 days on night shift, but gradual improvement during the week[87] • In first days of 2-week work block, night and swing-shift workers (after they changed to days in the middle of the work block) were more sleepy than day workers.[58] Differences in sleep quality and duration: Between shift types: • Overall, significantly better sleep quality for day-shift workers (vs. night or swing shifts, or non-day shifts)[22,47,84,91,92] • Sleep quality worsened significantly during 2 weeks of offshore work, but no differences between day and swing shifts[78,79] • Mixed results regarding sleep duration and/or efficiency for offshore swing-shift workers versus other shift patterns: significantly shorter sleep duration,[53,93,94] longer sleep duration[56] • Significantly impaired sleep quality and duration among those who worked overtime versus standard 12-h offshore shifts, with sleep duration decreasing as overtime hours increased[55,56,95] Within work blocks: • Change from night to day shift in the middle of a 2-week work block affected sleep negatively.[53,58,87] • First week of a 2-week work block: higher sleep efficiency for day shift versus night or swing shift, but better sleep quality for swing shift versus day or night shift;[53] significantly longer sleep duration (+41 min) during night-shift portion of a 2-week work block compared to the day shifts that followed[87] • For day-shift offshore workers, mean cumulative sleep loss over a 2-week work block was 21 h and 20 min[29] • For offshore swing-shift workers, melatonin reduced at-work sleepiness for workers during their week on the day shift and increased daily sleep by 15–20 min on average; results for the week on night shift were not significant.[48]

TABLE 3 (Continued)

Independent variables	Key findings

Mental health status (e.g., stress, risk perception, cognitive functioning) (14 papers)	Stress:
	• For seafarers whose work included supplying oil rigs, high levels of work stress were significantly associated with acute and longer-term fatigue.[96]
	• During a 4-week offshore work block, oil workers had significantly higher cortisol levels than those who were onshore and not working for 4 weeks; high cortisol levels were positively related to anxiety and negatively related to sleep quality.[63]
	Cognitive functioning:
	• For shift workers at a remote onshore gas processing plant, there was not a relationship between performance on a reaction-time test given at the end of night shifts and self-reported fatigue before workers went to sleep after these shifts.[85]
	• 57% of onshore oil and gas were fatigued at the beginning of a 2-week work block and 88% at the end, based on reaction-time test.[88]
	• 41% of offshore oil workers reported a dip in functioning during a 2-week work block, primarily at days 10 and 11 (68% worked day shift); 43% described both physical and mental decrements, 39% only mental decrements.[90]
	• For offshore day-shift oil workers, reaction times did not change over a 2-week work block; the same workers had significant increases in post-shift subjective fatigue, although not pre-shift.[89]
	• Swing-shift offshore oil workers reported steady and significant worsening of sleep-related and cognitive symptoms (e.g., irresistible sleepiness, heavy eyelids, reduced performance) from days 1–4 of the night shift, which began to improve only with the change to day shift on day 8.[87]
	Psychological well-being:
	• For offshore oil workers, anxiety was negatively associated with sleep duration during day and night shifts and during time off work.[56]
	• For seafarers whose work included supplying oil rigs:
	  o Longer-term fatigue accounted for 10% of the variance in psychological distress.[96]
	  o Psychological demands of work were significantly related to higher levels of physical and mental fatigue and lack of energy.[97]

Job tasks, job demands, and job control (7 papers)	• Among offshore workers who worked overtime, sleep duration was negatively associated with job demands.[95]
	• Fatigue reported more often by oil workers in positions with greater job responsibility and by those who performed more than one type of work[88]
	• No significant relationships between job category and sleep quality and duration among offshore workers[56]
	• Among occupations on remote onshore sites, drivers showed the greatest decreases in working capacity, as measured by visual-motor responses, across a 2-week work block.[69]
	• Among seafarers supplying offshore rigs:
	  o Significant associations between: (1) high job demands and acute and chronic fatigue[96] and (2) low levels of job control and mental fatigue[97]
	  o Significantly higher levels of physical and mental fatigue reported by temporary/apprentice workers compared to permanent workers[97]

Physical environment (work and off-duty) (5 papers)	• Significant relationship between adverse offshore work environment (e.g., heavy work, noise, vibration) and poor sleep quality[95] • Offshore workers reported poor sleep quality and difficulty recovering from work-induced fatigue due to location of helipad above living quarters and inadequate protection from noise and other disturbances.[98] • For oil industry supply ships, vessel motions were significantly associated with sleep interruptions, shorter sleep duration, mental and physical tiredness, and poor sleep quality.[99]
Health complaints, effects, and risk factors (4 papers)	• Significant associations between fatigue over the past week and self-reported poor health for merchant seamen working in shipping and in support to the offshore oil industry[96] • Higher body mass index (BMI) predicted severe sleepiness during the time before offshore work blocks.[59] • Smoking status and physical health predicted sleepiness during offshore work blocks.[59] • Other studies included health complaints in developing and reviewing fatigue assessment tools.[100,101]

(Continues)

TABLE 3 (Continued)

Independent variables	Key findings
Social and supervisor support, safety climate (4 papers)	• For offshore oil workers, negative organizational safety climate was significantly associated with poor sleep quality,[91] and mental and physical fatigue and lack of energy.[97] • For offshore oil workers, low levels of supervisory support were associated with poor sleep quality.[45] • Variables related to organizational safety climate (prioritization of safety, safety management and involvement, and consideration of safety above production) had significant positive correlations with offshore workers' sleep quality.[91] • For offshore workers who worked overtime, significant positive association between perceived levels of supervisory support and sleep duration[45] • Negative organizational safety climate was associated with physical fatigue for day-shift but not night-shift offshore workers; opposite results for group-level safety climate.[91]
Demographic factors (4 papers)	• Significant differences in subjective fatigue scores between ages <45 and ≥55, but not for comparisons with ages 45–54[90] • Significant inverse relationship between age and sleep duration for offshore workers during day shift, night shift, and nonwork periods; inverse relationship between age and sleep quality only for day-shift workers[56] • For night shift only, curvilinear relationship between age and sleep quality, with quality lowest at ages 38–42 years.[56] • Age did not mediate relationships between time period (pre-offshore, offshore, and post-offshore) and subjective and objective fatigue.[54]
Chronotype (3 papers)	• Among offshore workers working day shifts and swing shifts, morning chronotype was a significant predictor of better sleep efficiency, shorter sleep latency, and less insomnia[94] • Significantly lower levels of sleepiness before offshore work period for workers who were morning chronotype[54]

TABLE 4 Fatigue/sleepiness/sleep quality and duration as independent variables for safety-related outcomes

Outcomes of interest	Key findings
Adverse safety outcomes linked to fatigue and sleep characteristics (injuries, incidents, safety-related errors or violations, reduced situational awareness) (10 papers)	• Percentage of motor vehicle crashes involving fatigue decreased from 35% to 9% after implementing an enhanced fatigue risk management system (FRMS) (included fatigue training for managers and workers, fatigue self-evaluation, enhanced reporting procedures, restrictions on night driving, road hazard mapping, designated hotels where drivers could stop for rest).[102] • Workers reported taking numerous risks to get home after working 12-hour shifts for 14 consecutive days with frequent overtime; nearly all workers reported driving fatigued after completing the most recent 2-week work block.[103] • After implementation of one company's FRMS, percentage of offshore workers reporting a fatigue-related incident or near miss in the past 6 months decreased from 92% to 6%.[104] • Offshore oil workers who reported usually getting <5 h sleep had significantly higher incidence of musculoskeletal disorders in six of nine body regions.[105] • Emotional exhaustion, conceptualized as a component of fatigue, was significantly associated with higher levels of self-reported action errors and safety rule violations by offshore oil workers.[72] • For offshore workers, higher levels of sleep disruption and fatigue were significantly associated with lower work situation awareness.[75,76]

work are implicitly part of shiftwork as experienced by this workforce. The lack of research on long hours as an independent contributor to fatigue, sleepiness, or adverse safety outcomes might be related to he lack of research in the onshore OGE workforce. This workforce is a mixture of shift workers and other workers with highly variable and irregular working hours; because of this, studies on this workforce might be more likely to consider hours of work as an independent variable.

TABLE 5 OGE research needs related to shiftwork and fatigue, as noted in the literature[a]

Research methodologies
• Identify and evaluate potential interventions to mitigate the health and safety consequences of shiftwork and fatigue (13): biomathematical fatigue models, changes to the physical environment (e.g., lighting interventions), enhanced safety culture, training on fatigue management and situational awareness
• Conduct longitudinal, repeated-measures studies (11)
• Develop studies that employ objective measures: cardiovascular and metabolic parameters, actigraphy, heart rate variability, physical environment; includes evaluation of the feasibility and validity of using these measures in the offshore environment (8)
• Enhance and make better use of administrative records (incident/injury data, personnel and overtime records) in studies of shiftwork and fatigue (7)
• Explore discrepancies between subjective and objective indicators of fatigue and shiftwork effects (6)
• Study workers in areas of offshore activity other than the North Sea (e.g., Gulf of Mexico, Brazil), and determine transferability of research results from the North Sea to other parts of the world (5)
Shiftwork/shift type (day, night, swing, rotating)
• Conduct more studies of fatigue, sleepiness, and injury risk related to time of day and days on shift (and the interaction of these); develop better understanding of daily recovery processes (8)
• Assess adaptation/re-adaptation to shiftwork, especially effects of change to or from night shift in the middle of a 2-week offshore work block (5)
• Examine additive effects of overtime work and shifts greater than 12 h on safety risks and outcomes offshore (4)
• Make more comparisons across shift types: assess differences in sleep quality and duration, objective and subjective sleepiness (2)
• Incorporate assessment of sleep and fatigue before and after offshore work blocks (2)
Organization of work
• Assess how organization of work, work environment, and safety culture may be associated with fatigue and safety and health outcomes, including job type, job task, and employment arrangements (8)
Health effects
• Build knowledge of health effects of shiftwork and fatigue: incidence, or exposures associated with health effects; differences between shift types (5)
Mental health
• Improve understanding of (1) mental health consequences of shiftwork and fatigue and psychological and (2) individual factors as determinants of related mental health outcomes: role of personality traits; effects of age on injury risk, sleep quality, and ability to adapt/re-adapt to shiftwork; mental health consequences of shiftwork and fatigue (7)
Safety outcomes
• Improve understanding of safety outcomes of shiftwork and fatigue: safety impacts of travel and driving before and after work blocks, including the fly-in/fly-out workforce; effectiveness of administrative controls to manage pre- and post-shift travel; individual characteristics that affect situational awareness and safety behaviors while on shift (2)

(Continues)

[a]Numbers in parentheses are the numbers of papers noting each research need.

4.1 | OGE-specific research needs

Research needs were determined based on findings and research needs included in the papers reviewed and the feedback provided by attendees at the OGE session at the NIOSH Forum. Attendee input extends what appears in the scientific literature (largely etiologic), pointing to practical applications and interventions that need to be evaluated.

4.1.1 | Build knowledge about the impacts of fatigue in OGE

Papers examined in the scoping review reported conflicting findings regarding shiftwork and its impacts on physical health, health complaints, and adverse safety outcomes, indicating a need for more research. Further examination of the mental health consequences of fatigue was a common need cited in the papers reviewed. While a substantial number of papers examined the effects of shiftwork, very few reported on the effects of overtime in the absence of shiftwork and the effects of on-call working arrangements, a common feature of onshore working environments. Forum attendees noted that OSH professionals need data on the human, operational, and financial consequences of fatigue to persuade upper management to implement FRM. They also noted a need to develop criteria for identifying fatigue episodes and the role of fatigue in safety-critical incidents.

4.1.2 | Explore interactions between on- and off-the-job risk factors and behaviors

Research to date has not fully considered the range of factors that may predispose OGE workers to fatigue, notably sleep quantity and quality during off-duty time (whether at a residence or on-site housing). Forum attendees noted the need to assess the nature (e.g., solitary vs. carpooling), length, and timing of commutes and impacts on worker fatigue, in particular with the growing number of OGE workers with technical specialties who may travel long distances and experience highly variable working arrangements. Research findings on the effects of shiftwork on social and family life were mixed, indicating a need for additional research, including the effects of shiftwork in OGE compared to other industries.

4.1.3 | Identify and evaluate interventions to address fatigue in OGE, including FRMS

In the papers reviewed, the most frequently cited research need was for evaluations of fatigue mitigation interventions (Table 5)—individual interventions, comprehensive FRMS, and the effects of FRM independent of other OSH initiatives. Forum attendees recommended components to be included in such evaluations: characterizing barriers to successful FRMS implementation at company and worker level; assessing the effectiveness of sleep awareness training for employers, workers, and family members; and conducting cost-benefit analyses for use by small contractor companies with limited resources. Because fatigue as a causal factor and fatigue-related incidents and injuries are relatively rare outcomes, Forum attendees advocated the use of leading indicators in FRM (e.g., number of overtime shifts approved) and assessment of their ability to predict adverse safety and health outcomes; the availability of leading indicators will also enhance intervention evaluations.[36] Lastly, although there is an evidence base for napping as a fatigue management strategy[109] and OGE industry guidance recommends it,[36] its application in the OGE workforce is limited and has not been evaluated.

4.1.4 | Assess the effectiveness of technology in identifying and managing fatigue

OGE has been an early adopter of safety technologies such as in-vehicle monitoring systems, and OGE work environments may be conducive to field evaluations of technologies to identify, monitor, and manage fatigue. These solutions might include in-vehicle technologies or "wearables" such as smart watches, and they might be designed specifically for the industry or adapted from existing consumer products. Although this review identified a number of papers that used actigraphy as a research tool, no evaluations of fatigue detection technologies as an intervention were identified in this review; criteria for their evaluation within a larger FRMS in road transport may be useful.[110] For example, recommendations for redundancy in fatigue management countermeasures (i.e., not relying on technology alone), integration of technology into a comprehensive FRMS, and a supportive, nonpunitive culture of risk management[110] would all appear to be beneficial in the OGE context.

4.1.5 | Increase the diffusion of FRM information for OGE

The reach of voluntary FRM standards and guidance documents is generally limited to the large companies (primarily operators) who have put the resources into developing them. While US regulators often use industry standards to support findings from workplace inspections, they have little regular contact with smaller companies. Research is needed to identify the intermediaries (e.g., insurers or industry associations) who can reach smaller companies with FRM information and help engage them in testing the effectiveness of strategies such as education, policy, or technology. Forum attendees noted the importance of sharing effective strategies within the industry, including contractors and small companies.[38]

4.2 | Limitations

This scoping review has several limitations. Consistent with the literature on scoping reviews,[39,41] our purpose was to assess research topics and scope, not to assess quality of that research (although the papers reviewed did include three systematic reviews; Table 1). To better represent the scope of OGE research on fatigue and shiftwork, we included papers that were not peer-reviewed, notably papers from OnePetro, an important industry outlet for communicating research findings.

There are undoubtedly many papers that would have informed our assessment of research needs, yet were not retrieved because our literature search was limited to the OGE industry. For example, findings from evaluations of FRMS and fatigue detection technologies from industries such as construction and mining could also be applied to OGE.

4.3 | Summary

A scoping review addressing health and safety consequences of shiftwork, fatigue, and sleepiness in the OGE workforce yielded summaries of research findings to date and suggested unmet research needs. Because research to date has been largely etiologic and cross-sectional, intervention evaluations and longitudinal studies are needed. In addition, research has focused on offshore work environments, with the majority of studies conducted in the North Sea and few in the United States; more research is needed to assess the effects of shiftwork, unpredictable work schedules, overtime, on-call, and fatigue on the onshore OGE workforce and in other parts of the world.

Potential for positive impact of OGE-focused research on fatigue, sleep, and work hours is substantial. Despite the presence of US federal HOS regulations that apply to several segments of the industry, large companies have recognized that more is needed to effectively manage fatigue, and they have collaborated on consensus guidance over a period of years. Further collaboration between researchers and OGE operators and contractors can lead to development of action-oriented recommendations to mitigate fatigue throughout the OGE industry.

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CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest.

DISCLOSURE BY AJIM EDITOR OF RECORD

John Meyer declares that he has no conflict of interest in the review and publication decision regarding this article.

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The work was performed at the National Institute for Occupational Safety & Health. Institutional review and approval of human subjects protocols was not required because the work did not involve human subjects.

AUTHOR CONTRIBUTIONS

Kyla Hagan-Haynes: Led the conceptual design and writing of the work, including background, methods, results, and conclusions. Stephanie Pratt: Substantially involved in all aspects of the conceptual design, writing, including background, methods, results, and conclusions. Steven Lerman: Substantially involved in the conceptual design and writing of the work. Imelda Wong: Substantially involved in critical revisions of the work, improving its intellectual content. Angela Baker: Substantially involved in critical revisions of the work, improving its intellectual content. David Flower: Substantially involved in critical revisions of the work, improving its intellectual content. Vanessa Riethmeister: Substantially involved in critical revisions of the work, improving its intellectual content.

DISCLAIMER

The findings and conclusions in this report are those of the authors and do not necessarily reflect the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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