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Fatigue-Related Cognitive Performance in Oil and Gas Operations: A Review from an Applied Data Science Perspective

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ABSTRACT

Fatigue and environmental stressors are critical contributors to reduced concentration and safety risks among onshore and offshore oil and gas engineers. This review aims to synthesize existing research on the detection of reduced concentration levels related to fatigue and environmental factors, comparing onshore and offshore working conditions. Furthermore, this review suggests practical solutions for industry application. In this study, a structured literature review was conducted using quantitative, qualitative, and technology-based studies addressing fatigue detection, management strategies, and psychosocial and organizational risk factors across diverse operational contexts. The results indicate that offshore engineers experience higher fatigue prevalence due to shift work, isolation, and harsh environmental conditions, while onshore engineers are more affected by occupational monotony and limited social support. The reviewed studies indicate that fatigue detection approaches commonly combine subjective self-reports with physiological and performance-based indicators; however, their validation and standardization remain limited. Multidimensional interventions integrating sleep management, mental health support, and organizational reforms show potential but lack robust empirical evaluation. In conclusion, the review highlights the need for standardized, integrative fatigue assessment frameworks and context-specific fatigue risk management strategies to improve cognitive performance, safety, and well-being in both onshore and offshore oil and gas operations.

Keywords: cognitive performance; environmental stressors; fatigue detection; offshore operations; onshore operations

I. INTRODUCTION

Fatigue-related degradation of concentration has long been recognized as a critical contributor to occupational accidents and reduced performance in safety-sensitive industries, including oil and gas operations (Bergh et al., 2017; Kannan et al., 2018; Lukmana, 2020). As exploration and production activities intensify, engineers are increasingly exposed to extended working hours, rotating shift systems, and complex operational demands that challenge cognitive endurance and decision-making capacity (Hagan-Haynes et al., 2021; Holmes et al., 2021). In this context, reduced concentration is not merely an individual health issue but a systemic safety concern with direct implications for operational reliability and worker well-being.

Within the oil and gas sector, working conditions differ substantially between onshore and offshore environments, leading to distinct fatigue profiles. Offshore engineers often face isolation, confined living spaces, harsh environmental conditions, and prolonged shift rotations, whereas onshore engineers are more frequently affected by occupational monotony, workload intensity, and organizational pressures (Riethmeister et al., 2018; Sinagabariang & Kurniawidjaja, 2024). Empirical evidence indicates that fatigue contributes significantly to accidents, near-miss events, and productivity losses in both settings, although the underlying drivers and manifestations of fatigue may differ (Aria et al., 2024; R. McNamara & Smith, 2020).

Despite the increasing use of data-driven and computational methods to support decision-making in complex oil and gas operations, such as fuzzy logic–based approaches for hydrocarbon prospect evaluation (Zen et al., 2017), important knowledge gaps remain regarding the detection of reduced concentration levels among oil and gas engineers across onshore and offshore contexts. Existing studies often emphasize either physiological indicators (e.g., sleep loss, circadian disruption) or psychosocial dimensions (e.g., mental workload, isolation, stress), leading to fragmented insights and limited comparability (Mehta et al., 2017; Shortz et al., 2018). Moreover, methodological heterogeneity in fatigue assessment—ranging from subjective self-reports to objective physiological and performance-based measures— hinders the development of standardized detection frameworks applicable across operational environments (Dwinda &

Widanarko, 2024; Mihulkova et al., 2023). Consequently, industry stakeholders lack clear guidance on how to integrate fatigue detection and management strategies that are both evidence-based and context-specific.

This review, therefore, attempts to address the aforementioned gaps by adopting a multidimensional conceptualization of fatigue as a state shaped by sleep quality, mental workload, psychosocial hazards, and environmental stressors, which collectively impair cognitive performance and concentration (Rosekind et al., 1996; Smith & McNamara, 2015). By synthesizing evidence from diverse methodological approaches, the review seeks to clarify how reduced concentration is detected, and how fatigue manifests differently in onshore and offshore settings, and which intervention strategies show promise for practical application.

This review contributes by integrating fatigue mechanisms, psychosocial and environmental stressors, and fatigue detection modalities into a unified comparative onshore and offshore framework. From an applied data science perspective, it highlights how subjective measures, physiological sensing, and performance-based indicators can be structured into integrative assessment pipelines, while identifying critical gaps in validation that hinder real-time operational deployment.

The objective of this review is to synthesize current research on the detection of reduced concentration levels among onshore and offshore oil and gas engineers, with a particular focus on fatigue and environmental factors. Specifically, the review aims to (i) evaluate the impact of fatigue and environmental stressors on cognitive performance, (ii) benchmark fatigue detection and management approaches across onshore and offshore settings, (iii) identify key psychosocial and organizational risk factors, and (iv) compare practical intervention strategies relevant to industry implementation. Through this synthesis, the review seeks to inform the development of integrative fatigue risk management frameworks that enhance safety, productivity, and worker well-being in the oil and gas sector.

II. METHODS

This study employed a structured literature review approach to synthesize research on fatigue-related reduction of concentration among onshore and offshore oil and gas engineers. The review was designed to integrate empirical findings, methodological approaches, and applied industry perspectives to enable comparative analysis across operational environments.

A comprehensive literature search was conducted across multidisciplinary academic databases to identify peer-reviewed studies relevant to fatigue, concentration, environmental stressors, and fatigue management in safety-critical industries. To ensure systematic coverage, the primary research question was expanded into several focused search themes addressing (i) fatigue and concentration, (ii) psychosocial and environmental risk factors, (iii) fatigue detection and assessment methods, and (iv) comparative onshore and offshore operational contexts.

Inclusion criteria were applied to retain studies published between 2014 and 2025 that directly addressed fatigue-related cognitive performance, detection or assessment approaches, and organizational or environmental influences within the oil and gas industry or comparable safety-critical sectors. Studies that were peripheral, descriptive without analytical relevance, or unrelated to occupational fatigue and concentration were excluded.

Following relevance screening and qualitative appraisal, a focused set of approximately 20 core articles was selected for in-depth synthesis. These articles were explicitly cited in the manuscript and formed the primary empirical basis for thematic analysis, comparative discussion, and the development of **Tables 1–3**. Additional literature informed contextual understanding but was not included in the analytical synthesis or citation set.

Data synthesis was conducted using narrative and thematic analysis. The selected studies were systematically examined to identify patterns related to fatigue drivers, concentration outcomes, detection and assessment methodologies, psychosocial and environmental risk factors, and reported intervention strategies. Comparative analysis was then applied to distinguish similarities and differences between onshore and offshore environments, with emphasis on implications for fatigue risk management and operational safety.

III. RESULTS AND DISCUSSION

3.1. Descriptive Overview of the Reviewed Studies

The reviewed literature demonstrates a growing research interest in fatigue and cognitive performance within oil and gas engineering contexts. The selected studies encompass quantitative field assessments, cross-sectional surveys, longitudinal monitoring, systematic reviews, and technology-driven fatigue detection models conducted across diverse geographic regions and operational settings. Offshore-focused studies dominate the literature, reflecting the recognized severity of fatigue risks associated with isolation, extended work rotations, and harsh environmental conditions. In contrast, onshore studies predominantly emphasize psychosocial workload, job strain, and organizational stressors affecting sustained attention and alertness.

Across the reviewed body of work, fatigue is consistently treated as a multidimensional phenomenon with implications for cognitive performance, safety behavior, and operational reliability. To synthesize the heterogeneous findings and enable structured comparison between operational contexts, key characteristics of fatigue manifestation, detection approaches, and management practices in onshore and offshore environments are summarized in **Table 1**.

Table 1. Comparative Summary of Fatigue and Concentration Factors in Onshore and Offshore Oil and Gas Engineers

Aspect	Onshore Environment	Offshore Environment	Key References
Fatigue Prevalence	Moderate, often chronic	High, often cumulative	R. McNamara & Smith (2020); Aria et al. (2024)
Primary Fatigue Drivers	Mental workload, task monotony, job strain	Shift rotation, isolation, long duty cycles	Riethmeister et al. (2018); Mihulkova et al. (2023)
Environmental Stressors	Noise, workload pressure, organizational demands	Harsh weather, vibration, confined spaces	Sinagabariang & Kurniawidjaja (2024)
Psychosocial Factors	Low social support, work–life imbalance	Isolation, separation from family, confinement	Parkes (1998); D'Antoine et al. (2023)
Sleep Quality	Variable, often disrupted by stress	Consistently reduced due to shift work	Riethmeister et al. (2018); K. McNamara & Robbins (2023)
Impact on Concentration	Reduced alertness, cognitive disengagement	Impaired vigilance, slower reaction time	Shortz et al. (2018); Kang et al. (2023)
Fatigue Detection Methods	Questionnaires, surveys, workload indices	Multimodal (subjective + objective)	Mehta et al. (2017); Nartey et al. (2025)
Management Practices	Organizational interventions, workload control	Structured FRMS, rotation management	Linda et al. (2018); Holmes et al. (2021)

3.2. Fatigue and Reduced Concentration

Across the literature, fatigue is consistently associated with diminished concentration, impaired vigilance, and increased error rates in safety-critical oil and gas operations. Empirical studies report that extended shift duration, circadian disruption, and sleep deprivation significantly degrade cognitive performance, particularly in offshore environments. Several longitudinal investigations demonstrate progressive fatigue accumulation during offshore rotations, with measurable declines in attention span and reaction time over consecutive work periods.

Onshore engineers, while less exposed to extreme environmental stressors, experience fatigue linked to repetitive task demands, high mental workload, and limited job autonomy. These factors contribute to reduced alertness and cognitive disengagement, highlighting that fatigue-related concentration loss is not exclusive to offshore operations. The contrast between fatigue drivers in onshore and offshore settings, as well as their differential impacts on cognitive performance, is further illustrated in **Table 1**.

3.3. Detection and Assessment Methods

Fatigue and concentration detection methods vary substantially across the reviewed studies. Subjective instruments, including fatigue questionnaires, sleep quality indices, and psychosocial surveys, remain widely used due to their practicality and low implementation cost. However, multiple studies report inconsistencies between subjective fatigue perception and objective performance outcomes, particularly in prolonged or high-risk operational contexts.

Objective approaches include reaction-time testing, vigilance performance tasks, actigraphy-based sleep monitoring, physiological sensing, and emerging machine learning models integrating multimodal fatigue indicators. While these approaches offer greater sensitivity in detecting early cognitive degradation, their operational deployment remains constrained by cost, data integration challenges, and limited standardization. A comparative summary of fatigue detection and assessment approaches applied in onshore and offshore environments is presented in **Table 2**. These findings indicate significant opportunities for data-driven and machine learning-based fatigue detection systems using multimodal inputs, including performance metrics, physiological signals, and environmental data. Such approaches are particularly relevant for continuous monitoring in safety-critical oil and gas operations, although further validation is required to ensure robustness and operational feasibility across onshore and offshore contexts.

Table 2. Comparison of Fatigue Detection and Assessment Approaches

Detection Approach	Onshore Application	Offshore Application	Strengths	Limitations
Self-report questionnaires	Widely used	Widely used	Low cost, easy deployment	Subjective bias
Sleep quality indices	Common	Common	Links fatigue–sleep clearly	Retrospective
Performance-based tests	Limited use	Increasing use	Objective concentration metrics	Operational disruption
Physiological monitoring	Rare	Emerging	High sensitivity	Cost, feasibility
Multimodal ML-based systems	Experimental	Pilot implementations	Integrative detection	Limited validation

To further synthesize the methodological development of fatigue detection studies, **Figure 1** presents the input variable categories addressed in selected fatigue-related studies over time. The figure is intended to highlight how fatigue-related studies have evolved in terms of the input variables used for assessment, ranging from subjective self-report and sleep-related measures to physiological, environmental, and multimodal data-driven indicators.

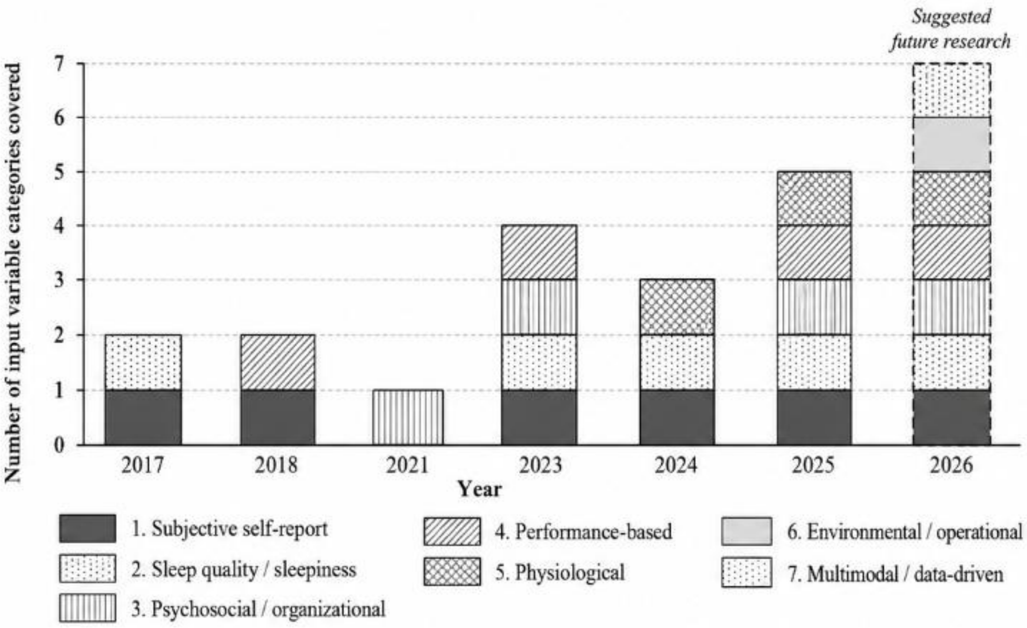

Figure 1. Synthesis of the input variable categories addressed in selected fatigue-related studies over time, showing a gradual shift from isolated indicators toward more integrative approaches. The 2026 bar represents suggested future research priorities derived from this review (Aria et al., 2024; Bergh et al., 2017; D'Antoine et al., 2023; Dwinda & Widanarko, 2024; Holmes et al., 2021; Kang et al., 2023; Mehta et al., 2017; Mihulkova et al., 2023; Nartey et al., 2025; Riethmeister et al., 2018; Shortz et al., 2018).

As shown in **Figure 1**, earlier studies generally relied on a limited number of input variable categories, such as subjective self-report, sleep quality, psychosocial or organizational factors, performance-based tests, and physiological indicators. Studies published between 2017 and 2021 tended to cover only one or two input categories, indicating a relatively fragmented fatigue assessment strategy. More recent studies from 2023 to 2025 show a gradual shift toward broader input coverage, including physiological and performance-based indicators. However, the integration of subjective, physiological, psychosocial, environmental, performance-based, and data-driven inputs remains limited.

The 2026 bar in **Figure 1** represents the suggested future research direction derived from this review. Future studies should move toward an integrative fatigue assessment framework that combines subjective self-report, sleep quality, psychosocial and organizational factors, performance-based tests, physiological indicators, environmental or operational variables, and multimodal data-driven detection. Such integration is important for developing standardized, context-specific, and operationally feasible fatigue detection systems for both onshore and offshore oil and gas operations.

3.4. Psychosocial and Environmental Risk Factors

The reviewed literature identifies fatigue as a multidimensional outcome shaped by psychosocial, environmental, and organizational factors. Offshore engineers face heightened psychosocial stress due to isolation, confined living conditions, and extended separation from family, which collectively exacerbate fatigue and reduce cognitive resilience. Conversely, onshore engineers are more strongly affected by job strain, workload imbalance, and limited social support within organizational structures.

Environmental stressors such as noise, vibration, thermal discomfort, and weather exposure further intensify fatigue in offshore settings, whereas organizational factors—including shift scheduling practices, leadership quality, and fatigue risk management maturity—play a critical role across both environments. These interacting risk factors reinforce the need for integrated assessment frameworks that extend beyond physiological fatigue indicators alone.

3.5. Comparative Analysis: Onshore vs Offshore

Comparative evidence indicates that offshore environments exhibit higher fatigue prevalence and more severe concentration decline than onshore settings. Offshore fatigue is primarily driven by shift rotations, sleep disruption, and psychosocial isolation, whereas onshore fatigue emerges predominantly from chronic psychosocial stress and task monotony. Despite these contextual differences, both environments share common vulnerabilities related to organizational practices, suboptimal shift design, and insufficient fatigue monitoring systems. These comparative patterns are systematically summarized in **Table 1**, highlighting both shared and context-specific fatigue mechanisms.

3.6. Practical Solutions for Industry Application

The reviewed studies suggest that effective fatigue mitigation requires integrated, multi-level intervention strategies. Promising approaches include optimized shift scheduling, structured sleep hygiene programs, psychosocial support systems, leadership and policy reforms, and the gradual adoption of real-time fatigue monitoring technologies. While several interventions demonstrate positive short-term outcomes, empirical evaluation of their long-term effectiveness remains limited.

A synthesis of reported fatigue mitigation strategies and their applicability in onshore and offshore operations is presented in **Table 3**. The findings underscore the need for standardized fatigue risk management frameworks tailored to operational context, combining organizational, technological, and human-centered interventions.

Table 3. Summary of Reported Fatigue Mitigation Strategies

Intervention Type	Onshore Context	Offshore Context	Reported Effectiveness
Shift scheduling optimization	Moderate impact	High impact	Consistent improvement
Sleep hygiene programs	Effective	Effective	Strong supporting evidence
Psychosocial support	Organizational-level	Individual + remote support	Promising
Leadership & policy reforms	Underutilized	Increasing adoption	Long-term benefit
Real-time monitoring systems	Rare	Pilot-tested	High potential, limited data

IV. CONCLUSION

This literature review demonstrates that fatigue-related reduction in concentration is a significant safety and performance concern for both onshore and offshore oil and gas engineers. Offshore operations present higher fatigue risks due to shift patterns, isolation, and environmental stressors, while onshore environments are more affected by psychosocial and organizational factors. Current fatigue detection approaches rely on a combination of subjective and objective methods, yet lack standardization and cross-context validation.

This review is limited by methodological heterogeneity across studies and variations in fatigue definitions and measurement instruments, which constrain direct comparability and generalizability.

The findings highlight the necessity of integrative fatigue assessment frameworks and context-specific fatigue management strategies. Future research should focus on validating multimodal detection systems, evaluating intervention effectiveness in operational settings, and developing industry-wide fatigue risk management standards to enhance safety, productivity, and worker well-being.

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