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Cognitive Readiness Monitoring as a Driver for Human Reliability and Operational Efficiency in Offshore Production Units

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Abstract

Offshore oil and gas operations are characterized by continuous processes, high task criticality, and complex socio-technical interactions, where human performance plays a decisive role in safety and operational efficiency. Traditional safety and ergonomics approaches often rely on lagging indicators and retrospective analyses, limiting their ability to anticipate performance degradation in real time. This paper presents a field-based application of a cognitive readiness monitoring program integrated with human factors and neuroergonomic assessment, implemented on a floating production, storage, and offloading (FPSO) unit operating in Brazil.

The study combined Ergonomic Work Analysis (EWA), in accordance with Brazilian regulatory guideline NR-17, with targeted neuroergonomic measurements to identify cognitive demands associated with critical offshore roles, including control room, field, marine stability, well, and crane operations. In situ observations, interviews, questionnaires, and physiological measurements (portable EEG and eye tracking) were used to characterize real work activity and generate structured ergonomic recommendations. These recommendations addressed organizational, technological, and physical factors that indirectly amplify cognitive load and affect human reliability.

Based on this diagnostic phase, a daily cognitive readiness assessment was implemented as a pre-shift digital test, completed individually in approximately three minutes. The monitoring program operated continuously for 22 months, during which 9,139 tests were conducted with high workforce acceptance (94%). Cognitive readiness data enabled the identification of function-specific and individual performance patterns and supported the activation of immediate mitigation actions when degraded cognitive readiness was detected.

Comparative analysis of operational data before and after implementation demonstrated a 76% reduction in incidents related to human failure and a 93% decrease in production downtime attributed to human error, from 47 to 3 hours. These improvements resulted in the preservation of approximately 77,000 barrels of oil equivalent, corresponding to an estimated financial impact of USD 5.1 million and a return on investment of 949%.

The findings indicate that cognitive readiness monitoring, when grounded in human factors engineering and real work analysis, can function as a leading indicator of human performance. For offshore oil and gas

operations facing increasing complexity and regulatory audits, this integrated approach offers a scalable and replicable framework to enhance human reliability, operational resilience, and production efficiency.

Introduction

In recent years, the oil and gas industry in Brazil has experienced increasing government audits regarding the management of human factors and ergonomics, particularly in high-risk and complex operational environments. Industry guidance such as IOGP Report 454 (IOGP, 216) emphasizes that human factors engineering (HFE) is a critical component of safe and reliable project execution, aiming to optimize human performance while minimizing design-induced risks to health, process safety, and operational integrity. The document highlights the growing expectation from regulators and operators that human factors considerations be systematically integrated across the project and operational life cycle, especially in environments characterized by high cognitive demands, time pressure, and operational uncertainty.

Within this context, offshore oil and gas operations represent socio-technical systems in which human performance plays a decisive role in safety and efficiency. Operators are required to manage complex process interfaces, interpret large volumes of information, and make time-critical decisions under conditions of fatigue, stress, and environmental constraints. The IOGP 454 guidance recognizes that human reliability is influenced not only by system design but also by cognitive and organizational factors that affect how individuals perceive, interpret, and respond to operational situations (IOGP, 2016). As a result, there is an increasing need for approaches that move beyond traditional ergonomic assessments and address the dynamic cognitive state of workers during operations.

Research on complex operations shows that human cognitive capabilities are frequently exceeded when individuals interact with dynamic systems characterized by multiple interdependencies, delayed effects, and non-linear behaviors. In such contexts, decision-makers tend to experience tunnel vision, narrow problem formulation, and difficulties in anticipating the unintended consequences of their actions. These limitations are not necessarily due to lack of knowledge, but to intrinsic constraints of human cognition when dealing with complexity, time pressure, and competing goals (Lafond, DuCharme, Gagnon and Tramblay, 2012).

Studies in the process industry highlight that many operational failures and accidents are associated with limitations in operators' readiness to recognize, interpret, and anticipate abnormal situations, particularly those that are rare and cannot be adequately learned through routine on-the-job experience. Human performance in such contexts depends strongly on situation awareness, defined as the ability to perceive relevant elements of the environment, comprehend their meaning, and project their future status. The capability to anticipate system evolution under dynamic and uncertain conditions is therefore a central component of effective decision-making in safety-critical operations (Manca, Brambilla and Colombo, 2013).

Cognitive Readiness (CR) emerges in the literature as a theoretical construct aimed at understanding and predicting human performance in complex, dynamic, and resource-limited environments. Originally developed within the defense domain, CR is defined as the mental preparation, encompassing knowledge, skills, abilities, motivations, and personal dispositions, that enables individuals to establish and sustain competent performance in unpredictable operational contexts (Morrison and Fletcher, 2002). Subsequent theoretical developments distinguish different levels of cognitive readiness, with operational cognitive readiness focusing specifically on the individual's preparedness prior to engaging in demanding tasks, where adaptability, situational awareness, and decision-making are critical (Crameri, Hettiarachchi and Hanoun, 2019).

From this perspective, cognitive readiness is not limited to knowing what to do, but involves the capacity to recognize patterns in apparently chaotic situations, adapt strategies as conditions evolve, and implement decisions while considering both immediate and downstream consequences. Studies on cognitive readiness emphasize that performance degradation in complex environments often stems from insufficient anticipation and limited understanding of system dynamics, rather than from procedural non-compliance alone (Lafond, DuCharme, Gagnon and Tramblay, 2012).

The literature consistently emphasizes that cognitive readiness is particularly relevant in environments where operators must cope with information overload, uncertainty, time pressure, and the need to respond effectively to unforeseen events. Reviews of cognitive readiness theory highlight its potential to serve as a predictor of performance before task execution, rather than solely as a retrospective evaluation of outcomes (Crameri, Hettiarachchi and Hanoun, 2019). Although initially applied to military and emergency response contexts, these characteristics closely resemble the operational conditions found in continuous process industries such as offshore oil and gas production. In the process industry, cognitive readiness has been explicitly associated with operators' ability to recognize early signs of deviation, understand their implications for system safety, and anticipate the progression of abnormal situations before they escalate into accidents (Manca, Brambilla and Colombo, 2013).

From a human factors' perspective, cognitive readiness can be understood as a construct that integrates multiple psychological mechanisms directly related to human performance, including attention, memory, situational awareness, decision-making, metacognition, and emotional regulation (Morrison and Fletcher, 2002). These mechanisms align with the broader human factors' framework described in IOGP 454, which defines human factors as the interaction between individuals, tasks, technologies, and organizational conditions that influence behavior and safety outcomes (IOGP, 2016). In this sense, cognitive readiness provides a conceptual bridge between traditional human factors engineering and training-oriented approaches that seek to enhance operators' ability to recognize, interpret, and respond to evolving operational states. Research in the process industry reinforces this view by showing that preparedness to perform under abnormal and stressful conditions is not limited to procedural knowledge, but relies on cognitive abilities related to anticipation, adaptability, and the interpretation of complex system dynamics (Manca, Brambilla and Colombo, 2013).

By linking cognitive readiness concepts with established human factors and ergonomics principles, there is an opportunity to enhance existing safety management approaches in offshore operations. Rather than treating human performance variability as a residual risk, cognitive readiness provides a structured way to assess mental preparedness prior to task execution, supporting proactive risk management and reinforcing the objectives of human factors engineering in high-hazard industries. Operational safety in offshore oil and gas production depends not only on robust systems but also on the cognitive readiness of personnel performing high-risk tasks.

This paper presents the results of a cognitive readiness monitoring program implemented on a FPSO unit. The initiative strengthens human reliability by continuously assessing operators' readiness before each shift and supporting decisions to mitigate risks from fatigue, distraction, and overload.

Methods, Procedures, Process

This study adopted a field-based human factors and neuroergonomic approach conducted in an offshore production environment. The research was carried out on an FPSO unit in Brazil, characterized by continuous process operations, and high task criticality. The methodological framework combined Ergonomic Work Analysis (EWA), in accordance with Brazilian regulatory guideline NR-17, with targeted neuroergonomic measurements to support the implementation of a Cognitive Readiness monitoring program.

Human Factors and Ergonomic Assessment

The initial phase consisted of a preliminary ergonomic assessment aimed at understanding real work activities, operational constraints, and cognitive demands associated with critical offshore roles. Data collection was conducted during an offshore campaign and included in-situ observations, task follow-up during normal operations, semi-structured interviews with workers and supervisors, photographic and video records, and the application of structured questionnaires.

The assessment followed the classical stages of Ergonomic Work Analysis (Guérin et al., 1991): analysis of demands, global assessment of work situations, detailed analysis of selected activities, ergonomic and neuroergonomic diagnosis, and validation. The focus was placed on how tasks are actually performed in real operational conditions, including how operators regulate their activities in response to workload, time pressure, environmental conditions, and unexpected events.

Cognitive and Neuroergonomic Assessment

In parallel with the ergonomic analysis, a neuroergonomic assessment was conducted to characterize cognitive demands during selected critical activities. Portable electroencephalography (EEG) and eye-tracking devices were used in specific operational contexts to support the identification of periods of increased cognitive load, stress, and attentional demands

These measurements were not intended as continuous monitoring during all operations, but as targeted diagnostic tools applied during representative tasks. The objective was to complement qualitative observations and interviews by providing physiological indicators related to attention, stress, decision-making, memory demands, and reaction time. The integration of neurophysiological data with task analysis allowed a more comprehensive understanding of cognitive demands embedded in real offshore work activiti

Subjective Assessment and Classification

Following the ergonomic diagnosis, workers were invited to complete an anonymous questionnaire based on the Ergonomics Work Analysis (EWA) method. Participants qualitatively classified identified ergonomic and cognitive factors using a four-point scale (good, regular, poor, very poor). In parallel, the analyst classified the same factors using a five-level severity scale to support prioritization of risks and improvement actions.

This dual classification approach enabled the comparison between operator perceptions and technical assessment, strengthening the validity of the findings and supporting the identification of factors with potential impact on safety, comfort, and operational performance.

Validation and Integration with the Cognitive Readiness Program

Validation occurred at multiple stages of the study. Preliminary findings were discussed with workers during the assessment to confirm the interpretation of observed activities. Subsequently, results and diagnoses were validated with supervisors and management. A consolidated summary of findings and recommendations was then presented to senior leadership

The outcomes of the ergonomic and neuroergonomic assessment served as the foundation for implementing the Cognitive Readiness monitoring program described in this paper. Based on the identified cognitive demands, selected roles were included in a daily pre-shift cognitive readiness assessment using a digital application. This integration ensured that the monitoring process was grounded in a detailed understanding of real work activity and human factors conditions present in the offshore operational context.

In the company in question, the functions selected for monitoring were: control room operator, field operator, marine stability operator, well operator, and crane operator. A digital daily test was then implemented, performed individually before each shift, measuring readiness levels. The test is completed in about three minutes and is based on psychophysical protocols validated in scientific literature (Go/No-Go), integrated into proprietary software.

When a decline is detected, a mitigation protocol is activated, guiding immediate action by supervisors. This protocol consists of implementing additional safety barriers to ensure workers and process safety. The system compiles daily data into a management dashboard that enables continuous monitoring of cognitive indicators, participation rates, and performance trends. The program's effectiveness was evaluated using behavioral, operational, and safety metrics.

Results

Human Factors Assessment and Ergonomic Recommendations

The Human Factors and Ergonomic Assessment conducted on the FPSO unit generated a structured set of findings and recommendations derived from in situ observations, interviews, questionnaires, and neuroergonomic measurements. The assessment covered key operational roles, including control room operators, field operators, marine stability operators, and supervisors, focusing on real work activity under normal operating conditions

A total of multiple ergonomic recommendations were produced and validated with workers, supervisors, and management. These recommendations were grouped into three main domains:

- Organizational factors, including team sizing versus workload, task allocation, shift dynamics (notably during shift changes), procedural standardization, and workforce turnover. Several recommendations addressed situations in which high task concurrency and staffing constraints increased cognitive load and the likelihood of human error.
- Interface, system, and technological factors, encompassing system representativeness, alarm visibility, information layout, contrast and legibility of control interfaces, and limitations in monitoring tools. These aspects were identified as contributors to increased attentional demands, reliance on memory, and delayed decision-making under time pressure.
- Physical and environmental factors, such as workstation layout, seating, lighting, thermal comfort, and input devices. Although traditionally classified as physical ergonomics, these elements were directly associated with increased cognitive effort, fatigue, and reduced sustained attention during long shifts.

Each recommendation was classified according to severity using an Ergonomics Work Analysis–based scale and prioritized based on potential impact on safety, health, and operational performance. The results indicate that a significant proportion of the identified issues were not isolated physical problems, but rather factors that indirectly amplified cognitive load and degraded human reliability during critical operations.

Cognitive Readiness Monitoring Outcomes

Following the ergonomic and neuroergonomic diagnosis, the Cognitive Readiness (CR) monitoring program was implemented and operated continuously over a 22-month period on the FPSO unit, from March 2024 to December 2025. During this period, 9,139 cognitive readiness tests were performed, with an average test duration of 2–3 minutes and high user acceptance, reaching 94% approval among participating workers.

The monitoring enabled the identification of function-specific cognitive patterns, demonstrating that cognitive fluctuations were predominantly individual and task-related rather than collective or driven by external environmental factors. Distinct cognitive demand profiles were observed across operational roles, such as production, crane operation, ballast control, and control room activities, supporting targeted and role-specific preventive actions.

Safety and Operational Performance Results

A comparative analysis of operational data before and after program implementation revealed a substantial reduction in incidents related to human failure. The average number of incidents decreased from 5.4 events per month to 1.3 events per month, corresponding to a 76% reduction. This decline was sustained over time, indicating a stable improvement in operational safety rather than a short-term effect.

In parallel, significant gains were observed in operational efficiency, particularly regarding production downtime attributed to human error. Total downtime was reduced from 47 hours to 3 hours, representing a 93% decrease. This improvement resulted in the recovery of approximately 44 productive hours, contributing to increased operational predictability and continuity.

Production and Financial Impact

The reduction in human-error-related disruptions translated directly into production preservation. Over the analyzed period, approximately 77,000 barrels of oil equivalent (boe) were preserved, corresponding to 93% of previously estimated losses. This volume represents an estimated financial impact of USD 5.1 million in preserved production.

From an economic perspective, the program demonstrated a return on investment (ROI) of 949%, equivalent to nearly ten times the invested amount, with a payback period of approximately one month. These results highlight that interventions grounded in human factors and cognitive readiness monitoring can generate measurable financial value in addition to safety benefits.

Integrated Interpretation of Results

Taken together, the results indicate that the combination of ergonomic recommendations and continuous cognitive readiness monitoring contributed to measurable improvements in safety, operational efficiency, and economic performance. The findings suggest that addressing cognitive demands as an explicit dimension of human factors management enables earlier identification of risk conditions, supports preventive decision-making, and strengthens human reliability in continuous offshore operations.

Conclusion

This study demonstrates that cognitive readiness monitoring, when grounded in a human factors and neuroergonomic assessment, can function as an effective driver of human reliability and operational efficiency in offshore oil and gas production units. By addressing the cognitive dimension of work, the proposed approach extends traditional safety and ergonomics practices toward a more proactive model of risk management.

The results show that understanding real work activity, through ergonomic analysis, identification of cognitive demands, and validation with operators, is essential for ensuring that digital monitoring tools are context-sensitive and operationally meaningful. The ergonomic recommendations generated in this study addressed organizational, technological, and environmental conditions that amplify cognitive load and contribute to human error, reinforcing the role of human factors engineering as a foundational element of safe offshore operations.

The implementation of daily cognitive readiness assessments provided a practical mechanism to evaluate operators' preparedness prior to task execution, enabling early identification of degraded cognitive states associated with fatigue, overload, or reduced attention. In this sense, cognitive readiness acted as a leading indicator of human performance, supporting timely mitigation actions and strengthening decision-making in high-risk, time-constrained operational scenarios.

From an industry perspective, the observed reductions in human-error-related incidents and production downtime highlight the operational relevance of integrating cognitive readiness into routine management practices. The associated gains in production continuity and financial performance indicate that investments in human factors and cognitive monitoring can yield tangible returns while simultaneously enhancing safety and resilience.

For the offshore oil and gas sector, particularly in regions characterized by aging assets, increasing production complexity, and heightened regulatory audits, the approach presented in this paper offers a scalable and replicable framework. By embedding cognitive readiness within human factors governance, operators can move beyond reactive safety indicators and adopt a more anticipatory strategy for managing human performance in continuous process environments.

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