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MONITORING COGNITIVE LOAD AND HAZARD ANTICIPATION IN TEAMS MANAGING FLOOD INFRASTRUCTURE

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Abstract
As with any critical hazard control, managing flood control systems like levees, reservoirs, and drainage networks is a multi-role team effort. It requires cognitive aptitude, hazard anticipation, and mental acuity. This study specifically examines how mental workload and scenario-response work patterns pulse within eye-tracking, real-time task analysis, and psychophysiology in different operational situations like routine surveillance, emergency situations, and cross-agency coordination. Advanced hybrid systems like NASA-TLX alongside EEG-derived cognitive workload gauges help assess information processing demands and communication flow failures to measure task regulation. Hazard anticipation is tested using simulations based on scenarios designed to measure participants' foresight and within-strategy intervention methods. The analysis shows that integrated and cohesive teams with shared knowledge perform hazard detection better than their disparate counterparts, alongside highlighting gaps in novice and expert operator cognitive load differences. This model aids in flood risk systems by designing adaptable control systems based on decisions made by real-time analysis. It closes the gap between monitoring cognitive performance with workflow drift and real-time droning frameworks, giving guidance to policymakers, systems and infrastructures engineers, and disaster response teams.

Keywords: cognitive load, hazard anticipation, flood infrastructure, team performance, decision-support systems, EEG monitoring

INTRODUCTION

Flood prevention infrastructure like levees, floodgates, spillways, and urban drainage systems are of utmost importance as they help control the risk of catastrophic water-related disasters [1][3][14]. Their successful operation is conditioned not only on construction reliability and sensor-based automation, but also on the human reasoning regarding monitoring, controlling, and responding to the anomalies within the systems, which streams the system's anomalies. In recent decades, changes in climate conditions have increased the challenge of managing flood disasters, which has heightened the importance of human choices in unpredictable and fast-changing scenarios [8]. In these scenarios, human cognitive factors such as overload, poor hazard risk detection, and bad interfaces between groups have been system failure factors that cause social, economic, and environmental losses. Managing flood infrastructure from the human side is often neglected as most studies focus on the model's structural resilience and prediction which is usually system-centric. However, the cognitive capacity to integrate floods and cooperate requires monitoring systems which are stream-centric [15]. The communication between the response teams which are usually the field, the engineers and the emergency coordinators is often controlled by the heroes and engineers. Each of these groups is heavily influenced by their allocated mental resources, especially in the field scenario. During the complex disaster scenarios, the burden from diverse cross-team collaboration is even more heightened as the infrastructure systems are interconnected, adding to the risk from systemic complexity.

This is done by collecting behavioral analytics as well as task complexity data, and merging them with psychophysiology to evaluate EEG and eye movements, applying a multi-modal cognitive assessment arch to track the framework [12].

Through a controlled simulated environment based on real-world flood scenarios, we analyze how individual and group cognitive loads differ across the tasks and how those changes impact hazard anticipation [9]. This study focuses on the effects of situational awareness, channeling communications designated by the roles, and different levels of experience on team performance.

This research goes beyond diagnosis by helping form adaptive decision-support systems capable of dynamic task assignment, cognitive strain detection, and anticipate distributed forecasting [11]. These systems could enhance resilience of critical infrastructure by helping human teams function closer to their cognitive best, especially during a crisis. With the aging of the global infrastructure systems and the climate crisis, there is a need for these approaches.

Key Contributions

- Multi-modal monitoring framework: This study develops a comprehensive system for real-time evaluation of cognitive workload through the integration of EEG signals and eye-tracking data with the monitoring of behavioral tasks of flood infrastructure teams.
- Role- based cognitive load evaluation: This assesses the strain of cognitive workload for hypothesized flood response roles (e.g. communication coordinators, emergency responders) and describes the effects of increasing cognitive workload on hazard prediction and situational awareness.
- Design recommendations oriented towards resilience: This research focuses on proposing changes to be made on cognitive- and situation-aware teams for the purpose of improving in situ training, interface design at the policy level, and adaptive team operation management.

The paper is divided into six sections. For Section I, the motivation and background on why cognitive load was chosen for studying flood management teams is presented. In Section II, the diverse psychology and operational strain encompassing the stress, team cognition, and the demand for real-time monitoring are evaluated regarding hazard acknowledgement. Section III explains the experiment's outline, covering the biometric instruments, simulation's structure, and the techniques for analyzing collected data. Section IV includes the results with the data and a performance comparison of roles within the team on cognitive load and anticipation accuracy. Section V describes the conclusions of the study and offers recommendations on the practical application of the results and the role interface, policies, and training frameworks as interface policy as policy training integration. Lastly, Section VI discusses operational resilience strategies and areas of for further research focus.

II. Cognitive Factors Influencing Hazard Recognition in Flood Infrastructure Teams

2.1 Impact of Cognitive Load on Operational Precision

Cognitive load is the mental effort associated with information processing. In the context of flood infrastructure management, operators have to interpret current data, make lightning-fast decisions, and communicate across teams [2]. Memory issues, reduced situational awareness, and critical decision delays all phenomena attributed to high cognitive load. It is important to understand task complexity, environmental stressors, and time pressure to mentally load optimize a team's readiness to reduce human-induced risk.

2.2 Prediction and Imagination Within Complex Dynamic Contexts

Forecasting the next possible state based on current data, trends, and anomalies is projection. In the case of floods, predicting breaches, equipment failures, and failures downstream is critical [10]. While using data and experience, teams have to pick signals out of a noisy environment [4]. According to cognitive models, trying to respond to scenarios as fast as possible enable mentally evaluated schemas to make quick assessments. This contrasts with novice, reactive thinkers, who are blind to the bigger picture.

2.3 Coordinated Team Actions and Shared Mental Models Within Team Cognition

The response to floods is an interconnected, segmented activity conducted by a large number of people, such as many technical staff, field engineers, and, finally, meteorologists and other emergency staff [13]. Shared mental models, a collective understanding of the system's design and state, enable efficient error recovery and division of many tasks. Communication breakdowns, particularly during high-pressure situations, can disrupt these models and reduce overall performance. Therefore, the assessment of team cognition is as critical as the evaluation of individual cognitive strain.

2.4 Stress and Fatigue Impact on Decision Making

Flood events usually require long duration performances in extremely strenuous and mentally taxing environments. Stress and fatigue can further compound a cognitive load by constraining focus, increasing distractibility, and reducing the ability to solve problems [6]. Research reveals that stressed people tend to revert to using familiar behaviors instead of analyzing the situation. For flood response teams, this could result in far too heavy dependence on standard operating procedures in situations that require flexibility [5].

2.5 Instant Cognitive Snapshot Demand Monitoring Tools

Performance evaluation in a given task usually centers on the output, but assessment in real time is focused on the cognitive state of the solver. Advanced focus estimation techniques, such as eye tracking, EEG, and variations in pulse can detect emergence of mental strain long before performance is likely to be impacted. With the right visualization tools, their fusion could guide supervisory interventions and suggest automation or reallocation of tasks. Placing such tools within infrastructure control rooms could enhance safety and encourage more efficient utilization of resources.

III. Integrated Assessment Framework for Cognitive Load and Hazard Anticipation

3.1 Overview of Assessment Architecture

In order to monitor and evaluate cognitive load while performing flood infrastructure operations, a multi-layered assessment system was developed. It integrates real-time biometric monitoring, activity logging, and scenario-based hazard simulations. EEG headbands and eye trackers are used to capture and monitor a person's gaze and EEG and eye tracking data are synchronized with interface engagement data to measure and record the amount of task switching done during varying levels of demand.

3.2 Simulation Design for Anticipatory Tasks Concerned with Hazards

Loss of control over a dam, pump failure, and activation of early-warning systems are just a few of the flood infrastructure management scenarios a simulation platform is able to replicate. Participants control the automation and respond to hazards manually and through automation. The platform assesses optimum hazard prediction, decision, and communication timeline performance while varying cognitive load through addition of stressed time, communication lags, and irrelevant prompts [7].

3.3 Tools for Behavioral and Cognitive Data Collection

Eye-tracking glasses record eye gaze fixation, saccade, and blink rates, and the system integrates lightweight EEG sensors like Emotive EPOC+ which monitor theta and beta waves to measure working memory and attentional workload. Tasks are completed and validated against workload measures by NASA-TLX questionnaires.A logging module captures response delays, how users navigate through the interface, and the rate at which errors occur in response to triangulation.

3.4 Module for Interpreting Data and Synchronizing Data

All data streams: EEG, eye-tracking, behavior logs, and self-reports, are synchronized with a timestamp engine, which allows for the synchronization of data with the peak load moments and the moments preceding potential hazards. Overload-complex and overload-anticipation states are classified and predicted by algorithms, classified, and predicted by algorithms. Cognitive overload heatmaps and timeline charts are created for interface design and training feedback.

IV. Experimental Results on Cognitive Load and Hazard Anticipation Accuracy

4.1 Participant Profile and Task Conditions

The experimental study included 24 participants. 6 Operational teams were created, each consisting of four common roles in flood infrastructure management: monitoring analyst, field technician, communication coordinator, and emergency responder. Participants went through three incremental scenarios: routine inspection, moderate-risk flooding, and high-risk system failure. Each scenario lasted 15–20 minutes and participants completed NASA-TLX assessments after each scenario.

4.2 Cognitive Load and Performance Metrics

Hazard anticipation and cognitive load were measured and tracked. Cognitive load estimated from EEG was benchmarked on a 0–100 scale. Participants' responses to simulated alerts were evaluated to gauge hazard anticipation. The effectiveness of hazard anticipation was measured through accuracy and timeliness. The data retrieved strongly supported the hypothesis of cognitive load varying with risk. This was most profound in high-risk scenarios and multirole demand circumstances such as the communication coordinator position. Strikingly, those deemed high performers displayed moderate load levels, suggesting better resource management, and precision, higher expectation on anticipation accuracy.

4.3 Role-specific cognitive load variation

Results showed that the role of an emergency responder displayed the most notable increase in cognitive load variability, whereas, monitoring analysts showed very little variation. The study also demonstrated that teams who communicated through concise speech showed lower cognitive strain and greater task success, which demonstrated the importance of team synergy.

4.4 Quantitative Results Summary

Table 1: Role-Based Cognitive Load and Hazard Anticipation Performance

Team Role	Avg. Cognitive Load (Routine)	Avg. Load (High-Risk)	Hazard Anticipation Accuracy (%)
Monitoring Analyst	48.2	62.9	84.1
Field Technician	52.5	70.3	76.4
Communication Coordinator	58.6	82.1	71.5
Emergency Responder	54.3	89.7	68.2

This table 1 shows average cognitive load (via EEG) of four operational roles: Monitoring Analyst, Field Technician, Communication Coordinator, and Emergency Responder during routine and high-risk flood management. Also included is each roles' hazard anticipation accuracy derived from their correct and timely responses to simulated flood scenarios. The data demonstrates the effects of increased operational complexity on mental workload and decision accuracy, its severity for certain roles like Emergency Responders, and the stress to cognitive strain vulnerability.

V. Strategic Insights for Enhancing Team Resilience in Flood Infrastructure Management

5.1 Developing Interfaces That Consider Cognitive Functions

In flood control rooms, systems interfaces should differ more than just the visual layout. Streamed data, alarms, and overall system structure should not result in mental fetching. Based on our findings, improving decision speed and accuracy on cognitive adaptive interfaces that highlight critical and anomalous changes in information while suppressing alert clutter would be beneficial. From a human-centered perspective, this approach would improve focus and cognitive errors while preserving the multi-hazard situation awareness during multi-agency collaborations.

5.2 Real-time Monitoring in Embedded Systems

Eyes and EEG sensors can monitor cognitive load in real-time. Integrating these sensors with supervisory systems enables real-time cognitive monitoring and proactive team leader engagement. For example, an overloaded communication coordinator can have their load monitored and automatically partial tasks reassigned. This approach fosters team resilience by managing the group's cognitive bandwidth during an incident lifecycle.

5.3 Predictive Anticipatory Workload Training

Over-cluttered training disregards cognitive resilience. Training equipped with adaptive feedback and cognitive load simulations enables better anticipatory performance. Prioritization, hazard recognition, and communication under pressure are skills that are teachable. Through the use of physiological feedback during training, people gain insight into their self-monitored mental conditions and learn to control their mental states. This self-regulation skills development is crucial for making complex decisions.

5.4 Communication Problems and Defined Role Boundaries

Evidence suggests anticipation breakdowns are associated with communication bottlenecks and poorly defined role boundaries. Teams with shared mental models and adherence to role coordination protocols are better performers under cognitive load. As a result, communication templates, interdisciplinary role dry runs, and hierarchal decision flowcharts supporting highly adaptable role changes during system surges or post personnel fatigue periods must be standardized.

5.5 Cross-Disciplinary Cognitive Ergonomics

Flood system control rooms, with their automated systems, still require high-level cognitive workload assessments during audits. There should be strict guidelines governing cognitive ergonomics that require assessment of the flood control systems for cognitive overload, enhancing the overall design with the operator using low workload displays and higher command AI.

CONCLUSION

Operational teams controlling flood infrastructure operations are the subjects of this study, where their cognitive load and hazard anticipation are monitored, forming the basis of a novel framework. Through physiological sensing such as EEG and eye-tracking, as well as behavioral measures, and scenario-based simulations, we map the mental workload intricacies across different roles and its effect on the accuracy of hazard assessment and decision timing. These findings emphasize the need for systems that are aware of cognitive processes and systems. Their results suggest that differences between user roles and interface design as well as collaboration frameworks require attention. Emergency responders and communication coordinators experienced the greatest susceptibility to overload, which impacted team-wide predictive capacity. Real-time assessment and adaptive workload control systems are effective for stress-optimal performance maintenance. Focused training on anticipatory skills and protocol-based, role-centric frameworks builds resilience. These findings support the integration of cognitive factors into the design of the next generation of decision-support systems and operational documents. Advances in technology and a well-planned human-centered design that enables teams to operate under pressure are crucial to enhancing human dependability in flood risk management.

REFERENCE

[1] Zafarmand, O. (2016). The study of the relationship between entertainment and water sport through creating tourism attraction and development (sport tourism) in Bushehr coasts. International Academic Journal of Innovative Research, 3(1), 18–22.

[2] Atashsooz, A., Nejad, R. E., & Sahraiy, M. (2019). Relationship between Personality Traits and Occupational Burnout in the Employees of Mahabad City Government Offices. International Academic Journal of Organizational Behavior and Human Resource Management, 6(1), 52–57. https://doi.org/10.9756/IAJOBHRM/V6I1/1910006

[3] Poornimadarshini, S. (2024). Comparative techno-economic assessment of hybrid renewable microgrids in urban net-zero models. Journal of Smart Infrastructure and Environmental Sustainability, 1(1), 44–51.

[4] Sindhu, S. (2025). Blockchain-enabled decentralized identity and finance: Advancing women's socioeconomic empowerment in developing economies. Journal of Women, Innovation, and Technological Empowerment, 1(1), 19–24.

[5] Umamaheswari, A., &Sathianathan, J. (2020). Implementation of Sap Success Factors (SF) Employee Central. International Academic Journal of Science and Engineering, 7(1), 1–8. https://doi.org/10.9756/IAJSE/V7I1/IAJSE0701
[6] Kadhim, S. S., & Jasim, E. O. (2022). The Effect of Workplace Democracy on Improving Employee Performance: An Analytical Study of the Opinions of a Sample of Employees at the General Company for Grain Trade / Diwaniya Branch. International Academic Journal of Social Sciences, 9(2), 80–90. https://doi.org/10.9756/IAJSS/V9I2/IAJSS0917
[7] Vishnupriya, T. (2025). Real-time infrared thermographic characterization of functionally graded materials under thermomechanical loads in high-temperature combustion chambers. Advances in Mechanical Engineering and Applications, 1(1), 32–40.
[8] Danh, N. T. (2025). Advanced geotechnical engineering techniques. Innovative Reviews in Engineering and Science, 2(1), 22-33. https://doi.org/10.31838/INES/02.01.03
[9] Arvinth, N. (2025). Effect of Pranayama on respiratory efficiency and stress levels in adolescent athletes. Journal of Yoga, Sports, and Health Sciences, 1(1), 1–8.
[10] Vasquez, E., & Mendoza, R. (2024). Membrane-Based Separation Methods for Effective Contaminant Removal in Wastewater and Water Systems. Engineering Perspectives in Filtration and Separation, 2(4), 21-27.
[11] Muralidharan, J. (2025). Integrative intervention of yoga and nutritional counseling for obesity management among college students: A holistic wellness approach. Journal of Yoga, Sports, and Health Sciences, 1(1), 17–23.
[12] Otieno, J., & Wanjiru, G. (2024). Seismic Innovations: Strengthening Tall Buildings with Advanced Earthquake-Resistant Technologies. Association Journal of Interdisciplinary Technics in Engineering Mechanics, 2(3), 18-21.
[13] Biswas, D., Dubey, A., & Gulati, M. (2025). Deep ocean exploration and marine data acquisition: Uses of autonomous underwater vehicles (AUVs). International Journal of Aquatic Research and Environmental Studies, 5(1), 501–509. https://doi.org/10.70102/IJARES/V5I1/5-1-46
[14] Veerappan, S. (2024). Digital Management and Sustainable Competitiveness: Using Eco-innovation and Green Absorptive Capacity in Travel and Hospitality Enterprises. Global Perspectives in Management, 2(3), 32-43.
[15] Rahim, R. (2024). Integrating digital twin and life cycle assessment for sustainable roadway material selection: A data-driven framework. Journal of Smart Infrastructure and Environmental Sustainability, 1(1), 23–30.
[16] Mendes, C., & Petrova, O. (2024). Terminology Mapping in Health Information Exchanges: A Case Study on ICD and LOINC Integration. Global Journal of Medical Terminology Research and Informatics, 2(2), 18-21.
[17] Ranjan, A., & Bhagat, S. (2024). Multilateral Partnerships for Clean Water Access an Evaluation of SDG 6 Collaborations. International Journal of SDG's Prospects and Breakthroughs, 2(3), 1-3.
[18] Patil, A., & Reddy, S. (2024). Electrical Safety in Urban Infrastructure: Insights from the Periodic Series on Public Policy and Engineering. In Smart Grid Integration (pp. 6-12). Periodic Series in Multidisciplinary Studies.
[19] Barhoumia, E. M., & Khan, Z. (2025). Neurocognitive mechanisms of adaptive decision-making: An fMRI-based investigation of prefrontal cortex dynamics in uncertain environments. Advances in Cognitive and Neural Studies, 1(1), 20–27.
[20] Lukić, A. (2023). GIS Analysis of the Vulnerability of Flash Floods in the Porečka River Basin (Serbia). Archives for Technical Sciences, 1(28), 57–68. https://doi.org/10.59456/afts.2023.1528.057L.