30th

International Maritime Lecturers Association Conference

Split Croatia

www.imla30.org

ASSESSING THE IMPACT OF WORKLOADS ON SITUATIONAL AWARENESS OF MARITIME STUDENTS IN ENGINE ROOM SIMULATIONS

Gerardo Ramon S. Galang*, Rodolfo R. Paiso, Rosangela Anne D. Salaya

Abstract. Situational awareness (SA) is a vital non-technical skill in maritime operations, particularly in engine rooms where human error often leads to accidents. While most research has focused on bridge operations, this study investigates SA among maritime students during engine room simulations under varying workload conditions. A triangulated approach was employed using three assessment methods: the 3D SART questionnaire (self-rating), expert evaluations (performance-based), and EEG signal analysis (process indices-based). This mixed-method strategy addresses the limitations of individual techniques and aims to provide a more reliable and comprehensive assessment of SA. Twenty Engine students who had completed their Power Plant Diesel course participated in two simulation exercises, one designed to reflect a low workload condition and the other a high workload condition, using a Multi-task Engine Room Simulator. During the simulations, students wore Neeuro SenzeBand 2 EEG devices to continuously monitor brain activity, specifically attention and relaxation levels. After each exercise, participants completed the 3D SART questionnaire, and their performance was evaluated by expert assessors based on perception, comprehension, and projection. The study followed a structured protocol including briefings, consent, assessment, and debriefing. Findings showed no statistically significant difference in SA levels between workload conditions based on 3D SART scores, which indicated moderate awareness in both. In contrast, EEG data revealed low attention and relaxation levels, suggesting cognitive fatigue regardless of workload. Expert assessments also reflected low SA and aligned more closely with EEG readings than with 3D SART scores. Spearman correlation analysis confirmed strong positive relationships between expert evaluations and EEG data. These findings support the integration of EEG-based assessments and targeted SA training into simulation exercises. It is recommended that situational awareness be formally incorporated into MAAP's curriculum starting in the second semester of Academic Year 2025–2026, in line with STCW standards.

Keywords: Marine Engineering; Engine Room Simulator; Engine Students; Situational Awareness; Neurosensor; Situational Awareness Rating Technique (SART); electroencephalographic (EEG) signal analysis.

Maritime Academy of Asia and the Pacific, Department of academics, Mariveles, Bataan, Philippines

* **Corresponding author:** gdgalang@maap.edu.ph

https://doi.org/10.7225/imla30.39

1. INTRODUCTION

Situational awareness (SA) is a state of knowledge, distinct from the process of attaining or maintaining that state. Clearly distinguishing this concept is essential for effective discussion on SA. According to Endsley, achieving situational awareness involves a three-step process: first, perceiving the current status, characteristics, and changes of relevant elements in a dynamic environment; second, understanding the meaning and implications of these elements; and third, using that understanding to anticipate future events and guide decisions (Endsley, 1995).

A lack of situational awareness is a contributing factor to accidents in seafaring, often linked to human error (Grundmann, et al., 2021; Li, et al., 2024). SA is vital for safe operation in marine engine rooms, yet most studies have focused on bridge operations, with relatively little attention given to the engine room despite its importance. Research from related industries, like nuclear power plants, highlights that many incidents result from lapses in awareness, including missed actions and poor understanding of system status (Han, et al., 2024). These findings emphasize the need for effective SA assessment and training specifically for engine room personnel. This paper therefore uses engine room simulator to provide a controlled and realistic environment to assess and enhance SA, allowing for targeted evaluation and development of the cognitive and decision-making skills essential for safe engine room operations. The STCW Convention, particularly after the 2010 Manila amendments, formally integrated human factor training such as Engine Room Resource Management (ERM) to address the high rate of maritime accidents caused by human error. Inspired by the aviation sector's Crew Resource Management (CRM), ERM emphasizes critical non-technical skills including leadership, communication, decision-making, and situational awareness. Under STCW Tables A-III/1 and A-III/2, ERM training became mandatory to enhance safe ship operations by improving the cognitive and behavioral competencies of engineering officers. Situational awareness, as one of ERM's core components, is essential for maintaining vigilance and effective decision-making in dynamic maritime environments (Ceylan, 2020).

Previous studies have explored the relationship between cognitive workload and situational awareness, particularly in automated environments. Findings indicate that as cognitive workload increases, measured through behavioral and physiological indicators, situational awareness tends to decline. Although some research initially hypothesized otherwise, this inverse relationship has been consistently observed, suggesting that higher mental demands may negatively impact an individual's ability to remain aware of their environment over time (Sahoo, et al., 2024). Supporting this, a study involving unmanned vehicle operations found that situational awareness decreased by approximately 20% as workload increased. These findings highlight the complexity of the SA–workload relationship and emphasize the need to consider individual variability and the nature of workload measurement when evaluating their interaction (Endsley, et al., 2024).

(Nguyen, et al., 2019) conducted a comprehensive review of various situational awareness (SA) assessment approaches. They identified six distinct types of probes used to measure SA: (1) Freeze-Probe Techniques, (2) Real-Time Probe Techniques, (3) Post-Trial Self-Rating Techniques, (4) Observer-Rating Techniques, (5) Performance-Based Rating Techniques, and (6) Process Indices-Based Rating Techniques. Each of these methods offers unique advantages and limitations, depending on the context, measurement objectives, and available resources. Situational awareness is commonly measured by having individuals perform specific tasks, often through simulations, followed by answering questions either during or after the activity (Grundmann, et al., 2021).

Freeze-probe techniques interrupt the task to ask the subject questions about the environment, while *real-time probe techniques* present queries during task execution without interruption. *Post-trial self-rating techniques* rely on subjects' subjective evaluations after task completion, though these may be biased by memory and performance outcomes. *Observer-rating techniques* involve experts assessing SA based on observed behavior but cannot access internal cognitive states. *Performance-based rating techniques* infer SA from task performance, though results may be influenced by individual skill and experience. Lastly, *process indices-based techniques* monitor physiological or behavioral indicators, such as eye movements, to infer SA, but these may not always reflect true perception or understanding.

According to (Munir, et al., 2022) existing methods have several limitations. Self-rating techniques are subjective and influenced by mission outcomes, while physiological measures such as EEG can indicate cognitive states but not actual environmental understanding. Surveys may suffer from recall bias and disrupt task performance under high workload. Moreover, many methods assess only specific aspects of SA, lacking a comprehensive and holistic view. This highlights the need for more reliable and multidimensional approaches to assessing situational awareness. Therefore, this study employs multiple assessment probes to generate more accurate results and to identify which method is most suitable for evaluating situational awareness in simulation-based environments, with a particular focus on (1) Post-Trial Self-Rating, (2) Performance-Based Rating, and (3) Process Indices-Based techniques.

The SART questionnaire, developed by (Taylor, 1989), employs post-trial self-rating techniques to capture a pilot's or user's subjective assessment of their attention and awareness during task performance. It evaluates various elements including situation stability and instability, complexity, variability, alertness, attention concentration and division, spare mental capacity, information quantity, and familiarity with the situation. In this paper 3D SART questionnaire is utilized, known to be the faster version of SART Technique which limits the ten (10) dimensions of situational awareness down to three (3) main dimensions (Attentional Demand, Attentional Supply, Understanding) (Taç & Tavacıoğlu, 2019).

Performance-based rating is emphasized in the study of (Atik, 2019) through the use of certified simulator assessors, whose evaluations are considered the ground truth for situational awareness during bridge resource management training. These expert assessments, based on observed task performance, serve as the benchmark against which newer and more objective measures such as eye tracking or EEG data are validated. Moreover, according to (Fernandes & Braarud, 2015), situational awareness is a significant predictor of performance, as reflected in both observer-rated and operator-rated evaluations. This supports the idea that situational awareness plays a critical role in performance within complex systems.

With respect to process indices-based techniques that monitor physiological or behavioral indicators, Electroencephalography (EEG) has emerged as a valuable tool for assessing brain activity in human factors research. Traditionally, mental workload, stress, and emotional states have been evaluated using post-task questionnaires, which offer only a broad and subjective overview of the participant's experience. In contrast, real-time EEG monitoring in maritime virtual simulators allows researchers to observe dynamic changes in brain states as subjects perform navigational tasks under different environmental and collaborative scenarios. By applying machine learning techniques to EEG data, cognitive states such as stress and workload can be more accurately recognized. This approach, when combined with subjective feedback, provides a more reliable and comprehensive understanding of participants' cognitive patterns and overall performance during simulations. (LIU, et al., 2017; Ronca, et al., 2023; YAURI, et al., 2021).

According to (Flanagan & Saikia, 2023), one of the popular EEG devices is NEEURO Senzeband 2. The Neeuro SenzeBand 2 is a portable, non-invasive EEG headband that monitors brain activity in real time. It has seven dry electrodes on the prefrontal cortex, a heart rate and oxygen sensor, and a motion sensor to track attention, relaxation, mental workload, fatigue, and stress. Lightweight and sweat-resistant, it provides real-time cognitive insights useful for education, workplace wellness, and research applications (Neeuro, 2025). In order to address the challenges mentioned by (Munir, et al., 2022), in this study, situational awareness (SA) was measured using the triangulation of three distinct assessment methods or "probes." The selection and design of these probes were guided by the available resources, time constraints, and operational priorities of the institution. This triangulated approach was adopted to ensure a more comprehensive, valid, and reliable measurement of SA.

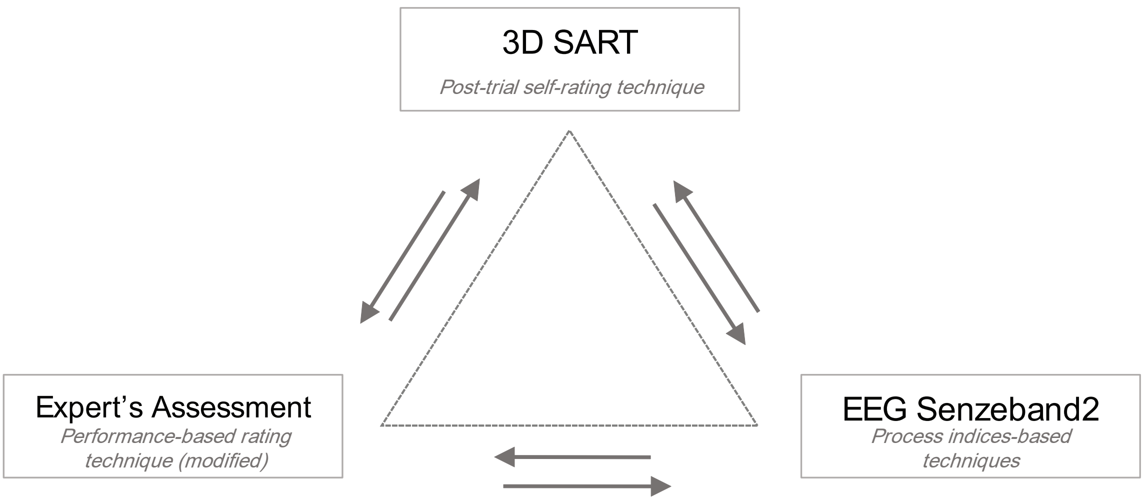

Figure 1. Triangulated approach using three assessment methods

This study aims to assess the impact of varying workload conditions on the situational awareness of maritime students during engine room simulations. It also seeks to identify the most reliable method for evaluating situational awareness by comparing multiple assessment techniques. Specifically, the study addresses the following research questions:

1. What is the difference in situational awareness levels of maritime students under low and high workload conditions as measured by the 3D SART questionnaire?
2. What is the difference in attention and relaxation levels of maritime students under low and high workload conditions as measured by EEG band signals?
3. Is there a significant correlation between EEG band signals (attention and relaxation), expert assessments, and 3D SART scores in evaluating situational awareness during engine room simulations?

2. METHODOLOGY

For the purpose of this study, a selected group of Engine students participated in two (2) Engine Room simulation exercises: one representing a low workload condition and the other a high workload condition. During these exercises, continuous neural data was collected using non-invasive EEG headbands. Upon completion, their situational awareness was further assessed through 3D SART questionnaire and expert's assessment.

2.1. Participants

A total of twenty (20) Engine students who had already completed their Power Plant Diesel (PPD) course were selected to participate in an Engine Room Simulation exercise using the Multi-task Engine Room Simulator. These students were already familiar with the features and operation of the simulator, having been previously exposed to its use during their academics.

2.2. Simulation Exercise

The Multi-task Engine Room Simulator was utilized for two (2) exercises: one designed for a **low workload scenario** and the other for a **high workload scenario**. The low workload exercise lasted for a total of 3 minutes, while the high workload exercise had a total duration of 10 minutes.

The Simulator model used for the study is the "RTFlex" (Wartsila Sulzer) ERS Model which caters the simulation of 12-cylinder Propulsion plant (Main Engine) equipped with three (3) Diesel Generators as well as Shaft and Steam turbine generator respectively fitted in a Container vessel as a ship model.

The low workload simulation mimics the engine room operation at sea wherein the participant is briefed to identify the underlying malfunction by observing the parameters available. The exact scenario is that a malfunction is injected (blockage in the Piston cooling oil return) wherein the participant's ability to detect and identify an underlying malfunction with aid of the working parameters available in the simulator is tried before a machinery alarm is sounded.

The high workload on the other hand exhibits a scenario wherein the Engine operation is at port and the participant must be able to prepare the Engine room for the departure. While preparing, the participant is also instructed to transfer fuel from storage to settling tank. The goal is to check the participants ability to adjust and respond accordingly with multiple tasks without causing disruption to the vessel's operation.

2.3. Measures

2.3.1. EEG Headbands

During the simulation exercises, students wore the Neeuro SenzeBand 2, an EEG device, which continuously recorded their brain activity. The device employs its own machine learning algorithm to analyze brain signals and determine levels of Attention and Relaxation based on Alpha, Beta, Gamma, Delta, and Theta brain waves (Neeuro, 2025).

2.3.2. 3D SART

After completing the simulation exercise, students were asked to answer the 3D SART questionnaire. The tool consists of a total of 10 items based on Table 1 Factors categorized under three Domains: Attentional Demand (D), Attentional Supply (S), and Situational Understanding (U). Each item was rated using a 7-point Likert scale. Average scores were calculated for each category, and the overall 3D SART score was computed using the formula (Taç & Tavacıoğlu, 2019):

Situational Awareness =
Understanding – (Attentional Demand – Attentional Supply)

Table 1. Dimensions and definitions of SART scale as per (Taç & Tavacıoğlu, 2019)

Domains	Factors	Definition
Understanding (3)	Information quantity	Amount of information received and understood
	Information quality	Degree of goodness of information
	Familiarity	Degree of acquaintance with situation experience
Attentional Demand (3)	Instability	Probability of situation to change suddenly
	Variability	Number of variables requiring attention
	Complexity	Degree of complication of situation
Attentional Supply (4)	Arousal	Degree of readiness of the individual to the activity
	Spare mental capacity	The amount of mental ability an individual has for new variables
	Concentration	Degree that one's thoughts are brought to bear on the situation
	Division of attention	Amount of division of attention in the situation

2.3.3. Expert's Assessment

In addition to the 3D SART questionnaire, students' situational awareness was evaluated by subject matter experts. Assessments were based on three key aspects: perception, comprehension, and projection (Endsley, 1995). Each aspect was rated on a scale of 1 to 5 per item, with a maximum total score of 15 points.

2.4. Procedure

Before each of the simulation exercises, participants were given a detailed briefing about the objectives and procedures of the activity. A consent form was distributed to ensure that each participant voluntarily agreed to take part in the study and was willing to wear the EEG device for data collection. Only those who submitted signed consent forms were included in the study. During the briefing, participants were encouraged to ask questions and raise any concerns, all of which were addressed prior to proceeding.

Following the briefing, the participants underwent the actual simulation scenarios for both low and high workload conditions, with each student experiencing both levels. Immediately after completing the exercises, they were given approximately 15 to 20 minutes to complete the 3D SART questionnaire and the assessment form. Once all participants had finished, a debriefing session was conducted.

3. RESULTS AND ANALYSIS

Given the small sample size of twenty participants, a series of non-parametric tests were employed to address the research questions (Field, 2013).

3.1. Research Question 1 (RQ1)

What is the difference in situational awareness levels of maritime students under low and high workload conditions as measured by the 3D SART questionnaire?

To compare the situational awareness of students under low and high workload conditions, the Wilcoxon Signed-Rank Test was used. The average 3D SART score under low workload was 10.24, slightly higher than the average score under high workload, which was 9.24. However, the resulting p-value = 0.231 was greater than the significance level of 0.05, indicating no statistically significant difference between the two workload conditions.

Given that the maximum possible 3D SART score is 13, the average scores for both conditions fall within the moderate range. This suggests that participants subjectively perceived themselves as having moderate situational awareness during both workload conditions.

3.2. Research Question 2 (RQ2)

What is the difference in attention and relaxation levels of maritime students under low and high workload conditions as measured by EEG band signals?

To assess differences in cognitive state based on EEG band signals, the Wilcoxon Signed-Rank Test was also applied. The average EEG Attention score under low workload was 0.14, compared to 0.13 under high workload, with a p-value = 0.756, indicating no significant difference.

Similarly, the average EEG Relaxation score under low workload was 0.16, slightly higher than 0.13 under high workload, with a p-value = 0.475, also indicating no significant difference.

Considering that EEG band scores range from 0 to 1 (with 1 representing the highest level), the low values observed for both attention and relaxation suggest that students were generally not attentive and not relaxed during the simulation exercises. These findings imply the presence of cognitive fatigue, distraction, or mental overload, regardless of workload intensity.

3.3. Research Question 3 (RQ3)

Is there a significant correlation between EEG band signals (attention and relaxation), expert assessments, and 3D SART scores in evaluating situational awareness during engine room simulations?

To determine the relationship between different measures of situational awareness, the Spearman's Rank Correlation Coefficient was used.

As shown in Table 2, there were:

- a very strong positive correlation between Attention and Relaxation (ρ = 0.946),
- a very strong positive correlation between Expert Assessment and Attention (ρ = 0.853),
- a very strong positive correlation between Expert Assessment and Relaxation (ρ = 0.844).

In contrast, correlations involving the 3D SART score were noticeably weaker:

- with Attention (ρ = 0.373),
- with Relaxation (ρ = 0.325),
- with Expert Assessment (ρ = 0.328).

These trends were consistent in Table 3, further reinforcing the observation that expert assessments are more strongly aligned with physiological EEG measures compared to the subjective 3D SART scores.

Given that expert assessments were conducted by subject matter experts, their results are considered more valid and reliable indicators of situational awareness. The strong positive correlations between expert scores and EEG signals (attention and relaxation) suggest that noninvasive EEG devices, such as the Senzeband 2, can serve as effective tools for assessing situational awareness in simulation environments. This positions EEG-based assessments as a potentially superior alternative to self-reported questionnaires like the 3D SART in future studies and training interventions. Moreover, this is supported by (Kästle, et al., 2021), which found that specific EEG patterns are positively correlated with situational awareness, highlighting EEG's potential as a reliable physiological marker for assessing cognitive states in real time.

4. CONCLUSION AND RECOMMENDATION

The findings of this study revealed that participants demonstrated moderate situational awareness across both low and high workload conditions based on 3D SART scores, with no statistically significant difference observed between these workload levels. However, expert assessments indicated low situational awareness for both conditions, a result further supported by EEG band signals, which reflected low levels of attention and relaxation. This however, contradicts the studies of studies of Sahoo et al. and Endsley et al. wherein varying workloads has an inverse effect to the SA of the participants. This discrepancy may be attributed to the nature of the participants. In the present study, students were the subjects, whereas in the cited studies, professionals were involved. Other contributing factors could include the briefing provided for each exercise under low and high workload conditions, as well as the timing of the simulations, particularly since the high workload scenario was administered at 1300H, immediately after the noon mess, which may have affected participants' alertness. To validate these assumptions, it is recommended to conduct a follow-up study with a more controlled schedule and a comparison group involving professional participants.

A strong positive correlation was found between expert assessment scores and EEG band results. This significant relationship validates the potential of non-invasive EEG as a physiological tool for assessing situational awareness in engine room simulations as expert's assessment is considered as the ground truth.

Table 2. Spearman Correlation Matrix for Low Workload

	Attention	Relaxation	3D SART Score	Expert Assessment
Attention	1.000000	0.946375	0.373163	0.852668
Relaxation	0.946375	1.000000	0.324916	0.843503
3D SART Score	0.373163	0.324916	1.000000	0.327771
Expert Assessment	0.852668	0.843503	0.327771	1.000000

Table 3. Spearman Correlation Matrix for High Workload

	Attention	Relaxation	3D SART Score	Expert Assessment
Attention	1.000000	0.725727	-0.358086	0.834512
Relaxation	0.725727	1.000000	-0.082140	0.815134
3D SART Score	-0.358086	-0.082140	1.000000	-0.234326
Expert Assessment	0.834512	0.815134	-0.234326	1.000000

EEG offers the advantage of continuous, objective, and real-time cognitive state monitoring, unlike traditional subjective measures such as the 3D SART. Although causality was not established, this strong correlation provides a foundational basis for future research.

Given the disparity between subjective and objective measures and the consistently low situational awareness identified through expert and EEG assessments, it is recommended that beginning 2nd semester of Academic Year 2025-2026, SA shall be considered and included in Maritime Academy of Asia and the Pacific (MAAP) curriculum particularly in laboratory exercises. The specific courses for inclusion shall be identified in close coordination with the Department of Academics to ensure alignment with learning outcomes and program objectives. The said modification in the curriculum shall also be align with the standards set by the STCW Convention.

Furthermore, the integration of EEG-based assessment tools in simulator exercises is encouraged, as these can provide real-time insights into students' cognitive states, enabling more effective training interventions. Strengthening this critical skill will better prepare maritime students for safe and effective operations in real-world settings.

Conflict of interest: The authors have no financial or personal relationships that could have influenced the work reported in this paper.

REFERENCES

Atik, O., 2019. Eye Tracking for Assessment of Situational Awareness in Bridge Resource Management Training. Available at: https://doi.org/10.16910/jemr.12.3.7

Ceylan, B. O., 2020. Enhancement of the Engine Room Resource Management Concept via the Integrated Model of Training Effectiveness and Evaluation: Maritime Transportation Engineering Programme. Available at: https://doi.org/10.13140/RG.2.2.30020.76161

Endsley, M. R., 1995. Toward a Theory of Situation Awareness in Dynamic Systems. s.l.: Human Factors.

Endsley, M. R. et al., 2024. Divergence in situation awareness and workload. Ergonomics. Available at: https://doi.org /10.1080/00140139.2024.2427859

Fernandes, A. & Braarud, P. Ø., 2015. Exploring measures of workload, situation awareness, and task performance in the Main Control Room. 6th International Conference on Applied Human Factors and Ergonomics (AHFE 2015) and the Affiliated Conferences, AHFE 2015. Available at: https://doi.org/10.1016/j.promfg.2015.07.273

Field, A., 2013. Discovering Statistics Using IBM SPSS Statistics. 4th ed. s.l.: Sage Publications.

Flanagan , K. & Saikia, M. J., 2023. Consumer-Grade Electroencephalogram and Functional Near-Infrared Spectroscopy Neurofeedback Technologies for Mental Health and Wellbeing. Sensors (Basel). Available at: https://doi.org/10.3390/s23208482

Grundmann, R., Hochgeschurz, S., Hohnrath, P. & Ujkani, A., 2021. Increasing Maritime Situational Awareness by Augmented Reality Solutions, Hamburg: Fraunhofer Center for Maritime Logistics and Services CML.

Han, C., Abeysiriwardhane, A., Islam, R. & Chai, S., 2024. Situation awareness for engine room monitoring at future shore control centre. Australian Journal of Maritime & Ocean Affairs. Available at: https://doi.org/10.1080/18366503.2024.2340168

Kästle, J. L., Anvari, B., Krol, J. & Wurdemann, H. A., 2021. Correlation between Situational Awareness and EEG signals. Neurocomputing. Available at: https://doi.org/10.1016/j.neucom.2020.12.026, Volume 432, pp. 70-79.

LIU, Y. et al., 2017. Human Factors Evaluation in Maritime Virtual Simulators using Mobile EEG – based Neuroimaging. Transdisciplinary Engineering: A Paradigm Shift. Available at: https://doi.org/10.3233/978-1-61499-779-5-261 URL: https://ebooks.iospress.nl/pdf/doi/10.3233/978-1-61499-779-5-261

Li, X. et al., 2024. Recognizing the situation awareness of forklift operators based on EEG techniques in a field experiment. Neurosci. Available at: https://doi.org/10.3389/fnins.2024.1323190

Munir, A., Aved, A. & Blasch, E., 2022. Situational Awareness: Techniques, Challenges, and Prospects. AI. Available at: https://doi.org/10.3390/ai3010005

Neeuro, 2025. Product Features – SenzeBand | Neeuro. [Online], available at: https://www.neeuro.com/senzeband/product-features

Nguyen, T. et al., 2019. A Review of Situation Awareness Assessment Approaches in Aviation Environments. IEEE SYSTEMS JOURNAL. Available at: https://doi.org/10.1109/JSYST.2019.2918283

Ronca, V. et al., 2023. Neurophysiological Assessment of An Innovative Maritime Safety System in Terms of Ship Operators' Mental Workload, Stress, and Attention in the Full Mission Bridge Simulator. Brain Sci. Available at: https://doi.org/10.3390/brainsci13091319

Sahoo, P., Bain, A. & Biondi, F., 2024. Investigating the interplay between cognitive workload and situation awareness during full driving automation. Theoretical Issues in Ergonomics Science. Available at: https://doi.org/10.1080/1463922X.2024.2446851

Taç, U. & Tavacıoğlu, L., 2019. Subjective Evaluation of Seafarers' Situational Awareness on Collision Avoidance. Available at: https://doi.org/10.17485/ijst/2019/v12i5/141402

Taylor, R., 1989. Situational Awareness Rating Technique (Sart): The Development of a Tool for Aircrew Systems Design. Copenhagen, Denmark: eBook ISBN 9781315087924.

Yauri, J., HernandezERNÁNDEZ-SABATÉ, A., FOLCH, P. & GIL, D., 2021. Mental Workload Detection Based on EEG Analysis. Artificial Intelligence Research and Development. Available at: https://doi.org/10.3233/FAIA210144