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Neuroscience Approach to Situational Awareness: A Research on Marine Navigation

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Abstract

This study investigates the cognitive levels of tugboat captains, key players during port manoeuvres, which are a crucial part of sea navigation. The objective is to reveal the main neurophysiological findings related to the measurements of the tugboat captains' brain activity during both rest and actual manoeuvring performance and to investigate the relationship between this brain activity and situational awareness. The study employed an experimental research method. Brain waves of the tugboat captains were recorded using the Emotiv X EEG device and the Emotiv Pro v2.0 program during real port manoeuvres which is a part of the sea navigation. Situational awareness levels were tried to be determined by analysing the obtained values in the Brain Products Vision Analyzer 2.1 software. The study examined the cognitive states of four tugboat captains during 16 manoeuvres and resting, focusing on the Fast Fourier Transform (FFT)/Band power graph values. Within the scope of the research non-parametric Friedman Test with five variables [Resting State (RS), 1st Manoeuvre Group, 2nd Manoeuvre Group, 3rd Manoeuvre Group, and 4th Manoeuvre Group] to analyse the FFT values of the participants. Post-hoc comparisons were calculated using Bonferroni correction. The results showed no difference in alpha wave power, while delta, theta, beta, and gamma power decreased. The primary outcome of the research indicates that professional tugboat captains, who were the participants of the study, exhibited consistent situational awareness levels both during manoeuvring and resting moments.

Keywords: Situational awareness, EEG, Tugboat captains, Fast Fourier Transform, FFT, Sea navigation

1. Introduction

Sea navigation involves ships traveling from one point to another around the world. Ship handling or maneuvering is crucial for managing the forces that affect the ship's movement [1]. In this study, tugboats were selected as the representative ship type, and tugboat captains were chosen as the navigators. Tugboats with towing and pulling capabilities are provided for manoeuvring support during the processes of docking and undocking in ports for ships that are considered to be insufficient or at risk of posing a risk to themselves, other vessels, port and coastal facilities, and the environment if they were to maneuver on their own [2]. During the provision of this service, tugboat captains comply with the instructions of the pilot captain on board the ship. Pilotage and towage services provided within the scope of technical navigation services are interconnected services [3].

Among the various factors contributing to maritime accidents, the human factor is considered the primary cause. Human factors in the maritime industry include mental workload, emotion, attention, pressure, and fatigue [4]. Safety investigations by the European Maritime Safety Agency [5] from 2014 to 2020 revealed that human factors played a role in 75% to 96% of incidents and accidents. Even with the latest technological advancements in marine vessels, it is essential to have qualified ship users (ship's master, maritime pilot, officer on watch or tugboat captains) who can operate them safely. Ship captains

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must consider various ship and weather conditions, make accurate and timely decisions, and have contingency plans for emergencies. Furthermore, as per Rightship's article in 2023 [6], half of the vessel incidents occurred within port limits. Ship maneuvering within port limits for berthing and unberthing is a very critical stage of ship navigation, where many external factors, variables, and much more data flow are involved for situational awareness. Therefore, a very crucial part of navigation is ship maneuvers in ports, and tugboat captains are one of the key players.

Situational awareness (SA) originated in the aviation industry and refers to being aware of what is happening around and understanding the meaning of information in the present and future. Endsley [7] developed a widely used approach to define situational awareness on three levels: perception, comprehension, and projection. Effective situational awareness is measured by making correct decisions and taking appropriate actions. The cognitive state of individuals is directly related to the components of situational awareness, such as mental workload, attention, stress, information processing, and memory [8]. There are significant similarities between workload and situational awareness. Both constructs are distinct from behavior and performance and can be measured using physiology, performance and subjective assessments combined with task analysis and computational modeling [9]. Mental workload is an influencing factor in human performance, and it is a non-independent variable in measuring human factors in the maritime industry [4].

Electroencephalography (EEG) is a widely used medical instrument for measuring the brain activity based on sensor voltage fluctuations. Early studies have demonstrated that the level of mental workload under different task complexities and difficulty levels can be classified into distinct classes by analyzing the temporal variation of the EEG Power Spectral Density (PSD) or the time-frequency characteristics of EEG time series data [9]. With the development of technology and the availability of physiological data collection equipment, EEG has found applications in various fields and environments. EEG is a non-invasive technique that records signals from the brain using electrodes placed on the scalp [10]. The use of EEG to measure the brain activity offers several advantages, including high temporal resolution and ease of application. EEG devices are equipped with software that enables the measurement of human brain activities. Consequently, there is growing interest in exploring human factors through the analysis of physiological data [11].

Researchers have used EEG in multidisciplinary studies, employing machine learning technology and signal processing. Its use has expanded beyond medicine into various disciplines, as shown in Table 1. In transportation, EEG has been used to measure driver behavior and investigate arousal changes during conflict detection and adjustment processes.

For instance, in the domain of land transportation, Abut et al. [12] employed different data collection tools along with EEG to measure driver behavior. Johnson et al. [13] investigated the impact of arousal changes on conflict detection and conflict adjustment processes during normal arousal fluctuations in behavioral and informatics. In the maritime industry, studying the physiological behavior of crew members has become crucial in identifying the primary causes of human errors and the direct factors contributing to accidents [4,14].

Table 1. *Literature review with the EEG device*

Authors	The field of Study	Research focus	Method
Tong et al. [15] 2017	Medical	Cognitive	EEG-HRV
Loris et al. [16] 2017	Medical	Cognitive	ECoG and EEG-DABS
Başar et al. [17] 2018	Medical	Cognitive	EEG, ANOVA test
Tsekoura and Foka [18] 2020	Medical	Brain-computer interface	EEG- EEGLAB toolbox
Johnson et al. [13] 2020	Medical	Cognitive	EEG - Behavioural Data Analysis
Çelik et al. [19] 2021	Medical	Cognitive	EEG-SCL-90
Mheich et al. [20] 2021	Medical	Cognitive	EEGLAB
Koctúrová and Juhár [21] 2021	Medical	Cognitive	Open BCI- EEG
Yakobi et al. [22] 2021	Human Factors	Cognitive	EEG- Go/No-Go Task
Wal et al. [23] 2020	Human Factors	Behavioural	EEG task and behavioral performance
Kirschner et al. [24] 2020	Human Factors	Cognitive/Behavioural	EEG-PES, PERI
Kaur et al. [25] 2020	Human Factors	Cognitive	EEG, fMRI, SA Index, PRAA, and PRAFA
Ma et al. [26] 2021	Human Factors	Cognitive	EEG-SVM-LTSM

Table 1. Continued			
Jin et al. [27] 2021	Human Factors	Cognitive	Temperaments Inventory
Nann et al. [28] 2021	Human Factors	Brain-computer interface	EEG-EOG-HOV
Berka et al. [29] 2006	Military	Cognitive	EEG/Naval Command Task simulation
Schnell et al. [30] 2008	Aviation	Cognitive	EEG-Cognitive Avionics Tool Set (CATS)
Borghini et al. [31] 2014	Aviation and Transportation	Cognitive	EEG, EOG, and HR data
Galant and Merkisz [32] 2017	Aviation	Cognitive	EEG; simulator-NASA TLX and SWAT
Trapsilawati et al. [33] 2019	Aviation	Cognitive	AT-SAT Test, EEG
Flumeri et al. [34] 2019	Aviation		EEG-eye tracking-Asa TLX
Klaproth et al. [35] 2020	Aviation	Cognitive	ACTR, EEG
Polat and Özerdem [36] 2016	Computer Engineering	Brain-computer interface	EEG- Power Spectral Density
Sözer and Fidan [37] 2019	Computer Engineering	Brain-computer interface	Brain-computer interface-EEG
Alakuş and Türkoğlu [38] 2018	Computer Engineering	Brain-computer interface	EEG-IAPS
Iqbal et al. [39] 2020	Computer and Chemical Engineering	Cognitive	EEG-Theta power spectral density
Ackermann et al. [40] 2016	Mechanical Engineering	Cognitive	EEG-DAEP
Kaya et al. [41] 2017	Machine Learning	Brain-computer interface	EEG-BCI Model
Yin and Zhang [11] 2014	Automation	Cognitive	Mental Workload Calculation -EEG
Roy et al. [42] 2021	Multidiscipliner	Cognitive	EEG-CPCA-MATLAB
Abut et al. [12] 2009	Transportation	Cognitive	EEG, CAN, Bus, IVMC Tool-eye tracking-laser sensor-pedal sensor
Xiaolil et al. [43] 2009	Transportation	Cognitive	EEG-PVT
Kim et al. [44] 2014	Transportation	Cognitive	EEG-WMS
He et al. [45] 2016	Transportation	Behavioural	EEG, head nodding angle, eye-tracking signal-Driving Model
Lee and Yang [46] 2019	Automotive Technology	Cognitive	EEG power spectrum analysis
Hu et al. [47] 2019	Transportation	Cognitive	EEG multichannel analysis
Siddharth and Trivedi [48] 2020	Transportation	Cognitive	EEG, PPG, GSR
Fu et al. [49] 2020	Transportation	Cognitive	EEG Scaling Analysis
Şahan [50] 2016	Business	Cognitive	EEG-Eye tracking-SPSS
Şeker [51] 2017	Cognitive Science	Cognitive	EEG-WEKA
Kısacık [52] 2018	Multidiscipliner	Cognitive	EEG-DEHB
Çetin [53] 2020	Artificial intelligence	Cognitive	EEG- Wavelet Package Transformation
Saymaz [54] 2020	Medical	Cognitive	EEG discrete wavelet transforms
Liu et al. [55] 2016	Sea Navigation	Cognitive	EEG-SVM
Fan et al. [4] 2017	Sea Navigation	Cognitive	EEG-NIFS
Fan et al. [56] 2017	Sea Navigation	Cognitive	EEG-SVM
Wu et al. [57] 2018	Sea navigation	Cognitive	EEG-NASA -TLX
Orlandi and Brooks [58] 2018	Ship Handling	Cognitive	EEG, ECG, and Simulation
Liu et al. [59] 2020	Sea Navigation	Cognitive	EEG-SVM
Taç [60] 2012	Sea Navigation	Cognitive	EEG-ANAM4
Yılmaz [61] 2012	Sea Navigation	Cognitive	EEG: Simulator sleep scoring criteria
Taç [62] 2018	Sea Navigation	Cognitive	EEG-CBT-GTDA-NASA TLX

Borghini et al. [31] conducted a literature review on neurophysiological measurements of pilots and automobile drivers, associating certain aspects of brain activity with concepts such as mental workload, mental fatigue, and situational awareness. They found that the accuracy of detecting the mental states of drivers and pilots using neurophysiological signals such as EEG, electrooculography (EOG), and heart rate (HR) approaches 90%. Schnell et al. [30] employed a neurocognitive assessment system called the Cognitive Avionics Toolkit (CATS) in aviation to assess pilot workload before flight using physiological and neurocognitive markers, rather than conducting an actual flight. Other studies have also investigated the potential use of EEG in evaluating the psychophysical condition of pilots and air traffic controllers (ATCo) [32]. Trapsilawati et al. [33] examined the stress levels and brain activity of ATCo operators during conflict resolution, whereas Flumeri et al. [34] studied the human-machine interface and alertness levels of ATCo operators in the context of a highly automated system. The latter proposed a system called the "Vigilance and Attention Controller" that combined EEG and eye tracking techniques.

In the maritime domain, Wu et al. [57] explored the relationship between heart rate and EEG values during maritime operation tasks conducted by maritime students in a simulation environment. Liu et al. [55] developed an EEG-based psychophysiological assessment system for monitoring, training, and assessing seafarers in marine simulators. They used raw EEG data to identify different brain states, including cognitive workload and stress, and provided recommendations based on EEG-based cognitive workload and stress recognition. Taç [60] conducted research on seafarers' cognition and its impact on operational processes, considering factors such as fatigue-drowsiness, noise, and thermal strain. Using EEG devices, Taç observed that fatigue increased, especially during the last quarter of a shift, and that cognitive performance was negatively affected by heat and noise [60]. Yılmaz [61] examined the sleep and fatigue conditions of watchkeeping officers during working and resting hours on a short sea voyage, analyzing EEG data within scenarios prepared in a simulator system. The study revealed that mistakes could occur during navigational shifts due to intense work, unrelated to lack of information, or extraordinary situations. Furthermore, Taç [62] conducted human factor research in the maritime field, finding statistically significant differences in cognitive abilities between ship captains and watch officers through Computer-Based Training (CBT). Proficiency was inversely related to situational awareness levels, and self-evaluation of situational awareness did not significantly correlate with performance.

While previous studies on simulator systems have focused on scenarios, this study aims to investigate the main neurophysiological findings related to measurements of tugboat captains' brain activity during both resting moments and actual navigation performance.

2. Model

The flow model is shown in Figure 1 below the article.

3. Methods

3.1. Electroencephalography and Fast Fourier Transform

In this section, the materials and methods used in this study are described. The brain wave data of the tugboat captains were recorded using an EEG device called Emotiv X and the compatible software Emotiv Pro v2.0. The EEG device was used during real sea navigation, employing an experimental research method. Fourteen standard electrode placements on the scalp, following the international 10-20 system, were used to obtain brain wave data. These electrodes were used to measure the electrical activity of the brain at specific locations. According to the FFT

Fast Fourier Transform/Band power graph values were examined in four maneuvers and compared with the resting and on-duty situations of four tugboat captains. Figure 1 shows the FFT value graph taken at the moment of maneuver by a tugboat captain participating in the research.

FFT was employed to process the brain wave data. FFT is a signal processing technique that converts the information contained in a signal into a usable data format. It decomposes a signal into its frequency components, expressing it as the sum of the cosine and sine fundamental components with different amplitudes, frequencies, and phases [63] (Figure 2).

Alpha waves (8-13 Hz) are commonly observed in awake individuals when they are relaxed or with their eyes closed. They are often detected in the occipital region of the brain and are associated with a state of relaxation or idleness. Alpha waves can be spontaneously generated when there is no specific mental activity. The mu rhythm, a type of alpha wave, is relevant in Brain-Computer Interface (BCI) applications and can be observed in sensorimotor areas. It decreases or disappears when the individual performs or imagines movement. The changes in the alpha activity have been observed during working memory retention, indicating its involvement in cognitive processes [58,64].

Beta waves (13-30 Hz) are typically found in the parietal and frontal lobes of individuals who are awake and actively concentrating. The enhanced beta wave activity is associated with activities such as focused attention, problem-solving, and deep concentration [24]. It can be observed in the anterior and central areas of the brain during such tasks. Studies have reported increased beta band strength in the occipital regions during spatial discrimination tasks and visual attention [11,64].

Delta waves have a frequency range of 0.5-4 Hz and are predominantly observed during slow-wave sleep in infants and adults. These are high-amplitude brain waves associated with deep sleep stages. However, delta waves are not limited

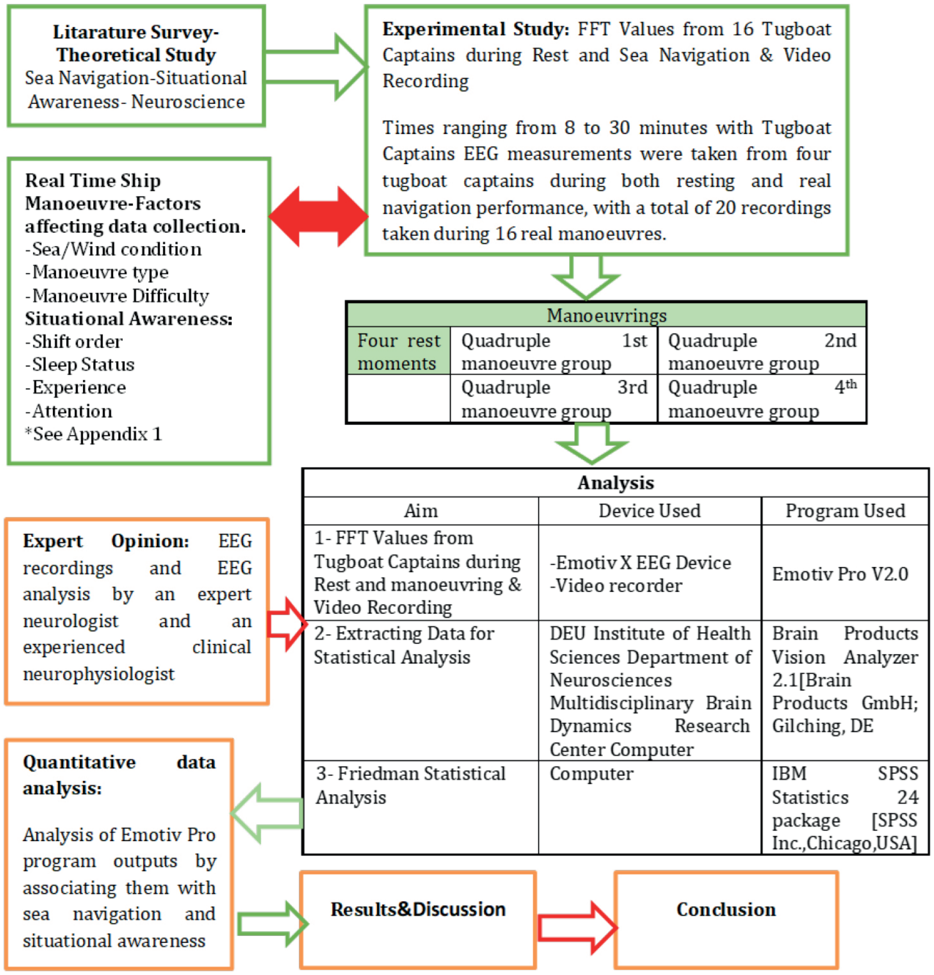

Figure 1. *Model*

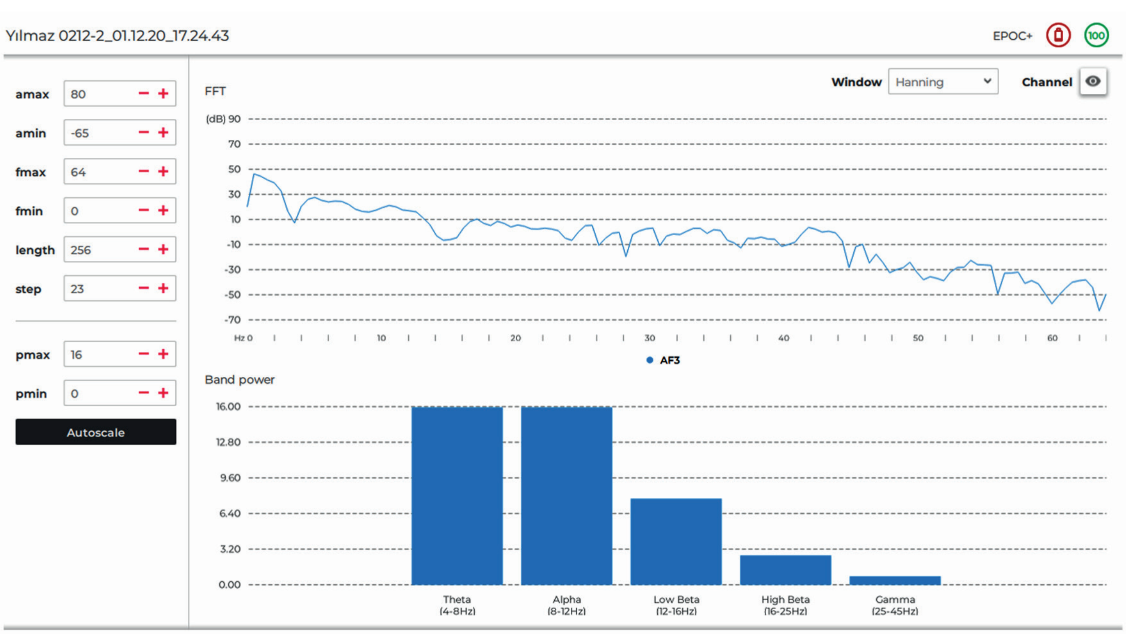

Figure 2. *Fourier transform sample chart*

to sleep and can also be detected in awake individuals. High frontal delta waves during wakefulness are associated with plasticity and cognitive processing [64].

Theta waves (4-8 Hz) are often associated with drowsiness or idleness in both children and adults. They have been linked to short-term memory and have been identified as a reliable measure of mental workload. Theta wave activity is observed in a drowsy state and is more common in children [11]. In adults, high theta activity without any attention or cognitive activity is considered abnormal and may be associated with certain brain disorders. However, theta activity is critical to attention processing and working memory [64].

Gamma waves have a frequency range of 30-100 Hz or higher and are commonly observed during tasks involving short-term memory and multisensory integration. Fast oscillations typically associated with conscious perception. Gamma activity is involved in attention, working memory, and long-term memory processes. While gamma waves have received less attention than other brain waves, recent studies have reported their relevance in motor tasks and their use in BCIs [9]. High gamma activity at temporal locations is associated with memory processes [64].

3.2. Experiment, Data Collection and Limitations

In this experimental study, data were collected from tugboat captains who worked shifts at the TCDD Izmir Port. These captains assist in the berthing and departure operations of ships at the port. The tugboat captains had an average age of 45 years and an average professional experience of 22 years. Their education levels varied, with two having vocational high school degrees, one with a college degree, and one with a bachelor's degree.

The tugboat captains worked according to a 6-day on (work) and 7-day off (rest) system, operating 24 h a day to accommodate ship traffic at İzmir Port. The experiment focused on real-time sea navigation, capturing brain wave data during the captains' duties. During data collection, moments of blinking and data contamination with artifacts were not considered for evaluation. One limitation of the study is the small number of participants, which is attributed to the difficulty in accessing and obtaining voluntary participation from tugboat captains involved in operationally critical ship maneuvers However, the similarity in gender and age among the participating captains contributes to the relative homogeneity of the research sample. In addition, the study benefits from optimal conditions for using a mobile EEG device during real-time sea navigation. The small sample size and specific context of the study may limit the generalizability of the findings (Figure 3).

Figure 3. *The view of a ship 's captain with an EEG device connected while sailing*

In the experiment, various data related to navigational conditions and situational awareness were collected from the tugboat captains. EEG measurements were taken from four tugboat captains during both resting and real navigation performance, with four tugboat captains, a total of 20 recordings taken during 16 real maneuvers The dataset in Appendix 1 includes the following information:

Navigational Data:

- Name of the tugboat
- The type of navigation
- Sea and meteorological conditions
- The type of ship involved in manoeuvre
- The duration of navigation.

Situational Awareness Data:

- Date and time of the experiment
- Age of the captain
- Shift order of the captain
- Sleep status of the captain.

Initially, EEG measurements were taken from the tugboat captains while the tugboat was not navigating. This was done in a quiet environment on the bridge when the tugboat's main engines were not in operation.

Subsequently, the captains of the tugboats, operating in a sequential system based on the İzmir Port traffic, underwent EEG data collection during maneuvers Each maneuver lasted between 3 and 30 min, and simultaneous video recordings were made.

During the maneuvers, the FFT/Band power graph values were recorded. The tugboats, stationed at a specific location in the port, would depart from their position for each maneuver and navigate to the side of the ship with which they were assisting. The captains then await orders from the maritime pilot responsible for the maneuver either delivering their rope from the bow or stern. According to the captains' statements, all recordings were taken after a minimum of 7 h of sleep.

The following conditions were considered when collecting data from the tugboat captains during real ship maneuvers:

- Ship maneuvers were a part of the sea voyage and were based on the course of the tugboats assisting ships approaching or departing from the port. The berth where the assisted ship would dock or depart from, and the type of vessel involved in the maneuver were also recorded.
- Tugboats and tugboat captains were selected as the sample because of their lower risk to maritime safety and the practical feasibility of the study.
- Although the characteristics of the tugboat were disregarded, the size of the maneuverer ship was considered during the situational awareness stage.
- Weather conditions, including wind strength and direction, sea conditions, current (knots), and visibility (miles), were noted. Local traffic, emergency situations, and accident probabilities were carefully observed during the study.
- Demographic information, such as the age, professional experience, and education status of the tugboat captain, as well as their sleep status (number of hours slept before the experiment) and the day of their current shift, were recorded.
- Because a mobile EEG device was used, the recorded values during the maneuver may have been influenced by other navigational devices present on the ship's bridge.
- The second half of the experimental study was conducted under COVID-19 conditions.

3.3. EEG Analysis

Offline analyzes were performed using Brain Products Vision Analyzer 2.1 [Brain Products GmbH; Gilching, Germany] by Dokuz Eylül University Institute of Health Sciences Department of Neuroscience Multidisciplinary Brain Dynamics Research Centre Specialist (4th author Dilara Mermi Dibek). The sampling rate of continuous EEG recordings was resampled to 256 Hz. Independent Component Analysis [ICA] with classical sphering and infomax algorithm was applied to data to eliminate artifacts. The EEG was filtered with a 0.3 low pass and 50 Hz Notch filter and a 12 dB/octave slope, and then segmented into 2000 ms epochs. Artefacts were manually eliminated following visual inspection. A minimum of 70 epochs were included in the analysis.

FFT was applied to all artefact-free epochs using maximum resolution power, Hanning window function, and non-complex output on the half spectrum with a resolution of 0.5 Hz. The peak power for each frequency (delta: 0.5-3.5 Hz, theta: 4-7.5 Hz, alpha: 8-12.5 Hz, beta: 15-30 Hz, gamma: 30-47.5 Hz) was calculated. The 14 electrodes were grouped as frontal (AF3, AF4, F3, F4, F8, FC5, FC6), temporal (T7, T8), parietal (P7, P8), and occipital (O1, O2).

4. Statistical Analysis

Data were statistically analyzed using IBM SPSS Statistics 24 package (SPSS Inc., Chicago, USA). Because our data did not meet the criteria for parametric analysis, the non-parametric Friedman Test with within-subject design 5 level variable [Resting State (RS), Maneuver-1, Maneuver-2, Maneuver-3, Maneuver-4, and Maneuver-5] was used. Post-hoc comparisons were calculated using the Bonferroni correction.

The Friedman test is a statistical analysis technique used to make meaningful comparisons between dependent groups in cases where the assumption of normality is not provided [65,66]. Citing Daniel (1990) [66] asymptotic efficiency of the Friedman test statistic, it is 0.955k/ (k+1) if the main mass is normally distributed, k/ (k+1) if the main mass is evenly distributed, and 3k/2 (k+1) if the main mass is double exponentially distributed.

5. Results and Discussion

Situational awareness is an important cognitive ability for a ship captain in sea navigation [67]. It is essential for ship captains to perceive what is happening around them, to understand them in line with their target, and to make decisions by interpreting this information effectively, primarily for environmental safety and for life and environment safety. In conclusion, this experimental study aimed to investigate the relationship between the resting moments of tugboat captains and their neurophysiological brain activity during real sea navigation, focusing on situational awareness. EEG measurements were taken from four tugboat captains during both resting and real navigation performance, with 20 recordings taken during 16 real maneuvers.

The findings of the statistical values obtained from the participants because of the FFT analysis within the scope of the experiment are given below.

Delta wave power: A non-parametric Friedman test produced a significant difference in temporal delta power between Maneuver-4 and the resting state [X2=11.00, p=0.027], showing that the temporal delta power decreased during Maneuver-4 [MR=1.75] compared with the resting state [MR=5.00] [p=0.037].

Theta wave power: The Friedman test showed a significant difference in temporal theta power [X2=9.60, p=0.048] between Maneuver-3 [MR=1.50] and resting state [MR=4.75], indicating that theta power decreased during Maneuver-3 compared with the resting state.

Alpha wave power: The Friedman test showed a significant difference in temporal alpha power [X2=11.60, p=0.021], but post-hoc comparisons showed no significant difference between conditions.

Beta wave power: A non-parametric Friedman test revealed a significant difference in frontal beta power between Maneuver-3 and resting state [X2=11.80, p=0.019], and showed reduced frontal beta power during Maneuver-3 [MR=1.25] compared to rest [MR=5.00] [p=0.003].

Gamma wave power: The Friedman test showed significant differences in the frontal gamma [X2=10.40, p=0.034] and parietal gamma power [X2=9.80, p=0.044]. Both show decreased gamma powers during Maneuver-3 [MR=1.25, MR=1.75, respectively] compared with the resting state [MR=4.75, MR=5.00, respectively] [p=0.017, p=0.037, respectively].

The analysis of the EEG data revealed interesting findings. There was a decrease in theta power and frontal beta power during the third maneuver indicating increased attention and perception. This maneuver seemed to involve higher alertness and attention levels than the other maneuvers previous studies (Kastle et al. [14]; Borghini et al. [31]; Deolindo et al. [67]) have also shown that an increase in theta power and changes in the alpha band are associated with decreased vigilance, whereas an increase in beta power indicates decreased alertness and arousal [68].

Enhanced beta waves were observed in the frontal and central lobes of the brain during activity, anxious thinking, problem-solving, and deep concentration. Gamma activity is involved in attention, working memory, and long-term memory processes [64]. The differences observed in the third maneuver may be attributed to the timing of the maneuvers with two conducted at night and one conducted in the early morning or evening. This suggests that maneuvers may be performed more comfortably during the daytime, and the use of "working memory" may be higher during dark or near-dark times.

During the fourth maneuver which involved berthing larger ships close to the end of the shift, higher mental workload was observed compared with the other maneuvers However, there was no remarkable change in the alpha frequency throughout all four maneuvers indicating that the maneuvers did not significantly affect the situational awareness of the ship captains.

The study did not find a difference in situational awareness and attention based on professional experience, shift order, or insomnia among the registered tugboat captains. Thus, Endsley's [7] "Situational Awareness Dynamic Decision-Making Model during perception, comprehension, and projection revealed no difference between maneuvering and non-maneuvering moments. This shows that these factors may not significantly impact situational awareness.

6. Conclusion

The key finding of the research suggests that professional tugboat captains who participated in the study demonstrated consistent levels of situational awareness during both maneuvering and resting periods. This study contributes to the limited body of research relating to the cognitive sensory status and situational awareness of ship captains in the international maritime field (Liu et al. [55], Fan et al. [4], Orlandi and Brooks [58], Taç [60-62], Yılmaz [61]). The EEG analysis provides real-time feedback on cognitive processing, assisting ship captains in better understanding their environment and anticipating potential risks. By integrating EEG analysis with decision support systems and other technologies, it may be possible to develop more effective strategies to enhance situational awareness and improve safety in sea navigation. Overall, this study presents novel insights into the cognitive aspects of ship captains (tugboat captains) during real navigation using neuroscience methodologies and contributes to the existing literature on situational awareness in the maritime field.

In future research, the data collection process can be enhanced by increasing the number of participants. Moreover, diversifying the types of ships studied can provide valuable insights. Creating a data pool by examining the special operations of different ship types and their captains, such as ferry boats, fast ferries, passenger ships with higher passenger capacities, container ships with high maneuverability and tanker/chemical tanker ships carrying hazardous loads, can be included.

Additionally, investigating the situational awareness of watch officers involved in Bridge Resource Management (BRM) can offer a more comprehensive understanding of navigational decision-making. As the number of female seafarers in the maritime profession increases, studying female ship captains can provide insights into gender-based differences in situational awareness.

To enhance the effectiveness of the results, it would be beneficial to compare the physiological data acquired from ship masters with those of pilots manoeuvring various ships across different straits, channels, and ports worldwide, similar to what was conducted in this study. Such a comprehensive comparison could provide valuable insights into the cognitive processes of navigators in diverse maritime settings, leading to a broader understanding of situational awareness in sea navigation.

Although previous studies have often used simulator-based approaches, incorporating real-time data into new studies can yield novel findings. Examining navigation data collected during both day and night, in heavy weather and heavy traffic environments, can shed light on the impact of these factors on situational awareness. Moreover, exploring variations marine life and professional experiences can provide a valuable context for understanding situational awareness.

The neuroscience approach in sea navigation can significantly contribute to navigational science and unveil the underlying brain functions related to situational awareness. As a pioneering real-time study in this field, this research is anticipated to set an example for the maritime sector. It also holds the potential for comparison with similar studies conducted on seafarers from different nationalities, offering cross-cultural insights.

Furthermore, the predictions made by Southampton University 's technology department regarding the 2030 maritime trends [69], which encompass unmanned systems, artificial intelligence, sensors, situational awareness, connectivity, cybersecurity, energy management, and sustainability, are highly relevant. The remarkable relationship between situational awareness and artificial intelligence can be further explored using the data obtained from this study. Utilizing the extensive dataset, research techniques can be developed to enhance professional competence and the recruitment process of ship captains, pilots, and watch officers. Ultimately, this can lead to significant advancements in the maritime industry.

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Ethics and App Permissions

• An application was submitted to the DEU Faculty of Medicine Non-Invasive Research Ethics Committee. On 21/09/2020, after the board's correction request, the application was re-applied and finally "Ethics Committee Approval" was received on 28/09/2020 (approval no: 2020/23-23 and date: 28.09.2020).

• In this process, application permits were obtained from the General Directorate of Coastal Safety (16565290-929-E-.36761) dated 17.08.2020 and TCDD İzmir Port (51968 number-03.07.2020).

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Authorship Contributions

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Appendix 1. *Data Set*

				Navigation Datas								Situational Awareness Datas			
No	Date	Time	Captain	Tugboat	Navigation Type	Maneouver	Winf Force	Wave	Wind Direction	Wind direction	Air Temperature	Experiment Time	Age	Date of duty/Exp. day	Total Sleep
							Beaufort Scale		0-360 degree		Celcius	minutes-seconds	Year		Hour
1	17.09.2020	11:57	1	KIZKULESİ	#16 Departure	Container	3	2	32	35	27	08:02	41	6/1	8
2	17.09.2020	12:00	1	KIZKULESİ	#10 Departure	General Cargo	3	2	32	35	27	05:00	41	6/2	8
3	17.09.2020	12:27	1	KIZKULESİ	#5 Departure	General Cargo	3	2	32	35	27	10:13	41	6/3	8
4	17.09.2020	12:54	1	KIZKULESİ	#12 Departure	General Cargo	3	2	32	35	27	02:51	41	6/4	8
5	17.09.2020	15:06	1	KIZKULESİ	#12 Yanaşma	General Cargo	3	2	32	35	27	19:01	41	6/5	8
6	11.10.2020	15.53	1	KIZKULESİ	Resting	..	5	6	250	250	24	05:06	41	1/1	9
7	11.10.2020	13:49	2	KIZKULESİ	Resting	..	5	6	250	250	24	04:25	45	1/1	9
8	11.10.2020	14:10	2	KIZKULESİ	#13 Arrival	Container	5	6	250	250	24	20:00	45	1/1	9
9	11.10.2020	14:35	2	KIZKULESİ	#26 Arrival	Multi Purpose	5	6	250	250	24	30:53	45	1/1	9
10	11.10.2020	16:38	2	KIZKULESİ	#7 Departure	General Cargo	5	6	250	250	24	12:52	45	1/1	9
11	3.11.2020	17:19	3	GARP	#26 Departure	General Cargo	2	1	33	35	21	02:58	45	6/1	8
12	3.11.2020	17.40	3	GARP	Resting	..	2	1	33	35	21	04:00	45	6/1	8
13	4.11.2020	16:47	1	KIZKULESİ	#13 Departure	Container	2	4	40	30	19	22:17	41	5/4	5
14	4.11.2020	17:41	1	KIZKULESİ	#25 Arrival	Multi Purpose	2	4	40	30	19	35:39	41	5/4	5
15	5.11.2020	14:50	4	ZÜBEYDE ANA	#13 Arrival	Konteyner	4	5	38	35	20	14:40	40	7/3	8
16	5.11.2020	16:11	3	GARP	#12 Arrival	General Cargo	4	5	30	30	20	21:02	45	6/5	7
17	5.11.2020	17:54	3	GARP	#25 Arrival	Tanker	4	5	30	30	20	24:03	45	6/5	7
18	5.11.2020	18:57	3	GARP	#26 Arrival	Multi Purpose	4	5	30	30	20	12:17	45	6/5	7
19	5.11.2020	19:30	3	GARP	#8 Departure	Volgabalt	4	5	30	30	20	13:24	45	6/5	7
20	7.11.2020	14:50	2	KIZKULESİ	#14 Departure	Container	5	6	35	35	19	12:58	45	5/2	8
21	7.11.2020	16.14	2	KIZKULESİ	#7 Departure	General Cargo	5	6	35	35	19	07:08	45	5/2	8
22	7.11.2020	16:57	2	KIZKULESİ	#16 Departure	Container	5	6	35	35	19	05.51	45	5/2	8
23	7.11.2020	17.29	2	KIZKULESİ	#23 Departure	General Cargo	5	6	35	35	19	11:05	45	5/2	8
24	20.11.2020	14:28	3	GARP	Resting	..	3	2	35	35	16	01:18	45	6/2	5
25	20.11.2020	14:41	3	GARP	#12 Departure	General Cargo	3	2	35	35	16	13:12	45	6/2	5
26	20.11.2020	16:12	3	GARP	#12 Arrival	General Cargo	3	2	35	35	16	18:16	45	6/2	5
27	26.11.2020	08:18	2	KIZKULESİ	#16 Arrival	Container	3	4	30	30	9	06:06	45	6/3	7
28	26.11.2020	09:09	2	KIZKULESİ	#3 Arrival	Multi Purpose	3	4	30	30	9	19.40	45	6/3	7
29	1.12.2020	13:22	3	GARP	#26 Arrival	Tanker	3	4	35	35	16	17:23	45	8/2	6
30	1.12.2020	17.24	3	GARP	#12 Arrival	General Cargo	3	4	35	35	14	23:11	45	8/2	6
31	1.12.2020	18.19	3	GARP	#7 Departure	General Cargo	2	1	30	30	10	12:25	45	8/2	6
32	1.12.2020	19:35	3	GARP	#7 Arrival	General Cargo	2	1	30	30	10	21.24	45	8/2	6
33	2.12.2020	11:30	3	GARP	#10 Departure	General Cargo	2	1	40	40	8	08:38	45	8/3	7
34	2.12.2020	12:15	3	GARP	#25 Arrival	General Cargo	2	1	40	40	8	14:51	45	8/3	7
35	2.12.2020	12:59	3	GARP	#8 Departure	General Cargo	2	1	40	40	8	14:40	45	8/3	7
36	2.12.2020	13:58	3	GARP	#10 Arrival	General Cargo	2	1	40	40	8	21:21	45	8/3	7
37	7.12.2020	16:54	4	ZÜBEYDE ANA	Resting	..	3	3	25	25	17	01:18	40	5/3	4
38	7.12.2020	17:19	4	ZÜBEYDE ANA	#4-5 Arrival	Bulk Carrier	3	3	25	25	17	18:05	40	5/3	4
39	7.12.2020	18:25	3	GARP	#10 Arrival	General Cargo	3	3	25	25	17	15.29	45	7/7	7
40	10.12.2020	05:51	4	ZÜBEYDE ANA	#17 Arrival	Container	4	2	225	220	11	28:08	40	5/5	3
41	10.12.2020	06:54	4	ZÜBEYDE ANA	#16 Arrival	Container	4	2	225	220	11	26:54	40	5/5	3
42	10.12.2020	08:01	5	Kurtarma 1	#13 Arrival	Container	4	2	225	220	12	27:14	42	5/4	0