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An assessment of situational awareness in sea navigation with a neuroscience approach

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Abstract

Sea navigation of a ship consists of sub-elements such as open sea navigation, inland water navigation, strait-channel passage, port approach and port manoeuvres. Navigational safety is very important for the ship, the cargo carried by the ship and the safety of the environment. The question of whether the human factor and performance in safety is primarily bodily or perceptual has become an increasingly important research topic in the relevant literature in recent years. Accuracy and timing in nautical decision-making directly change the entire operation. This study aims to explore the main neurophysiological findings related to the measurements of electroencephalography (EEG) and how particular aspects of this brain activity could be connected with the important concepts of 'situational awareness'. For this purpose, a systematic literature search was conducted on 'EEG'. As a result, it has been established that EEG measurement is applicable for situational awareness assessment in sea navigation.

Keywords: EEG, marine, navigation, neuroscience;

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1. Introduction

Although seamanship is one of the oldest fields in world history, it has developed and changed with many factors such as exploration, trade, wars and transportation [1]. While the sea vehicles we use today are technologically equipped and have instant information flow about weather and sea conditions, life, property and environmental safety need to be used by a qualified ship user (ship's captain, pilot, officer on watch or navigator). Sea navigation, which is one of the main modes of transportation and the building block of maritime transport, is a dynamic operation and there are variable ship and environmental conditions that the ship user must consider in navigation.

Whether the performance of human beings is primarily bodily or perceptual has been the subject of research in recent years. However, with the control of more complex systems, the cognitive level of the person has gained importance [1]. In addition to professional knowledge and experience, being able to dominate the events, comprehending the conditions of the living environment and interpret the next step according to all these affects the professional and social life of the person. At the same time, accuracy and timing in decision-making in businesses that are based on decision-making by their nature directly affect safety.

1.1. Purpose of the study

In the recent relevant studies, situational awareness measurement is determined by methods developed over a scenario prepared in the simulator setting. This study aims to explore the main neurophysiological findings related to the measurements of EEG and how particular aspects of this brain activity could be connected with the important concepts of 'situational awareness'. This research answers the following questions: What is an important part of the elements affecting the cognitive level, which is one of the main factors of situational awareness?

2. Materials and methods

In the next sections, we will get to know what is 'sea navigation', 'the concept of situational awareness', 'making use of neuroscience in the assessment of situational awareness' and 'EEG'. The main outcomes are determined with a particularised literature review based on the word 'EEG' in the Web of Science (WOS) database. The results obtained from the literature review are evaluated and discussed.

3. Results

3.1. Sea navigation

The word navigation means 'going, movement, advancing, going from one place to another' [2]. As a nautical meaning, navigation means 'ships sailing by following a certain route' [3]. The origin of the word 'navigation' is the word 'navigere', which is a combination of the Latin words 'navis' (ship) and 'agere' (to steer) [4]. Navigation also means 'the science and art of managing the technique and administration necessary for the ship to be taken from one place to another' [5]. The purpose of navigational science is to study how to move a ship from one location to another in the shortest time and in the safest way and to determine the geographical position of the ship by using celestial bodies in the open sea and coastal structures on the coastline [6]–[8]. According to another definition, navigation is the science or art of planning, ascertaining and recording the course of a vessel or aircraft, including fixing the present and predicting the future location and collision avoidance [9]. Navigation, in light of the above definitions, is a science that deals with the methods of being able to transport a sea, air and land vehicle from one point to a desired point most shortly and safely, and in this process, determining the position of the vehicle on the ground, its speed and the route to be taken.

3.2. The concept of situational awareness

SA, generally speaking, is a cognitive state beginning with perception and ending with decision-making. It was first conceptualised in the military aviation domain for solving some applied problems like improving the performance of operators interacting with mission-critical systems [10]. SA is the situation of mind required to carry out decision-making activities. This situation consists of three steps [11]: perceiving the environmental elements, acquiring what these elements mean and projecting the status of these elements to the near future. Endsley's [11] threefold situational awareness is briefly defined as being aware of the information means at present and in the future. As can be seen in Figure 1, situational awareness is buried within a cognitive model in human activities through a dynamic system.

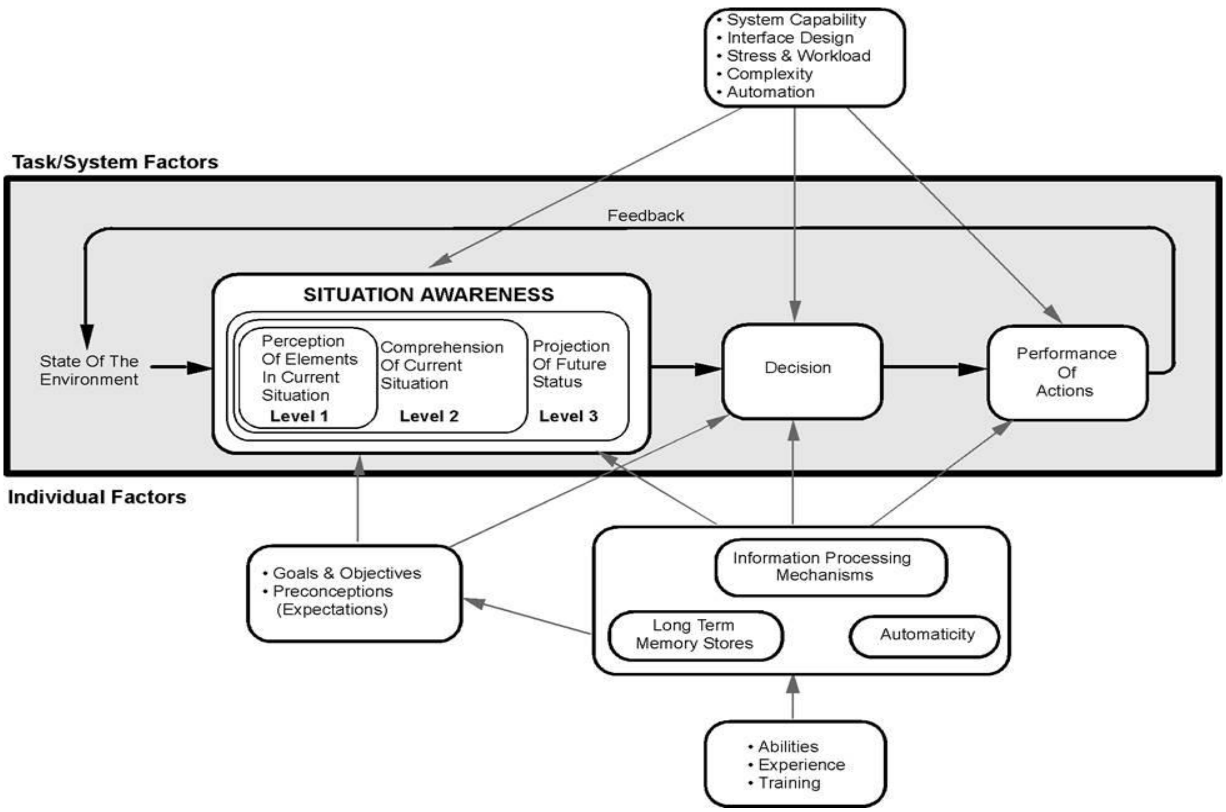

Figure 1. Model of SA in dynamic decision making [1]

Endsley states how it is affected by task factors and individual factors. Getting different results from two individuals is the result of different skills, experience and education received. The intersection we experience out present and what is likely to happen in the future is situational awareness. This awareness projects what part of the information is important for what we intend to do or what we aim at doing. Although situational awareness originates from aviation, it is of great importance in carrying out operational tasks and reaching the targets in such tasks [11].

In addition to professional knowledge and experience, the ability to command the events, perceive the conditions of the environment, predict the next step and act accordingly affects both the professional and special life of a person. Commanding a ship, no matter whether for a shipmaster or navigator, is based on decision-making. Timing and appropriateness of decision-making affect the ship as well as the environmental safety.

3.3. Making use of neuroscience in the assessment of situational awareness

With the development of technology and the increase in devices of different types to obtain data, neuroscience has entered all areas of life with the curiosity of revealing the complexity of the human brain structure. Neuroscience is a science based on the study of the nervous system [12]. The central and peripheral nervous system, brain, neuron, electrical potentials, synaptic connections, neurotransmitters, neural networks, nervous system development, sensory systems, motor control, learning, memory, language and cognition are some of the topics that neuroscience is interested in. Neuroscience, which deals with the nervous system from molecular, cellular, developmental, structural, functional, evolutionary, mathematical and medical aspects, is at the forefront of the disciplines in which we witness exciting developments.

Neuroscientists work in areas such as neurophysiology, neuroanatomy, neuropharmacology, behavioural neuroscience, developmental neuroscience, cognitive neuroscience, molecular neuroscience and neuroscience philosophy. Neuroscientists also research understanding the neural, genetic and molecular origins of neurological and psychiatric diseases and developing effective treatment methods. Neuroscience, which can traditionally be considered a branch of biology, has today gained an interdisciplinary identity in which medicine, biology, chemistry, mathematics, engineering, physics and psychology sciences work together [12] .

Cognitive abilities are the capacity to receive input to produce information from the external environment, interpret information and turn these results into action; cognition is the system formed by these capacities [13]. In other words, 'cognition' can be anything known or perceived. Cognitive abilities are encoded in memories and are largely dependent on previous experiences and can be defined as the process involving stimuli associated with learning.

Cognitive abilities mean the receiving of input to produce information from the outer environment and being able to interpret and transfer it to activity; on the other hand, consciousness is the system formed by these items. In other words, 'conscious' may be anything perceived. Cognitive abilities are coded in minds and are greatly dependent on previous experiences, and may be defined as the process which contains the stimuli related to learning. Cognitive abilities may be explained by relating them to four sub-abilities [13], [14]:

- The ability of the individual of learning;
- The ability of the individual's fast learning;
- The ability to adopt him/herself to the conditions that he/she is not used to;
- The ability to be able to use the data in the future.

Therefore, the environmental, psychological and physiological changes that may emerge during the exhibit of cognitive abilities will affect the cognition process.

Furthermore, when we look at the individual and task/system factors of the dynamic SA model (Figure 1) in detail, stress, workload, complexity, long-term memory stores, information processing, abilities, automaticity and abilities are determined.

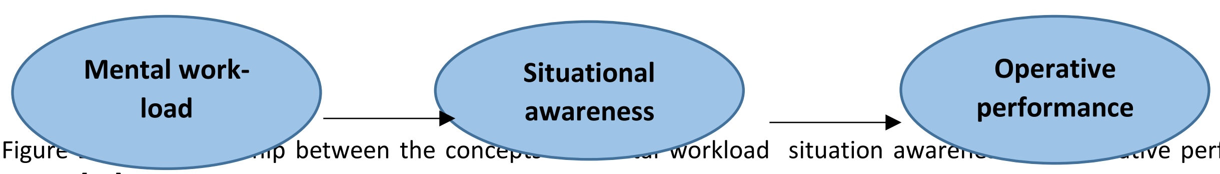

Figure ... ip between the concept... workload situation awarene... tive performance [15]

Being a precursor for performance, mental workload is an important measure of success. However, performance might be biased and subject to variations due to circumstances beyond an individual's control. There is a causal and logical relationship connecting mental workload with situation awareness and situation awareness with performance. An increase in mental workload (a more demanding task) leads to a decrease in situation awareness, which, in turn, leads to lower performance. The results are also an empirical justification for the use of the concept of situational awareness [15].

Neuroergonomics is the study of the behaviour of the human brain [15]. Its theories and principles are based on ergonomics, neuroscience and the extant literature on human beings. Neuroimaging studies use neuroimaging techniques to understand the structures, mechanisms and functions of the brain. Neuroimaging techniques are divided into two general categories: direct displays of neuronal activity in response to stimuli, such as electroencephalography (EEG) and positron emission tomography-computed tomography, and indirect metabolic indicators of neuronal activity, such as functional magnetic resonance imaging (fMRI), functional near-infrared spectroscopy and functional transcranial Doppler sonography. This review outlines the techniques and current applications of neuroergonomic methods used in mental workload and vigilance [15].

3.4. Electroencephalography (EEG)

Technology is central to the advancement of neuroscience, as we can judge from the unstoppable sophistication of data collection (imaging, multielectrode arrays, genomics, proteomics etc.), computer modelling and neural data processing. On the other hand, because neuroscience is still largely hypothesis-driven, neuroscience research has uncovered a huge amount of 'facts' about the multiscale brain system and progress keeps accelerating proportionally to the number of facts collected and quantified [17].

EEG, or electroencephalography, is a physiological method used to record all electrical activity produced by the encephalon (brain) through electrodes placed on the scalp surface. EEG measures the electrical activity generated by thousands of neurons to communicate with each other, and because it has an excellent temporal resolution, it allows the analysis of which areas of the brain are active at a given time.

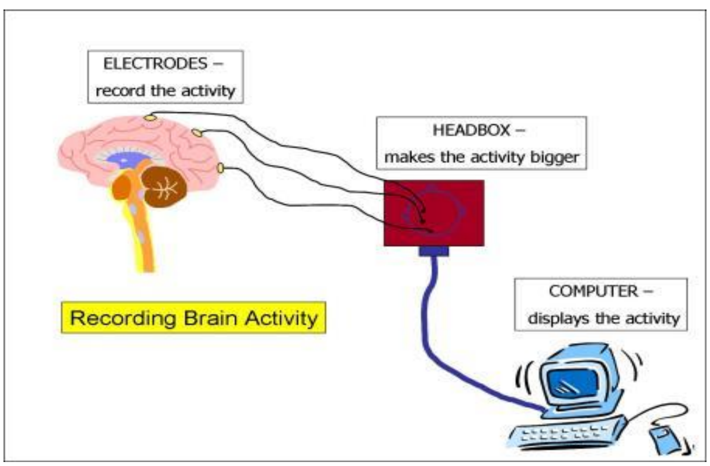

Figure 3. EEG device working principle [18]

Figure 4. EEG device photo [19]

As shown in Figure 3, an EEG test evaluates the electrical activity of the brain. EEG scans are performed by placing EEG sensors – small metal discs also called EEG electrodes – on the scalp. These electrodes pick up and record the electrical activity in our brain. The collected EEG signals are amplified, digitised and then sent to a computer or mobile device for storage and data processing. Figure 4 is an example of the portable EEG device.

Analysing EEG data is an exceptional way to study cognitive processes. It can help doctors establish a medical diagnosis; researchers understand the brain processes that underlie human behaviour; and individuals improve their productivity and wellness [20].

In Figure 5, the EEG device which is an EPOC X provides coverage of the frontal and prefrontal lobes; it also provides coverage of the temporal, parietal and occipital lobes. The image shows the sensor locations for EPOC X using the international 10–20 system. EPOC X has two electrode arms — each containing nine locations (7 sensors + 2 references). Two sensor locations (M1/M2) already have comfort pads fitted as they are the alternative reference positions (P3/P4).

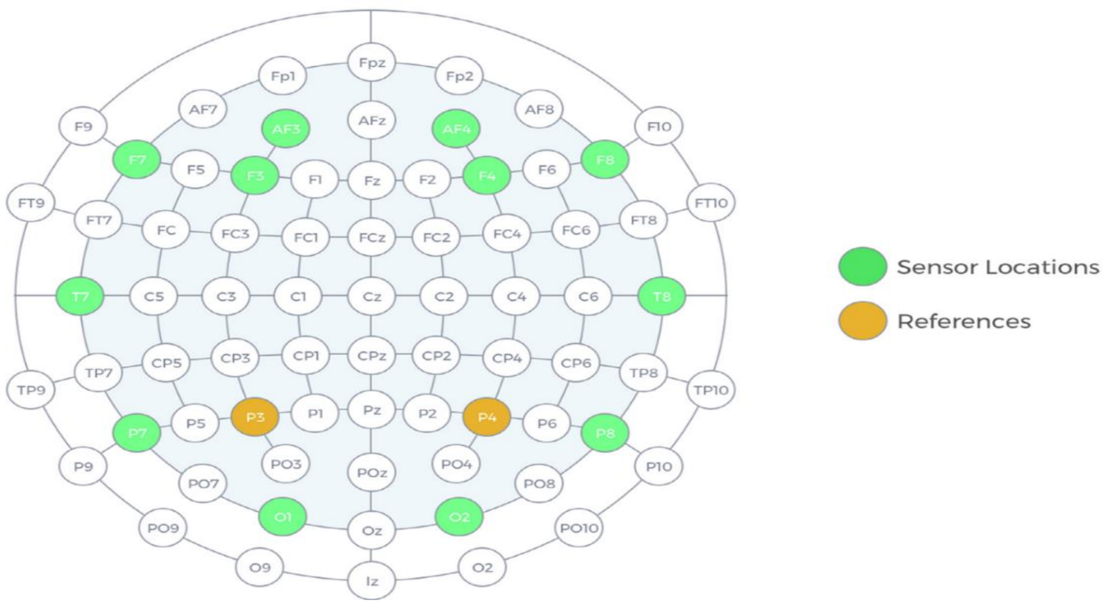

Figure 4. Points on the brain of the 14-channel Emotiv EPOC X device [20]

3.5. Literature review on EEG

In this section, a particularised literature review based on the word ‘EEG’ was examined in the WOSdatabase. The main outcomes are determined within the ‘EEG’ results and, secondly, the relevant outcomes have been explored using the words ‘situational awareness’ and ‘sea navigation’. Therefore, attention is drawn to important areas in Table 1. The time period between 1975 and 2020 was chosen as the data collection period, and articles and papers were included as document types. The literature research was conducted between the dates of 07/10/2019 and 30/06/2021.

A total of 15,969 articles and proceedings papers were examined in detail in the WOS research by searching the title of ‘EEG’. The fields of Neurosciences, Engineering Electric Electronic, Computer Sciences and Artificial Behavioural Sciences, Neuroimaging, Engineering Marine, Engineering Aerospace, Multidisciplinary Sciences, Automation Control Systems, Transportation, Engineering Multidisciplinary, Engineering Ocean and Transportation Science Technology were refined. Also, studies related to hospital, patient, disease, disability, epileptic and sleep apnoea were ignored.

In addition, while reaching a very high result in the field of neuroscience, the contents in the following fields were overlooked: Psychology Experimental, Psychology, Physiology, Clinical Neurology, Radiology Nuclear Medicine Medical Imaging, Psychiatry, Computer Science Theory Methods, Telecommunications, Pharmacology Pharmacy, Instruments Instrumentation, Biochemical Research Methods, Imaging Science Photographic Technology, Mathematical Computational Biology, Acoustics, Physics Applied, Chemistry Analytical, Linguistics, Medicine Research Experimental, Mathematics Interdisciplinary Applications, Optics, Endocrinology Metabolism, Applied Food Science Technology and Public Environmental Occupational Health.

Table 1. Studies on EEG obtained in the WOS database

WOS categories	Record count	%	WOS categories	Record count	%
Neurosciences	10,888	68.182	Robotics	85	0.532
Psychology Experimental	3,110	19.475	Optics	83	0.520
Psychology	3,048	19.087	Otorhinolaryngology	63	0.395
Engineering Electrical Electronic	2,961	18.542	Transportation	60	0.376
Clinical Neurology	2,580	16.156	Chemistry Multidisciplinary	58	0.363
Physiology	2,395	14.998	Psychology Multidisciplinary	58	0.363
Radiology Nuclear Medicine Medical Imaging	1,933	12.105	Ophthalmology	51	0.319
Neuroimaging	1,841	11.529	Cardiac Cardiovascular Systems	47	0.294
Computer Science Theory Methods	1,755	10.990	Haematology	45	0.282
Psychology Biological	1,727	10.815	Psychology Applied	43	0.269
Computer Science Artificial Intelligence	1,482	9.280	Public Environmental Occupational Health	41	0.257
Behavioural Sciences	1,376	8.617	Social Sciences Interdisciplinary	39	0.244
Telecommunications	1,101	6.895	Toxicology	38	0.238
Psychiatry	1,072	6.713	Anaesthesiology	37	0.232
Computer Science Information Systems	754	4.722	Anatomy Morphology	35	0.219
Instruments Instrumentation	585	3.663	Sport Sciences	33	0.207
Pharmacology Pharmacy	542	3.394	Biology	32	0.200
Biochemical Research Methods	459	2.874	Developmental Biology	31	0.194
Imaging Science Photographic Technology	449	2.812	Engineering Industrial	31	0.194
Mathematical Computational Biology	370	2.317	Engineering Civil	30	0.188
Engineering Biomedical	313	1.960	Psychology Clinical	30	0.188

Acoustics	304	1.904	Surgery	30	0.188
Computer Science Interdisciplinary App.	303	1.897	Mathematics Applied	29	0.182
Physics Applied	285	1.785	Nanoscience Nanotechnology	29	0.182
Chemistry Analytical	239	1.497	Mechanics	28	0.175
Engineering Multidisciplinary	239	1.497	Transportation Science Technology	28	0.175
Automation Control Systems	200	1.252	Food Science Technology	26	0.163
Computer Science Software Engineering	186	1.165	Remote Sensing	25	0.157
Audiology Speech Language Pathology	181	1.133	Medical Laboratory Technology	22	0.138
Multidisciplinary Sciences	180	1.127	Biochemistry Molecular Biology	21	0.132
Computer Science Hardware Architecture	174	1.090	Immunology	21	0.132
Linguistics	160	1.002	Medical Informatics	21	0.132
Medicine Research Experimental	146	0.914	Operations Research Management Science	21	0.132
Mathematics Interdisciplinary Applications	137	0.858	Paediatrics	20	0.125
Computer Science Cybernetics	108	0.676	Engineering Mechanical	19	0.119
Ergonomics	90	0.564	Critical Care Medicine	17	0.106
Psychology Developmental	90	0.564	Education Educational Research	17	0.106
Endocrinology Metabolism	86	0.539	Statistics Probability	15	0.094
Geriatrics Gerontology	86	0.539	Zoology	15	0.094
Materials Science Multidisciplinary	86	0.539	Physics Condensed Matter	14	0.088

Note: Indexes are SCI-EXPANDED, SSCI A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH and ESCI.

Engineering Mechanical, Cardiac Cardiovascular Systems, Geriatrics Gerontology, Psychology-Developmental, Otorhinolaryngology, Haematology, Critical Care Medicine, Ophthalmology, Psychology Toxicology, Anaesthesiology, Developmental Biology, Psychology-Clinical, Anatomy Morphology, Surgery, Biology, Engineering Civil, Mechanics, Medical Laboratory Technology, Paediatrics, Immunology, Statistics Probability, Physics Condensed Matter, Integrative Complementary Medicine, Psychology Educational, Gastroenterology Hepatology, Pathology, Geriatrics Gerontology, Materials Science Characterisation Testing, History Philosophy Of Science, Agriculture Dairy Animal Science, Economics, Veterinary Sciences, Healthcare Sciences Services, Orthopaedics, Physics Mathematical, Construction Building Technology, Electrochemistry, Peripheral Vascular Disease, Sociology, Information Science Library Science, Materials Science Biomaterials, Medicine General Internal, Thermodynamics, Emergency Medicine, Mineralogy, Physics Fluids Plasmas, Polymer Science, Urban Studies and Virology.

However, eight these were obtained in the 'Council of Higher Education Thesis Centre' by searching the title of 'EEG' (Table 2 – italics). There were 52 papers on the concept and dimensions of 'EEG', 9 of which were found to be on 'sea navigation' and 'ship manoeuvring' (Table 2 – bold).

Table 2. Related Studies on EEG obtained in the WOS database

	Authors	Field of study	Research focus	Method
1	Tong *et al*. [21]	Medical	Cognitive	EEG–HRV
2	Loris *et al*. [22]	Medical	Cognitive	ECoG and EEG–DABS
3	Başar *et al*. [23]	Medical	Cognitive	EEG, ANOVA test
4	Tsekoura and Foka [24]	Medical	BCI	EEG– EEGLAB toolbox
5	Johnson *et al*. [25]	Medical	Cognitive	EEG – Behavioural Data Analysis
6	Çelik *et al*. [26]	Medical	Cognitive	EEG–SCL-90
7	Mheich *et al*. [27]	Medical	Cognitive	EEGLAB
8	Koctúrová and Juhár [28]	Medical	Cognitive	Open BCI – EEG
9	Yakobi *et al*. [29]	Human Factors	Cognitive	EEG – Go/No Go Task
10	Wal *et al*. [30]	Human Factors	Behavioural	EEG – Task and behavioural performance
11	Kirschner *et al*. [31]	Human Factors	Cognitive/Behavioural	EEG – PES, PERI
12	Kaur *et al*. [32]	Human Factors	Cognitive	EEG, fMRI, SA Index, PRAA and PRAFA
13	Ma *et al*. [33]	Human Factors	Cognitive	EEG–SVM–LTSM
14	Jin *et al*. [34]	Human Factors	Cognitive	Temperaments Inventory
15	Nann *et al*. [35]	Human Factors	BCI	EEG–EOG–HOV
16	Berka *et al*. [36]	Military	Cognitive	EEG/ Naval Command Task simulation
17	Schnell *et al*. [37]	Aviation	Cognitive	EEG–Cognitive Avionics Tool Set (CATS)
18	Borghini *et al*. [15]	Aviation and Transportation	Cognitive	EEG, EOG and HR data
19	Galant and Merkisz [38]	Aviation	Cognitive	EEG; simulator-NASA TLX and SWAT
20	Trapsilawati *et al*. [39]	Aviation	Cognitive	AT-SAT Test, EEG
21	Flumeri *et al*. [40]	Aviation		EEG-eye tracking-Asa TLX
22	Klaproth *et al*. [41]	Aviation	Cognitive	ACTR, EEG

	Authors	Field of Study	Research focus	Method
23	Polat and Özerdem [42]	Computer Engineering	BCI	EEG – PSD
24	Sözer and Fidan [43]	Computer Engineering	BCI	BCI–EEG
25	Alakuş and Türkoğlu [44]	Computer Engineering	BCI	EEG–IAPS
26	Iqbal *et al*. [45]	Computers and Chemical Engineering	Cognitive	EEG–theta PSD
27	Ackermann *et al*. [46]	Mechanical Engineering	Cognitive	EEG–DAEP
28	Kaya *et al*. [47]	Machine Learning	BCI	EEG–BCI Model
29	Yin and, Zhang [48]	Automation	Cognitive	Mental Workload Calculation – EEG
30	Roy *et al*. [49]	Multidiscipline	Cognitive	EEG–CPCA–MATLAB
31	Abut *et al*. [50]	Transportation	Cognitive	EEG – CAN–Bus–IVMC Tool–eye-tracking–laser sensor–pedal sensor
32	Xiaolil *et al*. [51]	Transportation	Cognitive	EEG–PVT
33	Kim *et al*. [52]	Transportation	Cognitive	EEG–WMS
34	He *et al*. [53]	Transportation	Behavioural	EEG, head nodding angle, eye-tracking signal-driving model
35	Lee and Yang [54]	Automotive Technology	Cognitive	EEG – Power spectrum analysis
36	Hu *et al*. [55]	Transportation	Cognitive	EEG – Multichannel analysis
37	Siddharth and Trivedi [56]	Transportation	Cognitive	EEG; PPG; GSR
38	Fu *et al*. [57]	Transportation	Cognitive	EEG – scaling analysis
39	*Şahan [58]*	*Business*	*Cognitive*	*EEG–eye tracking–SPSS*
40	*Şeker [59]*	*Cognitive Science*	*Cognitive*	*EEG–WEKA*
41	*Kısacık [60]*	*Multidiscipline*	*Cognitive*	*EEG–DEHB*
42	*Çetin [61]*	*Artificial intelligence*	*Cognitive*	*EEG–Wavelet Package Transformation*

43	*Saymaz [62]*	*Medical*	*Cognitive*	*EEG–DWT*
44	**Liu *et al*. [63]**	**Sea Navigation**	**Cognitive**	**EEG–SVM**
45	**Fan *et al*. [64]**	**Sea Navigation**	**Cognitive**	**EEG–NIFS**
46	**Fan *et al*. [64]**	**Sea Navigation**	**Cognitive**	**EEG–SVM**
47	**Wu *et al*. [66]**	**Sea navigation**	**Cognitive**	**EEG–NASA–TLX**
48	**Orlandi and Brooks [67]**	**Ship Handling**	**Cognitive**	**EEG, ECG, Simulation**
49	**Liu *et al*. [68]**	**Sea Navigation**	**Cognitive**	**EEG–SVM**
50	***Taç [13]***	***Sea Navigation***	***Cognitive***	***EEG–ANAM4***
51	***Yılmaz [18]***	***Sea Navigation***	***Cognitive***	***EEG–Simulator–sleep scoring criteria***
52	***Taç [69]***	***Sea Navigation***	***Cognitive***	***EEG–CBT–GTDA–NASA TLX***

Tong *et al*. [21] propose a system for personalised healthcare targeting the analysis of electrocardiogram (ECG) and EEG signals through the integration of mobile sensors, mobile applications and web interfaces. Users can use the system to keep track of their health information, and their doctors/coaches/trainers (henceforth referred to as health advisors) can also keep track of the information through the system. Electrocorticographic (ECoG) signals present a novel strategy to detect complex behaviours. Loris *et al*. [22] developed a programme EEG Detection Analysis for Behavioural States (EEG-DABS) that is advanced. In Başar *et al*.'s [23] study, electroencephalogram (EEG) signals were collected according to the 10-20 international electrode system standards; samples are selected from three types (negative, neutral and positive) of emotional pictures from 'Nencki Affective Picture System' and shown to subjects according to emotional situations. Tsekoura and Foka [24] presented the classification of electroencephalograph (EEG) signals produced by the first-octave musical notes of the piano as stimuli. The EEG classification of musical notes was attempted for the first time, to the best of our knowledge.

Additionally, when drowsy, Johnson *et al*. [25] found an increase in long-range information sharing (connectivity) between brain regions in the same frequency band. These results show the resilience of the human cognitive control system when affected by internal fluctuations of alertness and suggest neural compensatory mechanisms at play in response to physiological pressure during diminished alertness. Çelik *et al*.'s [26] study examined this process by using the time-frequency analysis of EEG signals and analysed the obtained data by using the event-related oscillations method. This study aimed to examine the oscillatory brain responses and distinguish one's own body from another's body.

Mheich *et al*. [27] work provides the community with high-density electroencephalography (HD-EEG, 256 channels) data sets collected during task-free and task-related paradigms. It includes 43 healthy participants performing visual naming and spelling tasks, visual and auditory naming tasks and a visual working memory task in addition to a resting state. The HD-EEG data are furnished in the brain imaging data structure (BIDS) format. Koctúrová and Juhár's [28] study tried to examine the possibility to use high-dimensional EEG data as a source for brain–computer interface (BCI). Applications of EEG BCI vary from emotion recognition, simple computer/device control and speech recognition up to intelligent prosthesis.

Yakobi *et al*. [29] investigated the neural correlates of boredom. They recorded electroencephalographic signals from 83 participants during a resting state and while performing a go/no-go task. They found a negative correlation between trait boredom proneness and power in the alpha and theta bands during the resting state. Wal *et al*. [30] combined stereo EEG recordings from the human cortex, with single-lead and time-resolved decoding, using a wide range of temporal frequencies, to characterise decision processing during a rule-switching task. Kirschner *et al*. [31] used multiple, robust, single-trial EEG regressions to investigate the link between neural correlates of error processing [e.g., the error-related negativity (ERN) and error positivity (Pe)] and error awareness. They found that only aware errors had a slowing effect on reaction times in consecutive trials, but this slowing was not accompanied by post-error increases in inaccuracy. In [32], the influence of pre-task resting neural mechanisms on situational awareness (SA) is studied. The study involved pre-task resting EEG measurements from 18 healthy individuals, followed by functional magnetic resonance imaging (fMRI) acquisition during the SA task.

In the first step, the t-SNE algorithm was carried out to extract features from EEG signals [33]. Second, a recurrent neural network with long short-term memory (LSTM) layer, fully connected layer and SoftMax layer was established to train the features, classify the EEG signals and predict cognitive performance. Jin *et al*. [34] present a study adopting personality and cognitive neuroscience approach to investigate if participation in ballroom dancing is associated with sensation-seeking temperament and elevated cerebral cortical arousal during freely chosen musical recall. Nann *et al*. [35] suggest that hybrid EEG/EOG B/NHE control of two assistive devices is feasible and safe, paving the way to test this paradigm in larger clinical trials performing bimanual tasks in everyday life environments.

Berka *et al*. [36] present evidence for the feasibility of developing a real-time system that uses neurophysiological methods to assess the SA of individuals. Schnell *et al*. [37] developed a neurocognitive assessment system called the cognitive avionics tool set (CATS). This system has been used in fixed and rotary-wing aircrafts and in automobiles to assess operator workload using physiological and neurocognitive markers. Sensors that they used in the past include dense array EEG, ECG, galvanic skin response (GSR), pulse oximetry (sPO2), respiration (amplitude and frequency) and non-contact measures, such as facial feature point location, facial temperature differences and eye-tracking. And the published papers related to neurophysiological measurements [electroencephalography (EEG), electrooculography (EOG) and heart rate (HR)] in pilots/drivers during their driving tasks. The aim is to summarise the main neurophysiological findings related to the measurements of pilots/drivers' brain activity during drive performance and how particular aspects of this brain activity could be connected with the important concepts of 'mental workload', 'mental fatigue' or 'situational awareness' [15].

Another paper presents an analysis of the possibilities of using electroencephalography in assessing the psychophysical condition of the pilot [38]. Trapsilawati *et al*.'s [39] study examined the effects of conflict geometries on ATCO situation awareness, stress level and brain activity during conflict resolution. Fifteen participants were instructed to resolve six different conflict geometries: crossing level, crossing non-level, converging level, converging non-level, overtaking level and overtaking non-level. Flumeri *et al*. [40] presented the so-called 'vigilance and attention controller', a system based on electroencephalography (EEG) and eye-tracking (ET) techniques, aimed to assess in real time the vigilance level of an ATCo dealing with a highly automated human-machine interface and to use this measure to adapt the level of automation of the interface itself. Klopruth *et al*. [41] study presents the integration of a passive brain–computer interface (pBCI) and cognitive modelling as a method to trace pilots' perception and processing of auditory alerts and messages during operations. Missing alerts on the flight deck can result in out-of-the-loop problems that can lead to accidents. By tracing pilots' perceptions and responses to alerts, cognitive assistance can be provided based on individual needs to ensure they maintain adequate situation awareness.

The aim of Polat and Özerdem's [42] study was to investigate the reflection of emotions based on different stories onto EEG. Power spectral density (PSD) of EEG signal was considered as reflection. In Sözer and Fidan's [43] study, the steady-state visual evoked potential-based BCI implementation was performed by using the Emotiv EPOC electroencephalography (EEG) device for neuromuscular disorders. In Alakuş and Türkoğlu's [44] article, EEG data sets, emotion stimulus, feature extraction and classification algorithms were examined and their performance was compared. Iqbal *et al*. [45] proposed a single dry electrode EEG-based methodology for identifying the similarities and mismatch between the control room operators' mental model of the process and the actual process behaviour during abnormal situations.

For emotional recognition, Ackermann *et al*. [46] evaluated the use of state-of-the-art feature extraction, feature selection and classification algorithms for EEG emotion classification using data from the *de facto* standard data set, called DEAP. Kaya *et al*.'s [47] studied a BCI system design that can detect mental imagery of right- and left-hand movements from EEG data, by using a modified portable EPOC Emotiv EEG headset and the supported vector machines, one of the machine-learning methods.

Yin and Zhang [48] classify mental workload (MWL) into a few discrete levels using representative MWL indicators and small-sized training samples. A novel EEG-based approach by combining different techniques is proposed and evaluated by using the experimentally measured data. Roy *et al*.'s [49] study consisted of a random target detection task in natural scenes, where human subjects (18 subjects, 7 female) detected the presence or absence of a random target as indicated by the cue word displayed before stimulus display. Concurrently, the neural activities (EEG signals) were recorded. A separate behavioural experiment was performed by different subjects (20 subjects, 11 female) on the same set of images to categorise the tasks according to their difficulty levels.

Abut *et al*. [50] presented data collection activities and preliminary research findings from the real-world database collected with 'UYANIK', a passenger car instrumented with several sensors, EEG, CAN–Bus data logger, cameras, microphones, data acquisitions systems, computers and support systems. 16 TB of driver behaviour, vehicular and road data have been collected from more than 100 drivers on a 25 km route consisting of on roads. Xiaolil *et al*. [51] paper found that when driving at night, the delta band varies significantly with the degree of fatigue through simulation experiments. The results have implications for real-time automatic detecting of driver fatigue at night and are helpful for future development of driver fatigue countermeasures. Kim *et al*. [52] analysed EEG data collected through an urban road driving test. To overcome large deviations of EEG values among drivers, they used EEG variation rates instead of raw EEG values. We extracted five kinds of behaviour sections from the data: left-turn section, right-turn section, rapid acceleration section, rapid deceleration section and lane-change section.

Five fatigue-based indicators are proposed in He *et al*.'s [53] study, which is integrated to establish the evaluation model of driver fatigue with the artificial neural network. The EEG, head nodding angle, eye-tracking signal, driving time-of-day and time-on-task are sampled during experiments. The EEG-based indicator is determined and used to group the sample data into alert and drowsy. Lee and Yang's [54] study delivered a take-over transition alert to human drivers using diverse combinations of visual, auditory and haptic modalities and analysed the drivers' brainwave data. In Hu *et al*.'s [55] article, the proposed method based on EEG signals aimed to assess driver fatigue by using multi-entropy measures and comparing the performance with channel combination and multiple classifiers. Siddharth and Trivedi's [56] manuscript focuses on the specific problem of inferring driver awareness in the context of attention analysis and hazardous incident activity. They explore the applications of three different biosensing modalities, namely EEG, photoplethysmogram (PPG) and galvanic skin response (GSR), along with a camera-based vision system in a driver awareness context. Based on the operational EEG of drivers, a method is proposed by Fu *et al*. [57] to characterise and distinguish different EEG patterns. The EEG measurements from seven professional taxi drivers were collected in different states. The phase characterisation method was used to calculate the instantaneous phase from the EEG measurements.

Şahan [58] determined which website design features influence touristic purchasing decisions and how they do it by applying EEG (electroencephalography) and eye-tracking techniques. This study aimed to determine demographic features of tourists, website design features and the perception level differences of touristic products so as to demonstrate whether there are differences in touristic purchasing decisions or not, based on tourist types.

Şeker's [59] study aimed to analyse and classify the EEG responses related to pleasant–unpleasant odours. With the help of surveys belonging to participants and graphs of power spectrum density, the most dominant pleasant–unpleasant (two of each) odours were determined. Discrete wavelet transform (DWT) was applied to EEG odour responses and the dimension of feature vectors was decreased by using some statistical operations. Kısacık [60] investigated whether the behavioural data obtained from tests of visual attention and electrophysiological measures taken during these tests differ between healthy individuals who display and who do not display symptoms of ADHD. Çetin's [61] study aimed to design the BCI system that will detect the hunger and satiety status of people in a computer environment through EEG measurements. In this context, the database was created by recording EEG signals in the eyes open, eyes closed and event-related potential scenarios of 20 healthy participants in the first stage of the study.

Saymaz [62] investigated whether the happiness education programme has an effect on EEG signals or to what extent this effect will occur. In the scope of the research, there are 18 participants (training group) with happiness education and 12 participants (control group) who did not receive training during this period. EEG signals were recorded from both groups at the beginning and the end of the training period. Signals were recorded from the right and left frontoparietal regions by bipolar electrode assembly.

On the other hand, sea transportation-related studies on neuroscience are as follows: Liu *et al*. [63] used this to assess the psychophysiological state of subjects. Using the sensors during performing the task, we can recognise the cadet/captain's emotions, attentiveness/concentration, mental workload and stress level in real time. In this work, we propose a real-time brain state recognition system using EEG biosignals to monitor the mental workload and stress of cadets during the simulator-based assessment.

Fan *et al*.'s [64] research techniques of human factors related to neurophysiological measurements are analysed in the context of ship operators' behaviours. They suggest that a coherent sequence of changes in EEG and near-infrared spectroscopy (NIFS) signals exists during the transition from different sorts of human factor concepts. The objective of the review is to summarise human factors in maritime, and how particular neurophysiological features could be utilised in human factor concepts of 'mental workload', 'attention', 'fatigue' etc. Another study by Fan *et al*. [65] was conducted and is described in two sections: emotion calibration and test recognition. In the first section, two types of emotions are induced by the sound clips of the International Affective Digitised Sounds, developed by the National Institute of Mental Health Centre for the Study of Human Emotions. In the second section, emotion is recognised by the support vector machine (SVM) classifier, as well as self-rated after the crew-qualified test in a bridge simulator.

In Wu *et al*.'s [66] study, the participants carried out standard four-level calibration tasks and simulated four-level maritime operation tasks; their heart rate and EEG were continuously measured using a heart rate sensor and an ambulatory EEG device, which includes an accelerometer to distinguish signal corruption epochs induced by body movement artefact.

Another paper investigated the effects of ship-handling manoeuvres on mental workload and physiological reactions with EEG devices [67]. Liu *et al*. [68] proposed and implemented an EEG-based psychophysiological evaluation system to be used in maritime virtual simulators for monitoring, training and assessing the seafarers. The system includes an EEG processing part, visualisation part and evaluation part. By using the processing part of the system, different brain states including cognitive workload and stress can be identified from the raw EEG data recorded during maritime exercises in the simulator. By using the visualisation part, the identified brain states, raw EEG signals and videos recorded during the maritime exercises can be synchronised and displayed together. By using the evaluation part of the system, an indicative recommendation on 'pass', 'retrain' or 'fail' of the seafarers' performance can be obtained based on the EEG-based cognitive workload and stress recognition.

In Taç's [69] study, based on the definition of cognitive science, the effect of cognition of the seafarers during the operational processes are evaluated under certain stressor factors such as fatigue–sleepiness, noise and thermal strain. The research was conducted on the bridge and engine room during the voyage of a short route container vessel. Thus, all the data were collected under real time and real conditions including different operational processes. In Yılmaz's [70] study, watchkeeping officers' states of sleep and fatigue were examined during their work and rest hours on a short sea voyage. The EEG data obtained from watchkeeping officers were evaluated within the scenarios prepared in a full bridge simulator system.

Taç's [69] study aimed to contribute to the understanding of the situational awareness levels of seafarers, which is the weakness of the safety management system studies conducted under the human factor research in the maritime domain.

4. Discussion

In June 2010, major revisions to the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers and its associated code were adopted at a Diplomatic Conference in Manila (The Manila amendments) [70]. The Manila amendments set the course for future maritime leadership and teamwork training addressing SA and decision-making. Consequently, at present, a very large number of maritime officers are undergoing training to meet these requirements so that they will be able to handle critical situations in maritime operations independently or as a team. On the other hand, according to the predictions of Southampton University which is one of the 2030 maritime trends is; artificial intelligence, sensors and situational awareness, connectivity, cybersecurity and energy management and sustainability [71]. The relationship between situational awareness and artificial intelligence is remarkable.

It is known that comprehending the conditions of the living environment and interpreting the next step according to all these affects the life of the person. At the same time, accuracy and timing in decision-making in seamanship that is based on decision-making by their nature directly affect safety. Additionally, critical incidents were defined as events that were unplanned, non-routine and where accidents could be avoided. SA was defined by Endsley's three models involve the perception of cues in the environment (Level I SA), understanding the meaning of the cues (Level II SA) and projection of system state (Level III SA) [72].

As can be understood from the total 52 literature review, research has been found in the following areas. It has been observed that a very high rate of EEG measurement. In addition to the general methods, it has been determined that the experiment-specific methods are used.

Medical: Health information, behavioural states, emotional situation and EEG classification, EEG–drowsy relationship, EEG–body distinguish, working memory, emotional recognition, simple computer/device control, speech recognition and visual attention

Human factors: Boredom, SA limitations, SA ability, mental workload, trust, decision processing, error awareness, neural mechanisms on SA, the influence of pre-task resting, long short-term memory, cognitive sensation seeking consequences of ballroom dancing to music, brain measurement everyday life and purchasing decision.

Aviation: SA developing a real-time system, assessment for workload using physiological and neurocognitive, pilot/driver's brain activity (mental workload, mental fatigue, SA), psychophysical condition of the pilot (situation awareness, stress level and brain activity during conflict resolution), measure to adapt the level of automation of the interface, perception, and processing of auditory alerts and messages, SA and individual cognitive differences and the cognitive aspects underlying the process of situation awareness.

Computer Engineering: The reflection of emotions based on different stories, neuromuscular disorders, emotions, a mental model of the process and behaviour during abnormal situations and decision-making.

Mechanical/Machine Engineering: Emotional recognition and machine-learning systems.

Electric Electronic Engineering: Testing with pleasant–unpleasant odours.

Biomedical Engineering: Happiness education.

Automation/Multidiscipliner: Mental workload and categorising neural activities

Transportation: Driver behaviour, vehicular road data, fatigue detecting, driver fatigue info, drowsy, drivers' brainwave data, performance measures and driver awareness attention analysis.

In the results of the literature, the areas of direct study related to sea navigation are also given as follows: mental workload of ship navigators, captain's emotions, attentiveness/concentration, mental workload and stress level, navigators' physiological reactions, the effect of cognition of the seafarers during the operational processes, watchkeeping officers' states of sleep and fatigue and the situational awareness levels of seafarers.

4. Conclusion

This study investigated in what way it can measure the brain activity with EEG in sea navigation which is a kind of dynamic profession to specify situational awareness. As a result of the research, it has been noticed that brain-centred research has increased greatly in the last 5 years, and it has been concluded that with the development of technology, EEG devices are widely used in many multidisciplinary fields. In addition to differences such as education, physical condition and demographic characteristics, it has been understood that the cognitive level should also be determined, especially in operational works aimed at a certain goal. Furthermore, the measurement of brain values is useful in calculating the averages of human factors and behaviours in artificial intelligence studies.

Finally, the literature review explored the main neurophysiological findings related to the measurements of navigator's brain activity during sea navigation and how particular aspects of this brain activity could be connected with the important concepts of 'situational awareness'. Therefore, it has been established that EEG measurement is applicable for situational awareness assessment in sea navigation.

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