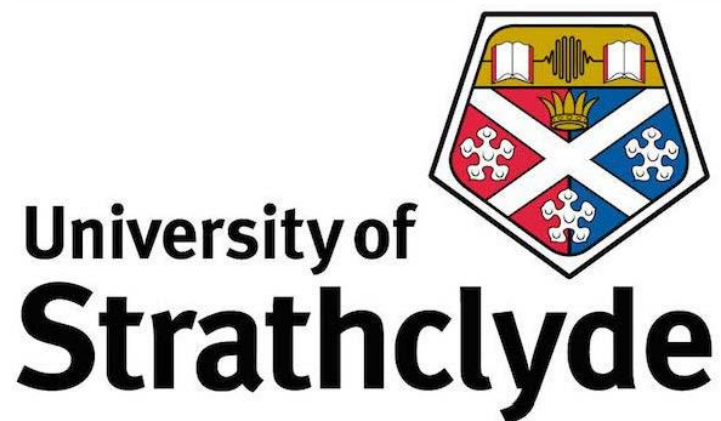


University of Strathclyde

Department of Naval Architecture, Ocean and Marine Engineering



**Enhancing Maritime Simulator Training for Safety
Critical Situations**

By

Hadi Bantan

A thesis presented in fulfillment of the requirements for the degree of Doctor of Philosophy

Glasgow, UK

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This thesis has resulted from the author's own efforts. It has been created for the purpose of the PhD award and has not been submitted for any previous examination nor awarded for any other degree.

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Signature:

Name: Hadi Bantan

Date:

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Tables of Abbreviations

Abbreviation	Meaning
AB	Able Seaman
AGCS	Allianz Globa Corporate and Specialty
AI	Artificial Intelligence
AOI	Area of Interest
ARPA	Automatic radar plotting aid
BRM	Bridge Resource Management
COC	Certificate of Competency
COE	Certificate of Endorsement
CRM	Crew Resource Management
DNV	Det Norske Veritas
ECDIS	Electronics Chart Display and Information System
EDA	Electrodermal activity
EEG	electroencephalogram
EMSA	European Maritime Safety Agency
HTW	Human Element, Training and Watchkeeping
IACS	International Association of Classification Societies
IMCA	International Marine Contractors Association
IMO	International Maritime Organization
MAIB	Marine Accident Investigation Branch
MARS	Major Accident Reporting System
MWL	Mental Workload
NASA	National Aeronautics and Space Administration
NASA TLX	Task Load Index
NTS	Nontechnical skills
OOW	Officer of Watch
OS	Ordinary Seaman
RADAR	Radio Detection and Ranging
SA	Situation Awareness
SHIELD	Safety Human Incident and Error Learning Database
SOLAS	International Convention for the Safety of Life at Sea
STCW	International Convention on Standards of Training Certification and Watchkeeping for Seafarers
SWAT	Subjective Workload Assessment Technique
TSS	Traffic Separation Scheme
UNCTAD	United Nations Conference on Trade and Development
VHF	Very High Frequency

VLCC	Very Large Crude Carrier
VR	Virtual Reality
VTs	Vessel Traffic Services

Abstract

There is no doubt that maritime transportation is the most critical transport for global trade. Maritime transportation is considered the largest international mode of cargo and passenger transportation, and in the last 30 years, it has increased by 240%. As the number and size of merchant vessels have increased, accidents onboard ships have become a main cause of concern. These accidents cause loss of lives, cargo, and ships and, in addition, cause environmental damage. However, marine accident statistics indicate that around 70% of maritime accidents are directly or indirectly related to human error, while 30% are due to technical factors and natural disasters. Maritime accident reports are a valuable resource to research these human errors. When the reports are analysed, it can be observed that the lack of appropriate training affects human and team performance, including situational awareness, communications, and lookout.

Human performance and human-system interaction play an important role in emergency and safety-critical situations. In addition, emergencies are unpredictable at sea, so accidents and incidents could occur at any time and anywhere, particularly in congested and restricted waters. Officers and crew should be prepared to face and avoid emergencies during their duty. Therefore, training and education are some of the most effective ways to increase officers' and crew's capability and knowledge to improve their performance in emergency situations. Developing training programs from the actual scenarios in the full mission simulation for deck officers is a unique opportunity to enhance human performance and teams in emergency and safety-critical situations.

The aim of this research is to explore the cognitive demand and behaviours of operators in the ship bridge environment individually and with assistance to develop IMO recognised intelligent training programs in full mission bridge simulation by utilising real accident scenarios and advanced assessment in order to prepare modern seafarers to deal with unexpected safety-critical situations.

Chapter 1 Introduction

International trade is crucial for the economic development of the countries. Countries with access to the sea contribute around 92% of the total value of international trade. Additionally, over 80% of the global commodity cargo by volume is transported by sea (Xu et al., 2020). The maritime sector is central to the connectivity of global supply chains, demonstrating remarkable resilience in maintaining the delivery of essential goods and supplies throughout the COVID-19 pandemic (IMO, 2021). It is the most economical way of transporting large volumes of cargo worldwide. From 2005 to 2010, the average annual growth rate of global deadweight tonnage was notably strong at 7.1%. However, as a result of the 2007 -2008 crisis, this growth decelerated to an average of 4.9% between 2011 and 2023. This slowdown can be attributed to factors such as consolidation within the shipbuilding industry and a reduction in ship financing. Moreover, the beginning of the COVID-19 pandemic influenced the growth of fleet capacity, which led to a further decrease averaging 3.1% per year (UNCTAD, 2023) . In 2022, the maritime trade sector, especially dry bulk and tanker, was impacted by the conflict that occurred in Ukraine. This war changed the shipping routes and extended the travel of commodities. Therefore, the growth in ton-mile surpassed the growth in tons in 2022, 2023, and projections for 2024

Figure 1.1:. In addition, the fleet’s capacity expanded at an annual rate of 3.2%, reaching a total of 2.27 billion deadweight tons, Figure 1.2:.

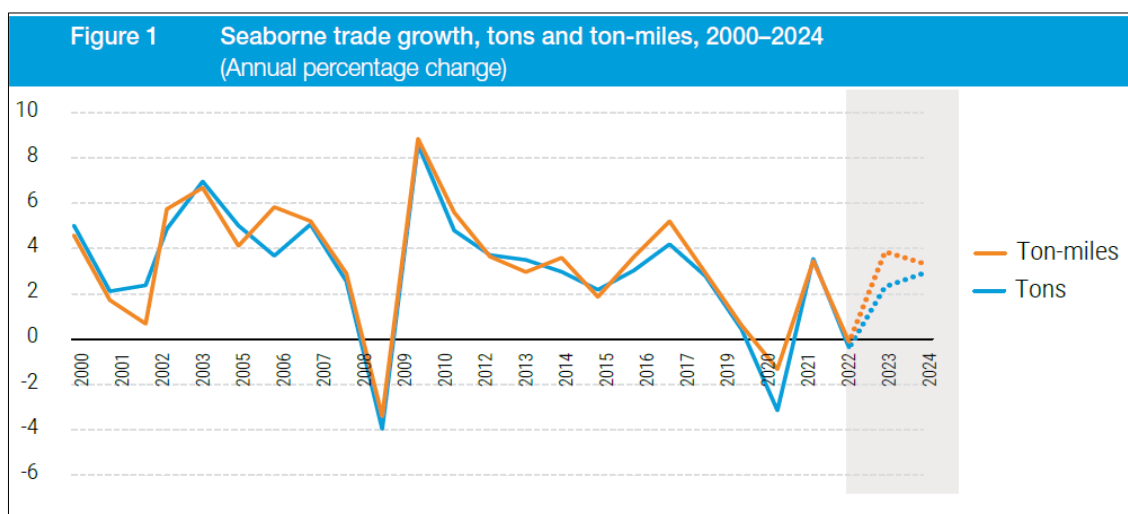


Figure 1.1: UNCTAD secretariat, based on Clarksons, Shipping Intelligence Network Time Series (as of July 2023)

Note: 2023 Data are estimated, and 2024 is the forecast

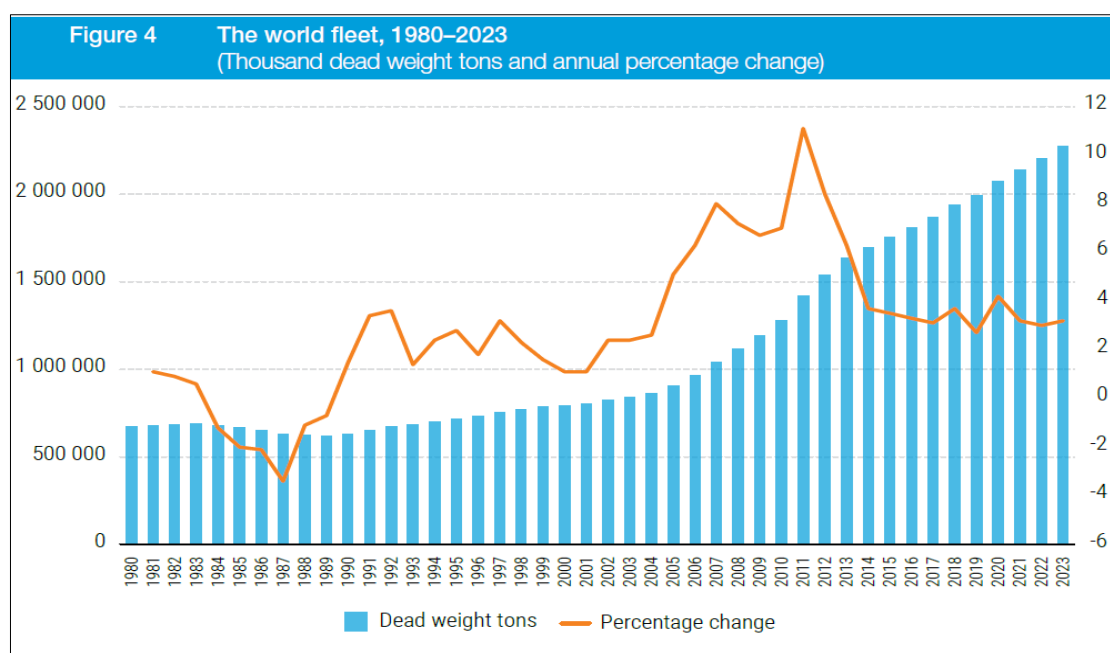


Figure 1.2: UNCTAD calculation, based on data from Clarksons Rresearch, 2023.

Notes: Propelled seagoing merchant vessels of 100 GT and above as of 1 January 2023. Deadweight tonnes for some individual vessels have been estimated.

The failure of ship transport can have significant consequences on the global economy. An important example is the accident of the Evergreen ship in March 2021. The Evergreen containership, 400 m in length, grounded in the Suez Canal and blocked the passage. This incident caused a six-day obstruction of one of the world's most critical maritime routes, resulting in a substantial delay in delivering goods valued at billions of dollars. The disruption not only affected the global shipping schedules but also resulted in increased shipping costs and exposed the fragility of the global supply chain (Mechai and Wicaksono, 2024). The accident caused around £7 billion loss a day in trade because of the blockage of the canal and a 10.9 m income loss each day for the canal (Michaelson and Safi, 2021). The accident highlights the essential role of uninterrupted maritime transport in maintaining the stability of global trade and economic health.

Among all the operations on board ships, navigation is considered the most critical area. However, safety is the most important factor, and to achieve a high standard of safety, educated and trained officers should be designated to navigate the ship from port to port without any accidents. Maritime training and education are considered essential approaches to creating a highly competent seafarer in

the shipping industry. Therefore, maritime universities, academics, and training institutions/companies contribute to the development of seafarers' performance. Well-trained and qualified officers are important for safe ship operations, especially in emergencies.

Due to the increase in the shipboard automated systems, the number of crew members has decreased over the years. This decrease in the number of crew members led to an increase in the responsibilities and tasks of the officer of the watch (OOW) on the ship's bridge, which affected his/her performance. Therefore, human errors are claimed to be the major causes of ship accidents at sea and harbour; they represent almost (80 %) of the accidents (Pazouki *et al.*, 2018). However, in the analysis of the maritime accidents between 1987 and 2001, it seems that most of the human errors are related to situation awareness issues (Sharma *et al.*, 2019a). Different measures could enhance the human performance on the ship's bridge to avoid unfortunate events. One of the methods that has helped improve human navigation skills is simulator training.

The research considered the relationship between simulator training and the improvement of the human factor in the ship's bridge. Simulator training is a powerful tool that can enhance human performance. Many industries, such as medical, aviation, rail, and nuclear, use a simulator as a training device to increase the competence of their workforce. Simulators in maritime education and training have been used for certification since the 1950s. Nevertheless, the use of the simulator as a pedagogical tool in the maritime domain needs more study (Sellberg, 2017). In addition, there is a shortage of maritime research to evaluate and assess the effectiveness of simulator training and its impact on human performance (Baldauf, Kataria and Benedict, 2016).

The use of a simulator is regulated in the International Convention on Standards of Training Certification and Watchkeeping for Seafarers (STCW), the first convention developed by the International Maritime Organization IMO to provide the minimum standards of training, certification, and watchkeeping for seafarers. Training and assessment and using a simulator were mentioned in the regulation (I/6 and I/12). The convention makes the simulator an important means of training. For simulator training and assessment, automatic radar plotting aid (ARPA) and electronic chart display and information system (ECDIS) are mandatory. For all other practices, including a full

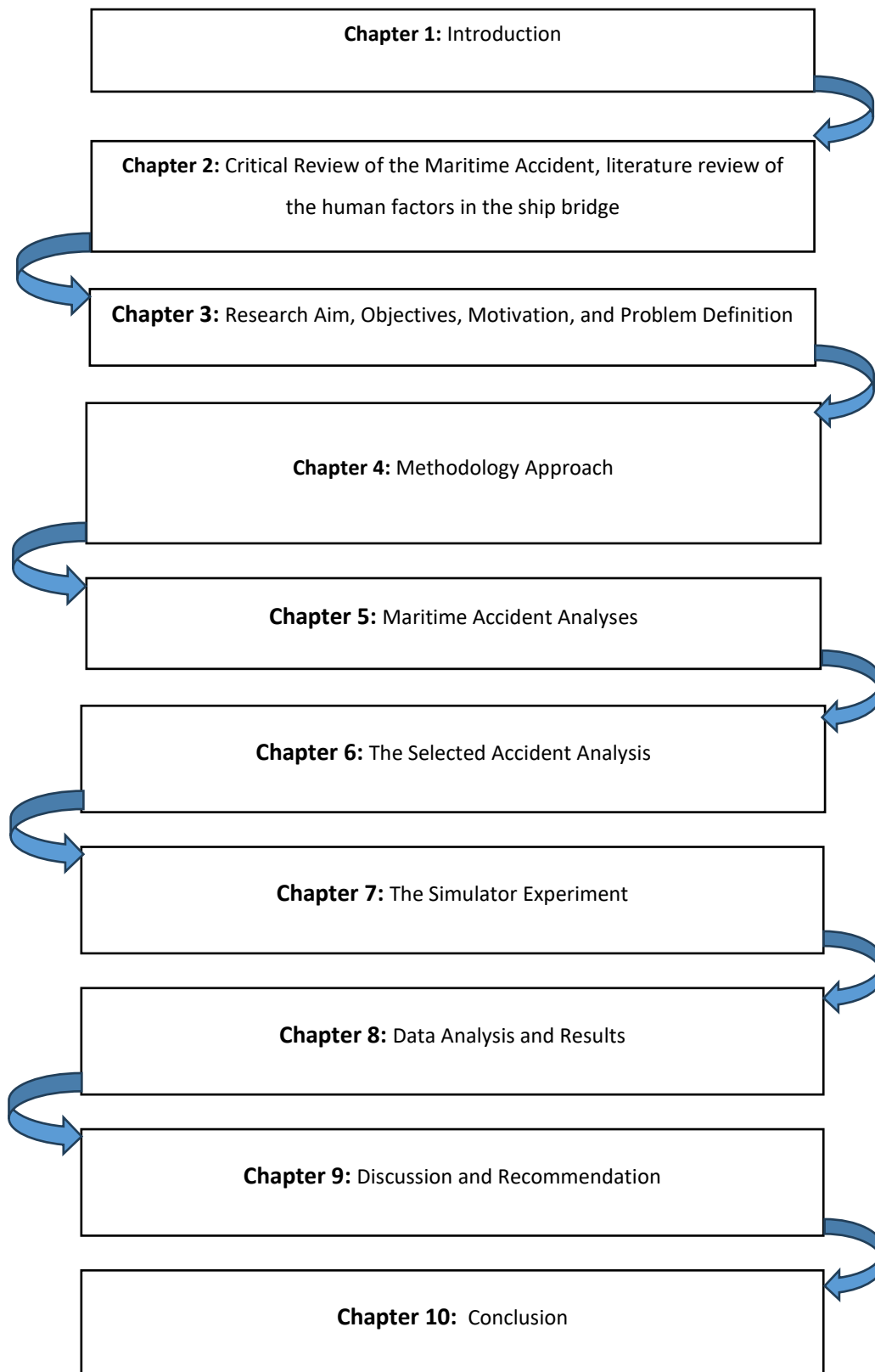
mission simulator is not mandatory. On the other hand, the aviation industry is more advanced than the maritime industry. The first aviation simulator was invented by Edward Link in 1929, where pilots trained for running on the ground (Page, 2000). Currently, pilots in aviation must undertake a minimum of training hours in the simulator before joining a real aircraft (Shashidhara et al.,2018). Commercial aviation uses the simulator to qualify and certify pilots and aircrew. In addition, the simulator enables the pilot to face a dangerous situation that cannot be performed on a real plane. Therefore, the effectiveness of the training enhances the pilot's performance in case an emergency occurs (Martinez,2017). Air transport is more developed than the maritime industry in terms of safety. Transferring the methodologies and techniques from air transport and adapting to the marine industry would improve human practice (Turan et al., 2016).

In this research, studying accident reports opens the mind to find out the human errors that occurred in the previous accident, and the idea is to design a scenario that could improve these issues. Simulator training provides the flexibility to create dangerous/safety-critical scenarios that cannot be created in the real ship, in which the officer is allowed to make mistakes and learn a lesson from his mistakes. Using objective measures in simulator training plays an important role in delivering the curriculum, providing educational support, and developing the officer's navigation skills and knowledge.

This research aims to improve human performance in the ship's bridge by exploring the cognitive process and behaviour during a training scenario individually and with assistance by using biosensors like electroencephalography (EEG) and eye tracking. Therefore, a training scenario has been done by adding an assistant as a "lookout" to see the influence of the lookout on the seafarers' cognitive process and their behaviour with the ship bridge environment. After that, an intelligent training program in full-mission simulation that considers emergencies and accidents that have already happened to enhance team situation awareness and skill performance would develop.

The first chapter of the thesis provides background information about the importance of maritime trade and the research that has been done. Then, chapter two, the critical review of the thesis, shows the reasons for the accident and how to improve the performance of the seafarers to reduce accidents. After that, chapter three provides the aims, motivation, problem, and gaps of the research that encourage us

to conduct the research. Furthermore, the methodology will be illustrated in chapter four to show the method and tools that are utilised in the research. Chapter Five shows the methodology used to analyse maritime accidents and human factors. Then, the experiment conducted in the research is demonstrated in chapter six, followed by the analysis of the data collected and analysis in chapter seven, and in eight, the analysis and result. Finally, chapter nine will be the discussion, followed by the conclusion in chapter ten, which will also include future work. The structure of the thesis will be as follows:



Chapter 2 Critical Review

2.1 Introduction

Maritime transportation continues to be the most critical industry for international trade, with an annual average growth rate of 3.4 % between 2019 and 2024 (UNCTAD, 2020). This sector is vital for the movement of large quantities of cargo across the oceans. However, maritime safety remains a significant concern due to frequent accidents that lead to loss of life and economic and environmental damage. Such incidents often result from multiple factors, including human errors, equipment malfunction, challenging environmental conditions, and issues related to shipping routes and cargo (Shkëlqim Sinanaj, 2020).

The ship's bridge is the nerve centre of ship operations, where captains and officers oversee navigation and ship control. It is crucial to enhance the skills and preparedness of seafarers to meet the evolving demands of modern maritime operations and qualify them as proficient watch officers.

This chapter will cover several important topics related to the research. It will begin with an introduction to maritime accidents and how they have escalated over time. Then, ship accident statistics will be provided, highlighting the main causes of the accidents. After that, the chapter shows the importance of maritime accident research and reports to emphasise the learning from past accidents and show the impact of the increasing ship size and how this would affect the accidents in the future. Furthermore, when the technology was introduced in the maritime industries, especially in the ship bridge, the different issues highlighted the ergonomic design and layout of the ship's bridge, which is essential to minimise human error. In addition, human factors in the ship bridge will be illustrated, including the responsibility of the officer of the watch and the bridge team, showing the duties of each officer and their impact on navigation safety. The importance of maritime education and training is then illustrated alongside the international standards of training, certification, and watchkeeping (STCW) convention, showing the amendment and the guidance of the practice of the simulator training, including the new focus area that should put the light on it. This chapter also covers psychological factors such as mental workload, situation awareness, stress, and attention and their influence on performance and maritime

safety. Finally, the application of biosensors like (EEG) and eye tracking to monitor the cognitive demand and behaviour of seafarers will be reviewed with potential benefits.

2.2 Maritime Accidents Background

Ship accidents have been a part of maritime history since the beginning of seafaring. Over the centuries, ships have faced a range of disasters, including collisions, groundings, fires, explosions, and sinkings. These accidents often result in significant consequences, such as loss of life, property damage, and environmental disasters.

The history of maritime accidents, including influential disasters like the Titanic in 1912, has driven the development of safety regulations aimed at preventing similar incidents. Following the Titanic's sinking, the International Convention for the Safety of Life at Sea (SOLAS) was established in 1914, marking the first major international effort to enhance safety at sea (IMO, 2019). The IMO later enforced these and other global maritime safety standards, continuously updating regulations in response to new accidents.

While the accidents are unpredictable, their consequences could substantially impact life, the environment, the economy, and society. Each significant accident has prompted updates to safety guidelines and policies. For example, Table 2.1 lists key maritime accidents and the specific regulations they influenced. Understanding this historical progression is crucial for recognising the role of human factors in maritime operations and the evolution of safety measures.

Initially, factors like overloading cargo were common causes of accidents, often due to ignorance of the ship's capacity limits. The work of Samuel Plimsoll, highlighting safe cargo limits, was pivotal in addressing this issue (Plimsoll, S., 1873). As maritime technology and automation advanced, they brought new challenges, including technical failures that led to accidents.

Contemporary studies, however, suggest that human factors remain the predominant cause of maritime mishaps (Ćorović and Djurović, 2013; Hetherington et al., 2006a; Salvendy and Karwowski, 2021). While automation has reduced some aspects of the crew's workload and enhanced operational

performance, it has also introduced complexities. Increased automation can lead to higher cognitive demands on operations and potential losses in situational awareness during navigation, thereby creating new risks (Pazouki et al., 2018)

Table 2.1 Selected accidents and reactive follow-up IMO (Hollnagel et al., 2013)

Year of Accident	Ship name	Resulting measure/instrument
1912	Titanic	SOLAS, 1914
1967	Torrey Canyon	Intervention Convention, 1969 1975 Civil Liability Convention, 1969 1975 MARPOL Convention, 1973 1983 STCW Convention, 1978
1976	Argo Merchant	MARPOL Convention, Protocol of 1978
1987	Herald of Free Enterprise	ISM Code, 1994
1989	Exxon Valdez	OPRC Convention, 1990 1995 MARPOL Convention, 1992 amendments (double hull)
1994	Estonia	SAR Convention, 1998 amendments (improvement of cooperation)
1999	Erika	Res. 949(23) Guidelines on places of refuge for ships in need of assistance
2002	Prestige	

2.2.1 Ship Accidents Overview

Despite extensive safety measures, maritime accidents have remained a critical concern in the industry. Understanding the causes and contributing factors of these incidents is crucial for mitigating risks and addressing underlying issues. The diagrams and tables provided elucidate the frequency of various types of maritime accidents.

According to the European Maritime Safety Agency (EMSA), which covers all the accidents around the European Union, from 2014 to 2019, “Loss of control” incidents were notably prevalent, recording 616 accidents, while “Loss of propulsion” incidents were the most frequent, with 3516 occurrences. Notably, the latter saw a continuous rise until a 12.6% decrease in 2020. Collision, contacts, and grounding/stranding collectively accounted for 6684 of the 15481 record accidents during this period,

representing 43% of the total, Table 2.2 and

navigational accidents could significantly decrease overall maritime accidents.

Figure 2.1 (EMSA, 2021). A reduction in these

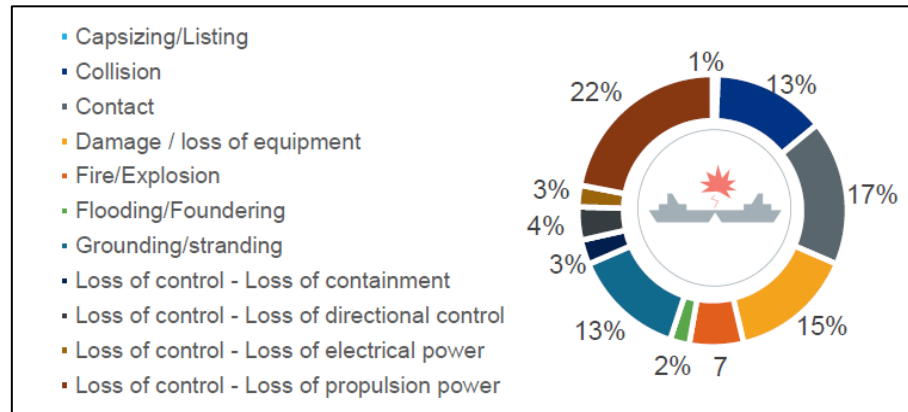


Figure 2.1 Distribution of casualty events with a ship (EMSA, 2021)

Table 2.2 Distribution of casualty events with a ship (EMSA,2021)

	2014	2015	2016	2017	2018	2019	2020	Total
Capsizing/Listing	11	14	7	14	17	19	5	87
Collision	333	297	320	293	282	292	186	2003
Contact	391	402	356	421	377	365	364	2676
Damage / loss of equipment	289	365	358	309	343	315	331	2310
Fire/Explosion	159	170	133	132	136	131	119	980
Flooding/Foundering	63	60	43	63	35	47	42	353
Grounding/stranding	325	328	290	292	302	249	219	2005
Hull failure	6	15	21	5	4	4	3	58
Loss of control - Other	1	1	12	4	5	0	1	24
Loss of control - Loss of containment	76	60	70	67	68	46	62	449
Loss of control - Loss of directional control	78	92	83	110	76	87	92	616
Loss of control - Loss of electrical power	61	49	47	65	59	66	51	398
Loss of control - Loss of propulsion power	372	374	471	506	552	662	579	3516
Missing	0	0	1	1	1	2	1	6
Total	2163	2227	2212	2282	2257	2285	2055	15481

Further analysis reveals that human actions are implicated in 53% of maritime accidents, whereas equipment failure accounts for 35% Figure 2.2. These findings highlight the necessity of minimising human errors and enhancing the reliability of navigational systems and equipment to reduce navigation-related accidents. By addressing these primary factors, human error, and equipment failure, the frequency of maritime incidents can be substantially lowered, thereby improving maritime safety.

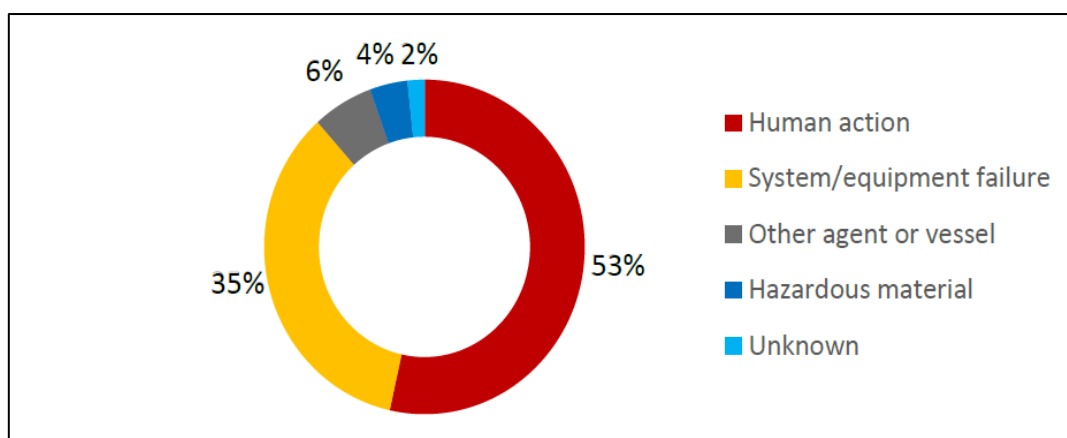


Figure 2.2: Distribution of accident event types for the period 2014 -2020 (EMSA, 2021)

Additionally, the southeast of Asia is considered the hotspot of maritime losses (Allianz, 2024). According to the 2024 Allianz report, over the past decades, 729 total losses were recorded. The southeast region recorded 184 incidents, accounting for nearly a third of vessels lost last year. The East Mediterranean and the Black Sea ranked second with 6 incidents. Cargo ships made up over 60% of vessels lost globally in 2023, with foundering as the main cause, responsible for 50% of losses. Extreme weather was a factor in at least 8 vessel losses in 2023.

Globally, shipping accidents declined slightly to 2951 from 3036 the previous year, with the British Isles experiencing the highest number at 695. Fire incidents onboard vessels also decreased but remained a significant concern, with over 200 reported in 2023. Fire continues to pose a key safety issue in larger vessels due to the potential for severe damage and high associated costs, contributing to a long-term increase in large marine insurance claims.

2.2.2 Main Causes of Ship Accidents

The maritime industry, responsible for approximately 90% of the world's trade (AGCS,2020), places enormous importance on the safety of ships. Accidents at sea, particularly those involving large vessels, can have catastrophic consequences for safety, life, and the environment. For instance, imagining the collision of two Very Large Crude Carriers (VLCC) near the coast or in a busy traffic area could result in an extreme environmental impact.

Examining the underlying cause of these accidents is crucial to mitigate such risks. The primary factor identified in maritime accidents is human error; however, understanding the specific behaviours and decisions leading to these errors is essential for developing prevention measures. These measures aim to decrease the likelihood and severity of maritime accidents, thereby enhancing overall maritime safety (Montewka et al., 2017). In addition, the analysis of maritime accidents done between 1987 and 2001 illustrates that 71% of the human error occurred because of situation awareness (SA) related problems and need further research to improve it (Grech et al. 2002; Sharma et al., 2019a). However, with increasing automation in the ship bridge, human-system interaction is one of the most common causes of maritime accidents because of missing or incomplete information acquired by the crew (Lee and Chung, 2018)

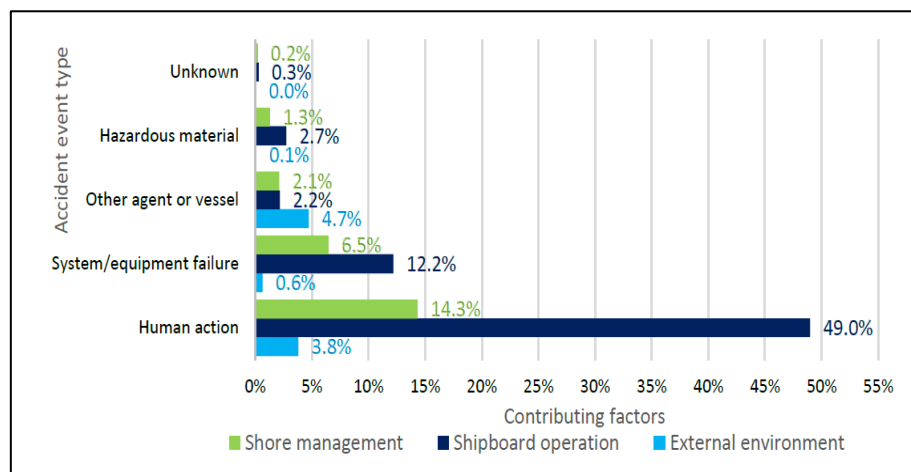


Figure 2.3: Contribute factors for human errors. (EMSA, 2021)

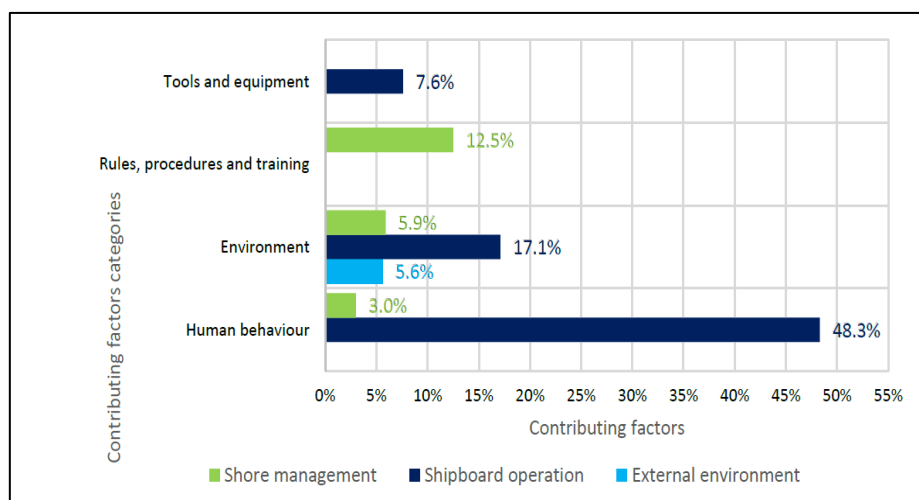


Figure 2.4: Contributing factors for human behaviour. (EMSA, 2021)

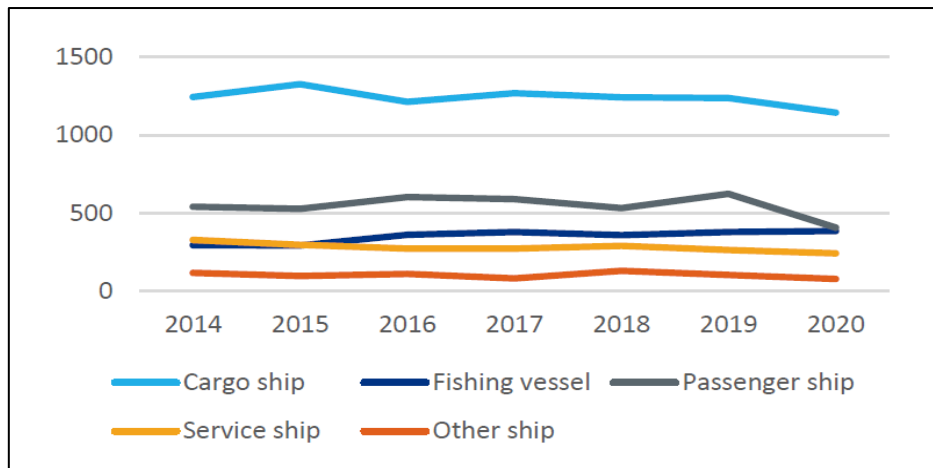


Figure 2.5: Most ship types involved (EMSA, 2021)

According to the (EMSA), human action is the predominant cause of accidents on board ships, Figure 2.3;, and human behaviour contributes to these errors Figure 2.4:.. Cargo ships are more frequently involved in accidents, Figure 2.5:;, which underscores the need for targeted safety intervention in this sector. Moreover, a consensus within maritime studies suggests that human errors are responsible for 75% to 96% of marine casualties.

The subsequent section of this thesis will explore maritime accident reports and how lessons learned from past maritime accident reports can support safety improvement. This includes a discussion on human factors in ship bridge operation and the interaction between humans and automation systems.

2.2.3 Maritime Accident Investigation Research and Reports

Over the past five decades, the focus of maritime accident research has evolved from structural issues in ships to more complex factors such as human error and fluctuating market conditions. This shift has required integrating data from different sources alongside applying sophisticated modelling and computational technologies. The increased attention to human, socio-economic and socio-technical factors has enhanced our understanding of maritime accident causation, enabling researchers to address existing knowledge gaps more effectively. This enhanced understanding is vital for developing targeted strategies to protect life and property at sea by mitigating and preventing maritime accidents (Luo and Shin, 2019a).

Globally, numerous maritime investigation agencies are tasked with examining maritime incidents and producing comprehensive reports that shed light on the root causes of these events. These reports are very important as they provide insights and evidence that support the ongoing education of maritime professionals to strengthen maritime safety (Raunek, 2021). These investigation bodies are mostly governmental agencies with the authority to investigate maritime incidents within their respective jurisdictions. They possess the mandate to issue safety recommendations and enforce regulations based on their investigative finding. Famous agencies dedicated to maritime accident investigation include:

- National Transportation Safety Board (NTSB) - United States
- Marine Accident Investigation Branch (MAIB) - United Kingdom
- Transportation Safety Board of Canada (TSB) - Canada
- Australian Transport Safety Bureau (ATSB) - Australia
- Bureau d'Enquêtes sur les Événements de Mer (BEAmer) - France
- Federal Bureau of Maritime Casualty Investigation (BSU) - Germany

Furthermore, in addition to governmental agencies, various private bodies, such as classification societies, insurance companies, and law firms, also conduct maritime accident investigations. These organisations may undertake investigations on behalf of shipowners, insurance companies, or other maritime stakeholders.

The publication of maritime accident investigation reports primarily serves to disseminate lessons learned from past errors. Over the last two decades, there has been a notable increase in maritime accident investigations. Since 1995, scholarly output in this field has grown significantly, with journals focusing on maritime safety and risk seeing a substantial rise in publication from an average of 1.73 to 41.6 papers annually. Notably, the research community is increasingly adopting multi-disciplinary approaches and leveraging multiple data sources to understand better the complex interaction between the natural environment, naval technology, human behaviour, and market conditions. (Luo and Shin, 2019b). This result highlights a significant shift toward studying human factors and the socio-technical conditions impacting maritime safety.

2.2.4 Learning from Past Accidents

It is natural to make mistakes. We are all humans, and we all make errors, but did we learn from our errors? Human error is ubiquitous and inevitable. Over time, these errors can lead to significant catastrophes. However, if the faults are identified early, they provide great learning opportunities. (Mukherjee,2020). Accidents often result from a combination of factors rather than a single cause. As (Reason, J., 1990) mentioned, the Swiss Cheese Model illustrates this interaction, depicting organisational defences as layers of Swiss Cheese. While each layer has failures or holes, accidents occur when holes in different layers momentarily line up, allowing a hazard to pass through multiple defences, Figure 2.6

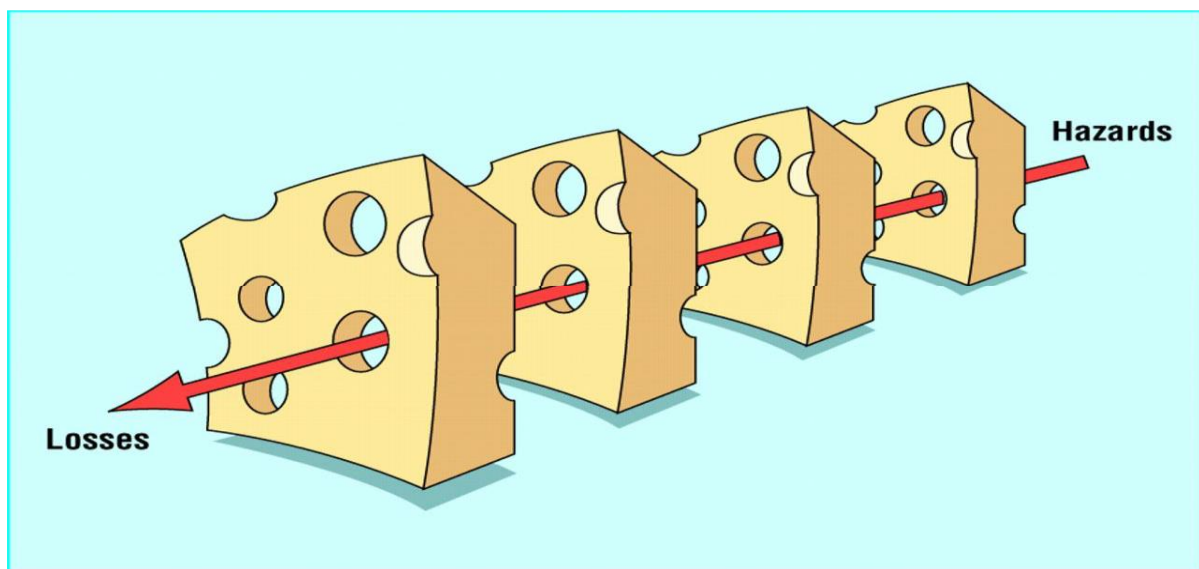


Figure 2.6 : The swiss cheese model of how defences, barriers, and safeguards may be (Reason,1990)

Understanding these factors is essential, as it allows us to devise strategies to prevent future occurrences. Therefore, accident reports are valuable. They identify root causes and contributing factors and facilitate the development of targeted recommendations and safety measures. These measures can subsequently enhance maritime safety and security and prevent pollution, thus preventing similar accidents in the future.

Despite the frequency of accidents across various industries, there is a notable shortage of research focusing on practical methods to mitigate accidents for future safety improvements. This gap suggests a practical approach: utilising findings from reports in full-mission simulators towards developing

mitigating solutions. This method allows for the simulation of past accident scenarios, offering a safe environment to identify weaknesses and develop as well as test preventive measures without real-world risks.

Accident investigation theories and their application are pivotal in recognising the underlying causes of incidents. The aim is to conduct thorough root-cause analyses to effectively understand and address the issues' origin. However, this method might not always be effective (Awal and Hasegawa, 2017). Accident causes are typically categorised as (immediate) or (contributory), encompassing factors such as unsafe acts by individuals, hazardous working conditions, management failures, and the physical and mental state of workers (Manger, 2011). Obtaining reliable data on human errors within the maritime sector is often fraught with challenges. Many incidents remain unreported, or the available data is incomplete, lacking the objective details needed to formulate effective preventative strategies.

The practical application of accident reports through simulation is proposed to address these challenges. Analysing these reports and replicating the scenarios in a full mission simulator can provide the officer of the watch (OOV) with a realistic training experience. This method not only identifies operational weaknesses but also helps with the development of effective strategies to prevent similar accidents in the future.

Several studies have focused on understanding and improving safety by analysing human factors and Non-Technical skill (NTS) deficiencies contributing to past accidents. (Navas De Maya et al., 2021; Tusher et al., 2022) conducted research to investigate NTS using maritime accident reports data from MAIB and the Major Accident Reporting System (MARS) to classify and analyse human factors from previous accidents. The result found that 27% of the accidents involved NTS deficiencies including poor SA, decision-making, communication, leadership, and time management. This refined classification and analysis aims to enhance the clarity and utility of HF data. In addition, a study uses simulation-based scenarios to replicate real maritime accidents, highlighting team dynamics issues such as authority gradients, group harmony pressures, and inter-specialty antagonisms. The researcher emphasises the importance of simulator training in recognizing these issues and mitigating human and organizational factors that contribute to the accidents (Baric et al., 2018). However, the advantages of

using a full mission simulator are manifold. It allows for the recreation of specific past accidents, facilitates the discovery of critical weaknesses, and aids in developing preventive measures. Most importantly, it provides a risk-free setting that safeguards trainees from the consequences of errors during the learning process. However, there is little focus on cognitive load and attention despite the use of the full mission simulator as an advanced technology for testing (Andrzej Hejmlich, 2022). While scenario-based training is commonly used, the importance of designing more realistic and varied scenarios that closely replicate real-world conditions is limited. There is a gap in certain of complex, multifaceted scenarios that include unexpected multifunction and stressors to assess how trainees respond under pressure (Kandemir et al., 2018). Consequently, the simulator environment offers valuable opportunities to demonstrate real-world conditions and test the operator to face this complex situation to be prepared for future critical conditions that could be faced without real catastrophic consequences.

2.2.5 The concern of the increasing ship fleets and capacity

According to the United Nations Conference on Trade and Development (UNCTAD) report of 2022, the global maritime fleet has expanded to 102,899 ships of 100 gross tonnage and above. Marking a 2.95% increase in carrying capacity (UNCTAD, 2022). Despite this growth, there are escalating concerns about the increase in ship size and capacity associated with amplified financial risks. Accidents involving large vessels, particularly in environmentally sensitive areas, can have substantial economic and environmental consequences. For example, the expense related to addressing the aftermath of a collision or grounding incident involving two large ships could exceed \$4 billion (Allianz, 2015). In addition, the reduction of the crew on these ships has created complex management systems. Hence, it may increase failure probabilities (MacDonald, n.d, 2006). Consequently, the complexities and costs associated with managing accidents involving large vessels have significantly increased. Furthermore, this increase will make the manoeuvrability between ships complex, especially in congested waters.

However, with the increase in ship size and the sea space becoming busier, ship manoeuvring becomes harder. Could this create more risk in the future? particularly with fewer crew members on the massive ship managing all the instruments? The question here is, how can the maritime industry and its organisations manage these challenges before they become too big to handle?

2.3 Technologies onboard ship

The level of computerisation and automation has significantly increased among industries worldwide and is still developing continuously. Over the last few decades, automation has been implemented to enhance safety measures, particularly within the maritime sector (Hadnett, 2008). The end of 1970, entering the 1980s, marked the inception of digital technologies on ships. A few years later, computers began to be installed on ship bridges, and soon after that, ship owners started integrating systems to streamline operations and augment safety measures (Ziarati et al., n.d. 2011). Nowadays, the bridge of a ship is vastly different from its predecessors, characterized by high standards of navigational equipment. The motivation for adopting automation is to reduce the workload of crew members, enhance human performance, and increase productivity during operation. In addition, technological advancements have been introduced to minimize and potentially eliminate transportation risks, thereby improving navigational safety (Dhami and Grabowski, 2011). Despite the enhancement, integrating such technologies has introduced new challenges related to maritime accidents, which will be explored in detail in this thesis.

2.3.1 Ship's bridge layout and equipment

Ships are large, long, and wide and require complex control systems for navigation and manoeuvring on the open seas and restricted coastal waters. As a result, the ship's bridge becomes apparent as a critical and complex area, typically positioned on the highest deck of the accommodation sector to provide an unobstructed view. Serving as the operational centre, the ship's bridge is where the captain and officers command all navigational and operational activities. Figure 2.7 illustrates a modern ship, showcasing the typical layout of equipment.

This equipment is under the view of officers who are tasked with monitoring and manoeuvring the vessel to prevent accidents. Furthermore, all devices on the bridge must be certified and undergo thorough testing by relevant authorities to verify their functionality and reliability. Effective management of this equipment necessitates highly competent and trained officers on the bridge to handle potential emergencies.

However, to highlight this further, the navigation and radio communication systems typically found in the wheelhouse of the modern ship are detailed in Table 2.3 and Table 2.4. As installed on the Japanese training ship (Oshoro-maru), the referenced equipment represents state-of-the-art technology in most new vessels. The (Oshoro-maru) is utilized for training and research purposes, embodying the advancement in maritime technology.

➤ **Navigation Equipment**

Table 2.3 Bridge equipment

Magnetic compass	Gyro compass
GPS Gyro Compass	Autopilot
ECDIS	No.1. RADAR
No.2 Radar	Ship manoeuvring system
GPS compass	GPS navigator
Navigation echo sounder	Electromagnetic log
AIS	Automatic meteorological observation system
Remote wave height meter	Monitor TV system

➤ **Radio Communication Equipment**

Table 2.4 Bridge equipment

MF/HF radio communication equipment	MF/HF receiver
DSC Receiver	NBDP

Weather Facsimile	No.1 VHF radio telephone
No.2 VHF radio telephone	Two-Way radio telephone
Navtex Receiver	Radar Transponder
Satellite EPIRB	Inmarsat FBB
Inmarsat C	VSAT
Onboard Communication System	27 MHz SSB radio telephone
27 MHz DSB radio telephone	Domestic VHF tel
Radio Direction Finder	Satellite TV receiver

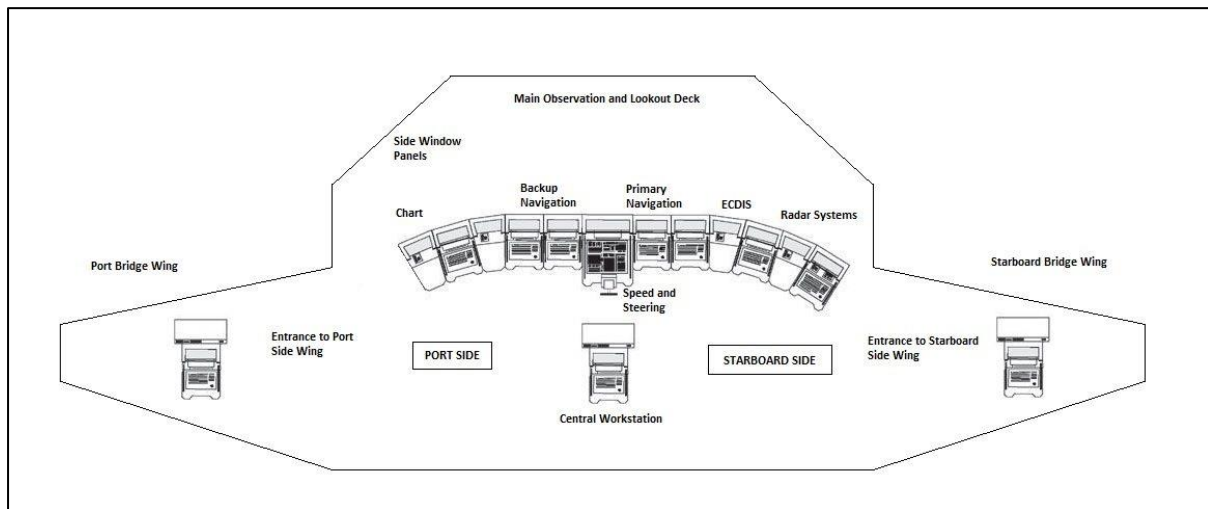


Figure 2.7 Ship's bridge layout (Marine Insight, 2020)

2.3.2 Ship's Bridge Ergonomics

Working on a ship fundamentally differs from employment in any other trading industry. Imagine yourself in a small floating city where awareness is required even during sleep to respond to any emergency situation that could occur promptly. Moreover, adverse weather conditions can cause the ship to roll and pitch, creating physical discomfort and impacting the mental state of the persons on board, particularly for officers working in critical zones such as the ship's bridge.

Modern ship's bridges represent highly complex systems filled with integrated navigation systems. If one of the automation elements fails, it could lead to incorrect outputs from other systems. A critical concern arises if the (OOW) fails to detect such failures, potentially leading to catastrophic results. In addition, the lack of standardization in the layout and equipment across different ship's bridges complicates matters further. Even if the same equipment is used, variations in instruction and layout

can force OOW to relearn operations, potentially leading to confusion and errors in navigation (Fraende,2020; ICS,2019).

2.3.3 Ship bridge design and navigational equipment



Figure 2.8 Modern ship bridge.(Church, 2022)

A modern ship includes a variety of digital and physical systems that support navigation and operation, such as radar, ECDIS, compasses, and other instruments. The types of equipment provide real-time data on the ship's position, speed, and heading. This information is shown on different screens across the bridge, supporting the OOW to make the correct decision. Alongside digital systems, the bridge also features physical controls, such as buttons for managing the engine and steering as well as traditional tools like binoculars and compasses (Chopra, 2020)

Despite these technological advances, the layout of traditional ship bridge presents ergonomic challenges, with navigational equipment distributed across different locations around the bridge as shown in Figure 2.8 illustrates a modern ship's bridge, highlighting the array of equipment that requires vigilant monitoring and frequent observation to ensure operational integrity. Furthermore, the process of introducing new technology or systems in the maritime industry is subject to regulatory approval, which typically takes a minimum of five years to be implemented. This delay is compounded by the

nature of navigational equipment development, where each system is developed separately over different times. Therefore, equipment is often located in available places on the bridge without consideration of its suitability for performing navigational duties. As a result, the OOW must move around the bridge to monitor and collect necessary information for various systems. Although newer ships have improved in terms of systems integration and ergonomics design, the OOW is still required to monitor multiple navigational systems together to ensure safe operation. Cross-referencing data from different systems remains crucial, including GPS with ARPA and ECDIS, AIS with ARPA and ECDIS, weather monitoring devices, and both magnetic and gyrocompasses.

2.3.4 Improving ship bridge design and operation

As mentioned in 2.2.5 about the ship size evolution, the ship bridge size also increases with ship size. The ship bridge size is between 50 to 60 m. However, ergonomics design, which shapes the work environment to fit human operators, has been recognised as a pivotal solution to reducing human errors in maritime operations (Mallam et al., 2015; Stranks, 2007). The Ergonomics is approached through two primary frameworks:

- 1- **Physical Ergonomics:** This aspect focuses on the physical capabilities of individuals to perform tasks and their placement within the environment. It encompasses activities such as lifting, moving within the workspace, reaching for and handling devices, controlling systems, and addressing safety and health considerations (Stranks, 2007)
- 2- **Cognitive Ergonomics:** this field concentrates on optimising the interaction between humans, machines, and automated systems to enhance human cognition and interaction. Effective cognitive ergonomics can aid in the decision-making process, enhance situational awareness, alleviate stress, and optimise overall task performance (Stranks, 2007).

This research is concentrated on cognitive ergonomics, which explores the interaction between humans and machines to improve performance and enhance the effectiveness of human-machine interaction. The primary aim is to increase human reliability in operational settings by optimising interfaces. By merging the cognitive ergonomics principle into the design of man-machine

interfaces, performance can be improved significantly, leading to fewer errors (Stranks, 2007). Special emphasis should be placed on human-machine interaction, particularly when controlling critical navigation systems used for collision avoidance, such as radar and ECDIS. An important of this interaction is the exchange of information between navigational systems and the OOW, who rely on this information for safe navigation. A well-designed interface can reduce operational stress, minimise human errors, and improve overall performance (Parasuraman and Riley, 1997; Stranks, 2007). However, many current ship bridge designs present usability challenges due to divided equipment integration, inconsistent design philosophies among manufacturers, and suboptimal physical ergonomics. For instance, the control console may be cluttered and difficult to access, impairing night vision, while alarms often produce a similar sound, making it difficult to determine between critical alerts (Danielsen et al., 2022). These design flaws require the OOW to adapt to the system, rather than the system being designed to optimise performance. Prioritising advanced technologies over human factors can result in overloaded interfaces that overwhelm the OOW with complex, multimodal information that is difficult to interpret (Bin Guo et al., 2022). This increases cognitive overload and distraction, highlighting the risk of human error. In addition, the lack of standardised push OOW to continuously adapt to varying bridge layouts and equipment configuration makes navigation confusion and could increase the likelihood of accidents.

Addressing these ergonomics issues is crucial to optimising human-machine interaction and improving operational efficiency and safety. Considering the physical abilities and limitations of users is essential for safe and efficient operation (Stranks, 2007). Moreover, by applying ergonomics principles to ship design and involving end-users in the design process, human errors can be reduced, and performance can be enhanced in high-pressure environments in navigation (Bin Guo et al., 2022).

Our research is dedicated to exploring cognitive ergonomics, specifically examining the interaction between humans and machines to identify factors that could influence the performance of the OOW during ship navigation.

2.4 Human factors in the ship bridge

The bridge of the modern cargo ship is like the heart of the body. It is the control room where the ship's operation is oriented. The bridge is equipped with different forms of advanced technology to assist OOWs, who are responsible for navigating the ship safely and effectively. It is like any other workplace; it can be analysed in terms of the tasks that are carried out in operation and the skills and abilities essential to perform those tasks. This is what “human factors” are all about; we can describe it as understanding the interaction between people and their working environment. (Salvendy and Karwowski, 2021).

Human factors are considered crucial in industrial operations. Historical records from the 20th century show they contribute to the most accidents, with a high percentage, around 66% and 90%, of industrial disasters in aviation and nuclear (Stellman, 1998). Despite some improvements in ship accidents in the last decade, the number of accidents with the technologies utilised in the maritime industry is still a concern (Luo and Shin, 2019c). The advancement of the technologies on board ships and the digital information available are reshaping the work's design, organisation, and operation in the ship bridge. As technologies capable of high automation and autonomy become more sophisticated and practical, the interaction and contribution of humans within these systems are growing. Therefore, the role of humans, including the training, work tasks, and skills needed to manage complex socio-technical systems, are being continuously reshaped by technological progress (Mallam et al., 2020). The increasing technologies and digitalisation in the ship bridge will develop different aspects of human navigation errors, leading to accidents. Addressing these root causes and trying to break them before they happen will improve the performance of the OOW and reduce accidents.

2.4.1 OOW Definition.

As the key person, it is important to describe the Officer Of the Watch (OOW) and his responsibility to understand the role of the human factors on the ship. The officer of the watch, referred to as OOW., is the sole person responsible for maintaining a navigational watch over the ship. This mandate in Rule 5 of the COLREG, and expanded upon STCW 78, as amended, section A-VIII/2, which states that “the

officer on the watch on a seagoing ship of 500 gross tonnages or more shall, as a general rule, not be engaged in any activities other than those relating to the safe navigation of the ship and the proper and safe performance of lookout and bridge duty”. This further supported by rule 34 of the COLREG, which states that the OOW” shall ensure that watch arrangements are adequate for maintaining a proper lookout.”

2.4.2 OOW navigation Responsibility.

Navigation philosophy is founded on complex systems developed over 400 years of maritime history. At the heart of this system is the OOW, who assumes the delegated responsibility for the ship on behalf of the master and, in particular situations, might also be the master. The most important duty of the OOW is ensuring safe navigation. (Olsen, 2024).

The Manila Amendments to the STCW Code, which focuses on the specific requirements for officers in charge of a navigational watch on ships over 500 gross tons or more at the operational level, defines the standard of competence. Officers must demonstrate a deep understanding of and proficiency in several areas (STCW Resolution Chapter II, Table A-II)

- **Navigation:** Officers are expected to plan and conduct safe passage proficiently, using traditional celestial methods and modern electronic aids to determine the ship's position accurately. They must also understand the application of nautical charts, publications, and navigational systems, ensuring the use of the most updated and applicable resources for their trip.
- **Watchkeeping:** Maintaining a safe navigational watch is critical, and this includes a thorough knowledge of the international regulations for preventing Collisions at sea (COLREG,1972). Officers must also adeptly manage using RADAR and ARPA to maintain observation over navigational safety.
- **Emergency Situation:** Officers should be trained to respond to navigational emergencies using standard maritime operational practices, ensuring safety and compliance under all circumstances.

- **Operational use of English:** Competence in English, as required for maritime operations, is essential to ensure clear and effective communication on board.

Therefore, the massive role that pointed to the OOW created different issues that affected the performance on the ship's bridge, which will be mentioned in the following section.

2.4.3 Ship Bridge Team

The main role of the ship bridge team is safe navigation and avoiding critical situations that could be dangerous to people, property, and the environment. The team must work together efficiently and effectively during a single watch or multiple watches. The decision made, and all situations that occurred in one watch could affect the next watch. Therefore, proper and clear communication and management are the key factors to ensure a safe operation among the team. The bridge team is every person assigned to duty inside the ship bridge. According to the (SOLAS) convention, enforced by the flag state, ships are required to maintain a minimum safe manning level. This includes ensuring that crew members possess the necessary documentation, that safety performance is regularly monitored, and that the designated working language is in use (IMO, 1974). (STCW) establishes international standards that outline the minimum qualifications for each member onboard the ship, including all competencies required and certification (IMO, 2017). During the normal bridge watches, the OOW must be present and supported by the rating member, such as an ordinary seaman (OS) or Able Seaman (AB), who performs lookout duties or steers the wheel as a helmsman. In critical situations, the presence of the ship's captain is required to provide additional support to the bridge team. Moreover, a deck cadet and pilot are also required to assist the bridge team during specific circumstances such as training or when entering or departing a port.

2.4.3.1 The master of the ship/ The Captain

The captain or Master is the one who has the highest ranking on board the ship. The master is also known as the commander of the ship. For qualification, the captain must possess a certificate of Competency (CoC) grade 1 or an equivalent Certificate of Endorsement (CoE), in addition to the Bridge Resource Management (BRM) as a mandate by (STCW) convention. These qualifications require formal maritime education, training, and sea service. The captain is responsible for ensuring the efficient

operation of the ship bridge, the security of all crew members, the safety of the ship, and compliance with regulations. Furthermore, the captain oversees the bridge team and manages all available resources to make sure of safe navigation.

2.4.3.2 Officer of the Watch (OOW)

The responsibility of the (OOW) is to maintain a safe navigational watch when the captain is not present. The OOW must possess a (CoC) between grades 2 and 4, depending on rank with a BRM certificate, before engaging in bridge duties. The Chief Officer ranked second command after the captain. Holds (CoC) grade 2. In addition, the Second Officer holds a (CoC) grade 3 while the third officer is a grade 4. The OOW must perform and maintain a safe navigational watch and strictly follow the ship bridge procedures. The OOW, under no circumstances, leaves the ship bridge unmanned unless an equivalent OOW or the captain is available to replace him. The OOW must also ensure a vigilant lookout by using all available navigational equipment and maintaining clear communication and teamwork with other bridge team members.

2.4.3.3 Deck Rating

Deck rating crew members are not required to hold a CoC to work on the ship and do not participate in the BRM course, though they are required to complete various safety courses. The primary role of the rating is to assist the captain and OOW during navigational watches, either as lookouts or by steering the ship when necessary. Given their duties on the ship bridge, deck ratings are expected to maintain a lookout, communicate effectively with other team members, and report any potential hazards that could compromise navigational safety.

2.4.3.4 Deck Cadet

A deck cadet is a seafarer who completes his practical training during his study or after his study nautical studies at a maritime institution to prepare to get a CoC. The cadet must complete a sea service between 12 to 18 months at sea to qualify for the CoC exam to be an official OOW. Although the cadet is not required to participate in BRM, the cadet is exposed to BRM fundamentals during his academic training. On board the ship, the cadet should work under the supervision of the OOW and the Bosun, assisting both on the bridge and on deck. His responsibilities include maintaining a full navigational

watch involving communication, teamwork, lookout duties, and additional tasks assigned by the captain or OOW. Although BRM training is not mandatory for cadets, it is important to improve his performance and contribution to the bridge team.

2.4.3.5 The Pilot

The pilot is a seafarer with specialised knowledge of a specific area, such as ports or channels, that the ship's captain may be less familiar with and that may pose navigational risks. Pilots are required to have extensive local knowledge and, in most countries, hold a CoC along with a pilot certificate, although some countries do not require a CoC. During pilotage, the pilot works closely with the captain and the bridge team, sharing important information and providing instructions for berthing and unberthing. While the pilot is responsible for manoeuvring the ship, the captain retains ultimate responsibility for the ship's safety. In case the captain leaves the bridge, the OOW assumes control of the ship.

2.4.3.6 Bridge Resource Management

Bridge resource management (BRM) course, as required by the (IMO) under the (STCW), evaluates both technical and non-technical skills. A key aspect of BRM is ensuring that the officers are capable of maintaining proper situational awareness, which involves perceiving, understanding, and anticipating the status of various environmental factors, such as the positions of close ships and potential hazards, to ensure effective navigation (Atik, 2020). Furthermore, the (BRM) course is designed to improve the skill of the bridge team members by maximising the use of available resources to ensure safe navigation. However, the course is primarily intended for captains (OOWs) and pilots, while other bridge teams, such as lookout, wheelmen, and cadets, are not included. This is a significant omission towards achieving complete situational awareness on the bridge. Additionally, a review of BRM course content between different maritime institutions has revealed inconsistencies in the materials covered. (Gommosani, 2021). On the other hand, the aviation industry has a similar course, Crew Resource Management (CRM), which standardised content in different aviation institutions and is designed to enhance the performance of all crew members, both in everyday and critical situations (Hayward and Lowe, 2010). However, focusing on human errors individually and exploring the behaviour and the

cognitive demands of each member of the ship bridge will give us a comprehensive understating of the situational awareness which can support the bridge team and improve the training of the (BRM) Course.

2.4.4 Human Factors in the Safety of Navigation

The shipping industries of the 21st century face significant challenges due to technological advances and shifts in operational practices. Technological improvements in ship design and navigation aids have reduced crew size dramatically. 25 years ago, the crew number was 40 to 50, and it has become 22 on a very large crude oil carrier (VLCC) today (Hetherington et al., 2006a). However, Despite the decrease in the number of serious accidents, human errors continue to play a significant role in causing accidents, emphasising the need for effective crew management and training (Grech et al., 2002).

Moreover, as maritime operations evolve toward greater automation with the rise of digital and autonomous shipping technologies, there is a growing need to reassess and adapt training and regulatory frameworks; the role of seafarers is changing, becoming more supervisory and strategic rather than operational, necessitating new approaches to manage massive amounts of navigational data and potential information overload to ensure they enhance navigational safety (ICS,2019). This will refer to and impact the cognitive processing in the OOW during navigation (Saus et al., 2012).

(Albayrak, T. and Ziarati, R., 2010) Mentioned some issues also that automation brought to OOW performance in the ship's bridge, which are:

- OOW is not able to respond effectively when automation fails.
- OOW does not understand all the automation features and their limitations and weaknesses.

There is also a risk that an over-reliance on technological systems may lead to a reduction in traditional navigation skills. As a result, seafarers might struggle to manage dangerous situations if the navigation support systems fail. In addition, excessive dependence on technology, along with a lack of understanding of its limitations and undue confidence in the data provided, can create a false sense of security and lead to incorrect perception or understanding of the external environment. (Schröder-Hinrichs et al., 2012). The combination of some factors might result in some system performance error (Mišković et al., 2018) Figure 2.9.

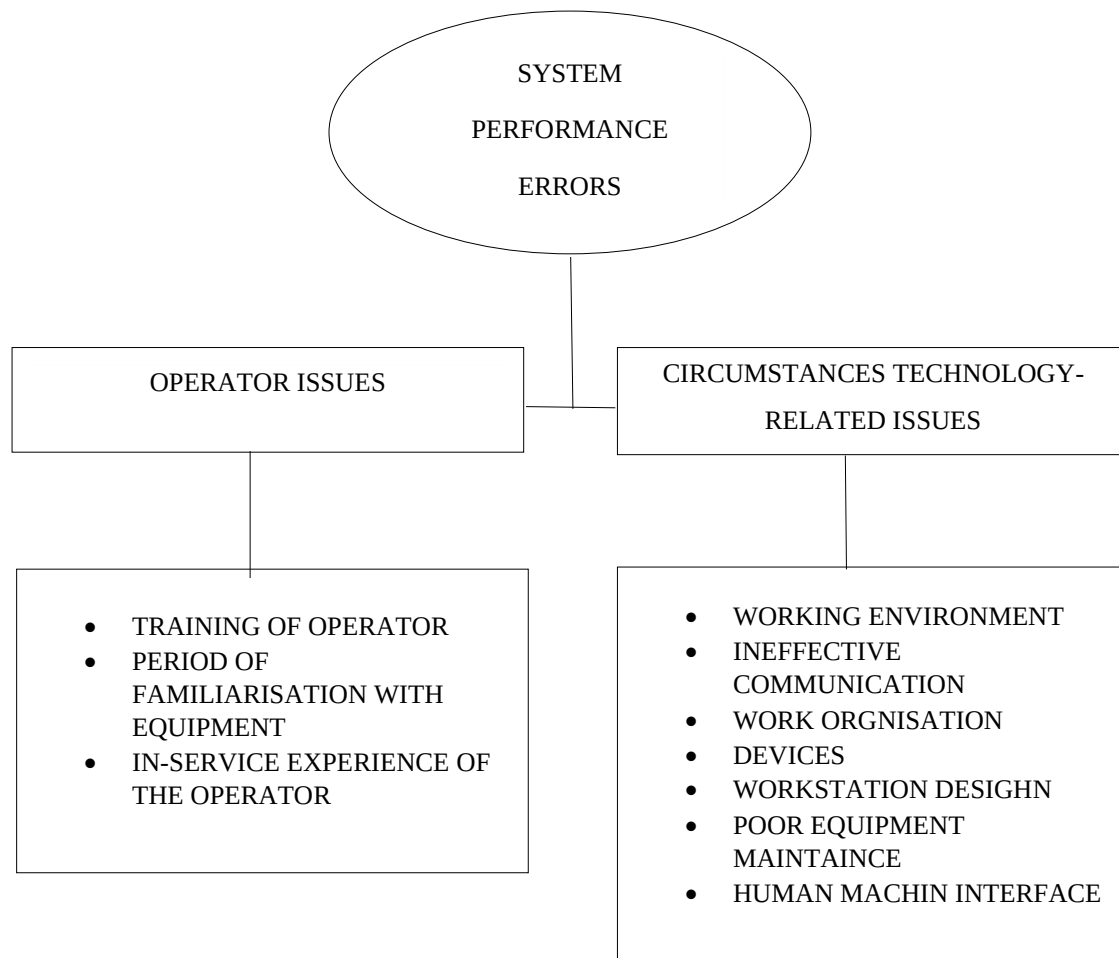


Figure 2.9 Elements that might cause system performance errors (Mišković et al., 2018)

The research underscores that advancements in maritime safety are not solely technologically driven but also heavily reliant on human factors. Managing marine resources and crew training is pivotal in reducing accidents and improving the financial efficiency of maritime operations (Zagorodnia et al., 2021). Incorporating seafarers' psychological factors into maritime safety assessments highlights the pivotal role of human elements in maritime operations. Recognizing that psychological factors such as mental workload, fatigue, and situational awareness critically influence seafarers' performance and safety, advanced neurophysiological tools are being developed to measure these elements precisely. This approach aims to integrate such metrics into regular safety protocols to mitigate the risk associated with human errors more effectively (Fan et al., 2023).

Simulator-based training has been identified as crucial for enhancing situational awareness (SA) among maritime personnel, which is vital for operational safety and efficiency. Cognitive mapping, another method used in analysing and modelling human errors, offers a systematic approach to understanding the interrelated factors leading to maritime accidents and emphasises the role of human factors beyond immediate operational errors, encompassing broader organisational and supervisory elements (Akyuz and Celik, 2014)

Simulator training ensures officers are not only skilled in using the technology and tools of modern navigation but are also equipped to handle the responsibilities and potential challenges faced while managing a watch on a large ship. The structured approach, encompassing practical and theoretical knowledge, ensures officers meet international standards and can operate effectively at the operational level.

2.5 Maritime Education and Training (MET)

The rapid advancement of technology is significantly transforming the maritime industry. The increasing automation in the maritime industries, particularly on-board ships, is changing maritime operations, and there is a pressing need to reshape and reevaluate the role of the seafarers. The shipping industry has become more advanced and demands a new type of training that can improve the performance of the seafarers, equipping them with the skills and competence to face the continuously evolving technology.

Traditional seafarer training mostly focuses on practical and cognitive skills as part of applied science and has evolved since the 1990s to incorporate academic competencies. This shift aims to develop officers proficient in utilising advanced technologies (Demirel, 2020).

The role of maritime education and training schools is to prepare the seafarers for current education and future requirements and development. It is important to understand the impact of advanced technology and its effect on the maritime industry and adopt a new program to improve the teaching and learning approach. A comprehensive teaching approach is valuable to prepare learners with the ability to use and understand new technology systems effectively.

2.5.1 The Importance of MET

The safe operation and management of ships depend on the skill and expertise of the shipboard crew rather than the sophistication of the ship's equipment. The ship operation on the voyage faced different environmental conditions and sea states. The seafarer's knowledge, skill, and proper learning method are important factors in ensuring safety on board a ship and protecting the crew, cargo, and pollution. However, the concept of employing new technology, such as virtual reality and ship simulators on the top technologies for professional training and operation, is not new. Recent advancement and widespread adoption now facilitate their practical implementation in real-world scenarios. Specifically, integrating these technologies into maritime education, training, and operation introduces new possibilities and paradigms to enhance support for operators and operations onshore and offshore (Mallam et al., 2019).

In the past, there was no standardisation for the maritime and education to shape the seafarers' knowledge and skills. Therefore, the 1978 convention was founded by the International Maritime Organisation (IMO) to set the international standard for seafarers' training, certification, and watchkeeping (STCW). Before this, the individual governments established their own standards and procedures, often without consideration of practices in other nations, leading to significant variability despite the essentially international nature of the shipping industry. The convention mandates minimum training, certification, and watchkeeping standards that member countries must meet or surpass (STCW,n.d.). The next section will explore the use of the simulator in the STCW.

2.6 STCW

2.6.1 Introduction

The International Maritime Organisation (IMO) is the agency of the United Nations that sets standards to enhance the safety of international shipping and prevent ship pollution. In this context, the IMO mandates that all masters and watchkeeping officers undergo careful training on the shore before assuming their duties on navigational watch. This ensures adequate learning and qualification to improve safety on board the ship. Therefore, STCW sets global standards for the training and

certification of seafarers. The convention has undergone several amendments to keep up to date with the evolving demands and technological advancement in the maritime industry. One crucial factor influenced by the amendment is simulator training and assessment.

2.6.2 STCW amendment overview

STCW entered into force in 1984, and several amendments were made in 1991, 1994, 1995, 1997, 1998, 2004 and 2006. The last amendment was in 2010, adopted during the STCW convention conference in Manila, Philippines, and updated the standard of competence, particularly regarding advanced technologies. The amendment also introduced new training and certification requirements and methodologies. To understand the STCW requirement-related simulator training, it is essential to understand this requirement under these categories:

- 1- Regulation I/12 Use of Simulator.
- 2- Section A-I/12 Standards governing the use of simulators (mandatory).
- 3- Section B-I/12 Guidance regarding the Use of Simulators.

2.6.3 Regulation I/12 Use of Simulator

This regulation offers the framework for the performance standards of marine simulators utilized in seafarers' training assessment and certification, ensuring compliance with the STCW convention.

2.6.4 Section A-I/12-Standards governing the Use of Simulator (Mandatory)

This section consists of two parts:

Part 1: outlines the performance standards for simulators used in the training and assessment of seafarers. The STCW emphasizes the critical importance of scenario design in maximising the training value of the simulator exercise. It mandates that the simulator possesses realistic visual capabilities to accurately replicate vital operating conditions, selecting appropriate actions and responses from trainees under real-world pressures. A key requirement standard is that the simulator must allow instructors to maintain control over the training session (Ali, A., 2006)

Part2: addresses additional provisions concerning the training and assessment procedures for simulator trainers and assessors. The STCW stipulates that any simulator-based exercise must include briefing, planning, familiarisation, monitoring, and debriefing stages. It underscores the importance of instructor guidance and motivation during the monitoring phase and the use of peer assessment techniques during debriefing. Simulator exercises must be designed and validated by the simulator instructor to ensure they meet specific training objectives.

2.6.5 Section B-I/12 Guidance regarding the Use of Simulators

In the STCW, the mandatory simulator training for the seafarers is only RADAR/ ARPA and ECDIS. The guidance on the implementation of these two navigation equipment provided in STCW (1995, pp. 292-295) outlines the following key areas:

In RADAR:

- Theory factors affecting performance and accuracy
- Detection of misrepresentation of information, including false echoes and sea returns
- Setting up and maintaining displays
- Range and bearing
- Plotting techniques and relative motion concepts
- Course and speed of other ships
- Time and distance of closest approach of crossing, meeting or overtaking ships
- Detecting course and speed changes of other ships
- Effects of changes in own ship's course or speed or both
- Application of the International Regulations for Preventing Collisions at Sea
- Training and assessment in the operational use of automatic radar plotting aids (ARPA)

Using of ARPA:

- Possible risks of over-reliance on ARPA

- Principal types of ARPA systems and their display characteristics
- Factors affecting system performance and accuracy
- Tracking capabilities and limitations
- Processing delays
- Operational warnings, their benefits and limitations
- System operational tests
- Manual and automatic acquisition of targets and their respective limitations
- True and relative vectors and typical graphic representation of target information and danger Areas
- Information on the past position of targets being tracked
- Setting up and maintaining display

Obtaining information from the ARPA display

In addition to the RADAR and ARPA, ECDIS must be installed on different ship types and sizes to comply with (SOLAS) Chapter V regulation 19.2.10 from July 1, 2012, to July 1, 2018. Amendment to the STCW convention (STCW, 2010) requires that any marine officer responsible for keeping a navigational watch on SOLAS vessels equipped with ECDIS and certified as competent in its use to ensure navigation (Yang et al., 2020). With all these amendments and enhancements to the STCW convention, there are differences in the training facilities available among IMO member states, leading to variations in the implementation of regulation and the quality of maritime training across different countries. Although such variation is anticipated, it has not been sufficiently studied by academia (Nazir and Jungfeldt, 2017). Also, research indicates that international bodies have generally been slow or lack resources to identify the deficiencies in STCW content, language competence, automation, emergency situations, and environment (Albayrak, 2012). Nevertheless, the BRM course involves both theoretical and practical training, with the simulator being essential for the practical aspects. As BRM has become mandatory under the STCW convention, the simulator plays a critical role in fulfilling this training requirement by offering practical, realistic experience to improve safety and performance on

the bridge (Gommosani, 2021). However, BRM is not primarily focused on individual skills, rather, its core objective is to enhance the collective performance of the entire bridge team.

The STCW code section A-I/12 outlines the standards of training and assessment using the simulators. Member states of the convention must meet the goals and objectives of simulator-based training as part of a training program. The training objectives and tasks should be close to the real shipboard tasks and operations. It is the responsibility of all member states to make sure to comply with the STCW convention requirements to achieve the approval of the IMO white list. Therefore, to ensure that the members follow the standards of the STCW, they should be certified by the classification society if they use the simulator for formal certification training of seafarers.

2.6.6 Classification Society

Seven leading classification societies were established in 1968 known now as The International Association of Classification Society (IACS), which are (ABS, BV, DNV, GL, LR, NK, and RINA). (ClassNK, n.d.). classification societies are organisations responsible for establishing and implementing technical standards for the design, construction, and inspection of ships. They conduct surveys and inspections of ships and may authorised by flag states to perform statutory surveys and certification on their behalf. There are around 50 classification societies globally. However, only 11 of them are recognised by the European Union, which allows them to operate on behalf of the EU member state (EMSA, 2024)

2.6.6.1 Ship Bridge Simulator and Classification Society

The STCW convention mandates the approval of simulators when they are used for mandatory simulator-based training or to demonstrate competence. Classification societies such as DNV aim to ensure that simulators provide a suitable level of physical and behavioural realism, which is essential for achieving established training and assessment objectives. Moreover, the validity of the certification of the simulator is five years. After five years, the certificate can be renewed for an additional five years if the annual test results are satisfactory (DNV, 2011; Torsten, 2024). However, the certification for the simulator is only for the training centres that provide certified training. If the simulator is used for

research purposes without the goal of certifying seafarers, it may not require a classification society certification.

2.6.7 New Focus Area on STCW

The IMO has initiated a long-anticipated comprehensive review of the STCW convention and code. In February 2024, the International Marine Contractors Association (IMCA) participated in the IMO's Sub-Committee on Human Element, Training, and Watchkeeping (HTW) meeting and took part in the working Group established to review the 1978 STCW Convention and Code (IMO, 2024). A roadmap and methodology were created by the working group for the review process, identifying 22 specific areas that require attention, as a table outlined below in Table 2.5 (Fitzgerald, 2024)

Table 2.5 : STCW outline of key areas for review

1	Integration of emerging technologies in ship operation.	12	Addressing taxonomy and terminologies across the convention.
2	Digitalisation of STCW-related documentation, including certificates	13	Providing flexibility in the revalidation of certification and endorsements.
3	Adoption of new technologies in maritime education and training.	14	Reviewing the implementation of the STCW convention, including the need to update the “Whitelist”
4	Enhancing flexibility, facilitation, and quality in onboard, shore-based, and workshop training, including the use of simulators.	15	Lesson learned from past experiences.
5	Organise flexibility and efficiency in the implementation of new training requirements and reduce administrative burdens.	16	Flexibility
6	Updating sea-time and practical experience requirements to incorporate new technologies, including simulation.	17	Evaluation of alternative certification under Chapter VII
7	Promoting psychological safety, addressing bullying, harassment, and gender-related issues, including sexual assault and harassment (SASH), as well as fostering gender diversity and awareness.	18	Revising watchkeeping arrangements and guiding principles as outlined in Chapter VIII.
8	Focusing on mental health.	19	Aligning the STCW conventions with other IO and international regulatory requirements for ships, seafarers, and ship owners.
9	Developing 21st-century skills and enhancing interpersonal abilities.	20	Addressing the Cybersecurity
10	Addressing inconsistencies in training and certification.	21	Implementation and transitional provisions.
11	Classify different interpretations of STCW regulation.	22	Updating outdated training requirements.

The research in this thesis connects to several key areas identified in the review of the STCW convention and code, particularly around the new technologies, flexible training, and psychological aspects of seafarers' performance. Using a full mission ship bridge simulator, we can replicate real-world conditions, allowing operators to practice and adapt to new technologies. From this, we aim to create a new training method that improves the performance of the (OOW) in recognising the rare safety-critical events through simulator-based training and focuses more on the mental and behavioural aspects of ship operation rather than purely on team-based. A crucial part of our study is analysing past maritime accidents to understand human behaviour and how seafarers realise critical situations and interact with navigational equipment. Specifically, we explore cognitive demand and behaviour in the ship bridge environment, especially in the presence of an assistant "lookout". The research investigates whether the presence of the lookout changes the OOW performance and reaction during a critical situation. furthermore, we consider how mistakes from past accidents can be used as learning opportunities to refine current training practices. One potential outcome is the development of a training framework that allows seafarers to earn credit hours through simulator-based training, which would supplement traditional onboard training. By calculating the appropriate number of hours that can be credited from simulator use, we can create a more structured and effective training program that not only improves technical skills but also enhances the cognitive performance of the OOW.

2.7 Full Mission Ship Bridge Simulator

The development of the radar and navigation simulator began in 1959 with the creation of initial specifications and the introduction of radar observer technique, plotting skills, and blind navigation training (Muirhead, 2001). Throughout the 1960s, significant advancements were made, including the addition of navigation aids, computer-assisted solution systems, and ARPA radar, which enhanced the sophistication of ship models. By 1967, the simulation had evolved by offering full mission capabilities, a motion platform, dynamic and hydrodynamic effects, and improved visuals. Emergency response training and manned models were also integrated. Fisheries simulators were developed in the 1960s to include gear handling and various manoeuvres, incorporating equipment like fish sonar and computer-assisted solution navigation systems. The 1970s saw further integration of instruments like GPS and

ECDIS (Muirhead, 2001). Considering the critical role of the simulator instructor in delivering high-quality training and achieving the desired outcomes of competency-based training under STCW, the industry has made numerous efforts to enhance the qualification of the simulator instructor so that all the scenarios and environment can be controlled (Ali. A,2006). Figure 2.10, Figure 2.11, and Figure 2.12 illustrate some of the advanced ship bridges with the instructor room with different visualisations . Training simulators are extensively utilised to equip operators working within complex systems with the necessary skills to manage both normal and abnormal situations. Advanced technology and increased computational power have greatly enhanced the integration of training simulators into training programs. However, research suggests that simulators are poorly implemented in maritime education and training and need to be investigated further (Hjelmervik et al., 2018; Sellberg et al., 2018).



Figure 2.10 Ship bridge simulator with instructor room (Wartsila, 2020)



Figure 2.11 Ship bridge simulator (Wartsila, 2020)



Figure 2.12 Ship bridge simulator (360) (Wartsila, 2020)

Furthermore, with the advancement in technologies, the market for the simulator has increased. Besides the navigation simulator, there are many types of simulators have been developed to improve the different aspects of the maritime industry. Wartsila and Kongsberg are the largest companies that developed ship simulators. They offer the most developed immersive training simulator to prepare seafarers for real life on board a ship. Table 2.6 will exhibit the simulator available in the market (Kongsberg, 2024; Wärtsilä, 2024)

Table 2.6 : Different types of simulators

No.	Type of Simulator	Function
1	Search and Rescue operation simulator	Help the trainee to train in safe highly realistic scenarios on different boats, helicopters, and facilities for rescue.
2	Inland operation simulator	A realistic environment to support the inland vessel crew training.
3	R&D simulator	The world's first simulator is built to test autonomous vessels and navigation algorithms using digital twin and sensors
4	Offshore and dynamic positioning simulator	For the training use anchor handling, dynamic positioning (DP), and rig crane.
5	Survival craft simulator	For the platform training using a lifeboat,
6	Fishing Simulator	For an end-to-end training of fishing cadets and experienced crew in all processes, it is highly realistic.
7	Oil spill response simulator	Training for vessel and equipment handling during oil spill response operation
8	VTs Simulation	For reality-based training and certification of VTs operators and supervisors.
9	Navigation Simulator	A single platform enables blended navigational learning with different equipment.
10	GMDSS simulator	Imitates ship-to-ship and ship-to-shore communication
11	Tug Simulator	Capable of training a range of functions from basic tug handling manoeuvres for trainees to advanced towing methods for tug masters.
12	Small craft simulator	Life-like training simulation for control, manoeuvring and communication equipment.
13	ECDIS Simulator	The most realistic, scalable, and cost-efficient ECDIS training solution that is fully compliant with the latest international regulatory requirement
14	ICE navigation and management simulator	For the ship navigation and equipment handling in cold weather conditions (Below 0 degree)

With all advancements, the study of the psychological factors of seafarers has become a valuable method for exploring the human factors related to accidents using simulators. However, there is a lack of objective methods in the ship bridge training simulator (Tusher et al., 2023). The use of bio-sensory tools becomes a crucial tool to measure psychological factors and cognitive load in seafarers. Different researchers used EEG and eye-tracking tools to explore and enhance seafarer performance.

2.8 Psychological Factors in Maritime

Following the discussion on the factors that adversely affect human performance during the navigational watch and their impact on the (OOW), it is necessary to take measures to support the OOW and improve navigational safety. Understanding the characteristics of how humans learn, and process information is crucial for enhancing human performance. Moreover, addressing human psychology and integrating human-machine systems is vital for enhancing the navigational process. This also

contributes to a better working environment on a navigational bridge, ensuring optimal performance. Achieving this understanding of the brain processes facilitates learning new skills and retrieving existing knowledge for problem-solving. These concepts are explored within the realm of educational psychology, specifically under cognitive load theory (Leppink, 2017).

Psychological factors are recognized as major contributors to human errors in industries other than maritime, such as aviation and healthcare. However, in the maritime sector, there is limited research of study about these psychological factors, and how psychological factors impact ship handling and decision-making in maritime environments, even though they play a significant role in the majority of shipping accidents (Andrzej Hejmlich, 2022; Fan et al., 2023).

This section provides a brief overview of human factors in the maritime sector, focusing on how neurophysiological elements such as mental workload, stress, situational awareness, and attention can be incorporated into the discussion of human factors.

2.8.1 Mental Workload

The relationship between mental workload (MWL) and maritime safety is critical, particularly considering the technological advancement in maritime operations.

Recent technological advancements in ship navigation have led to increased automation, positioning maritime operations at a crossroads between human expertise and automated processes. While automation is often viewed as a means to reduce human error, the complexities of human interaction with systems can paradoxically increase the risk of mistakes due to the mental workload imposed on ship operators.(Mišković et al., 2018; Pazouki et al., 2018). Mental workload refers to the mental effort required to perform a task. The concept is critical in understanding how operators interact with the complex system (Longo et al., 2022). Figure 2.13 below shows how OOW deals and operates with different tasks in the modern ship bridge, which creates a mental workload.



Figure 2.13: OOW in ship bridge operation (created by the author)

Across various professional settings, high mental workload is closely associated with burnout and reduced job performance. This relationship is evident in sectors like academia, where multitasking cross-teaching, research, and administrative duties can lead to significant stress. In air traffic control, increased task complexities have been shown to correlate with a higher mental workload, suggesting a similar application in maritime operations for optimizing task allocation (Akca and Küçükoğlu, 2020).

Mental workload varies among individuals and is influenced by cognitive abilities, task complexities, and situational awareness (SA). It encompasses a variety of cognitive processes and directly impacts performance and safety in high-stakes environments like maritime navigation. Integrating advanced automation in maritime operations has highlighted the importance of maintaining an optimal mental workload. High or low levels can lead to performance degradation and increased safety risks. (Zhang et al., 2023). This is particularly evident in maritime autonomous surface ships (MASS), where the balance between automation and human oversight is crucial (Yoshida et al., 2021). The role of (SA) is also pivotal; a higher mental workload can significantly reduce SA, thereby compromising safety (Müller-Plath et al., 2023).

Psychological factors have been emphasised significantly in maritime safety. The role of psychological factors in maritime settings, linking them directly to operational and safety outcomes. By integrating

psychological principles into maritime operations, there is a potential to enhance job satisfaction, reduce stress and MWL, and improve overall safety conditions. This holistic approach not only focuses on individual well-being but also on creating a supportive organisational culture that enhances the resilience and psychological capital of seafarers (MacLachlan, 2017)

Different studies have developed several techniques to measure (MWL), which can be assessed through performance metrics, subjective evaluation, and psychological indicators. Between these, subjective assessment methods, for example, The Task Load Index (NASA-TLX) developed by the National Aeronautics and Space Administration (NASA), the Subjective Workload Assessment Technique (SWAT), and the Workload Profile Method have become increasingly significant and widely used gauging operator workload (Kartoglu et al., 2022; Li et al., 2022). A study argues that subjective evaluation methods are easy to implement and, cost-effective and straightforward to administer. However, the accuracy of subjective data has been a longstanding topic within the scientific community (Yan et al., 2019). The uncertainty stems from concerns that participants might interfere with outcomes, make inaccurate estimations, display unreliable participation, or exhibit response biases (Yan et al., 2019).

Recent research has provided robust methodological mental workload through physiological signals such as EEG and ECG, which are crucial in understanding cognitive demands and stress in the maritime environment. Using Random Forest and other machine learning models to analyse physiological data has proven effective in predicting mental workload, thereby supporting dynamic task allocation and enhancing safety on board. This approach improves the reliability of assessments and supports the development of adaptive systems that adjust to the operator's mental state, thus preventing cognitive overload and potential errors (Fan et al., 2020). The advancements in EEG-based technologies have significantly enhanced our understanding of mental workload variations during maritime tasks, emphasising the impact of cognitive demands on operational performance. Studies have shown that different cognitive office tasks and social media interruption can lead to variations in mental workload, highlighting the need for tailored strategies to manage these effectively in high-stress environments like maritime operations (Ding et al., 2020).

2.8.2 Situational Awareness

In recent years, SA has emerged as a pivotal aspect of human factors crucial for accident prevention, particularly in industries where operational complexities and dynamic environments play significant challenges (Endsley, 1995). Even though the first studies of SA were in the military and aviation, SA has become an important research area across various industries where understanding human performance in complicated and evolving scenarios is essential (Salmon et al., 2006). Especially in the maritime industry, SA has been identified as a leading human factor contributing to accidents, highlighting its enhanced safety and operational protocol (Chauvin et al., 2013).

SA has been a topic of extensive research over the past decades, with several definitions proposed to describe this complex concept. The last common definition for the SA was by:

- Endsley, in 1995, offered perhaps the most widely adopted definition, stating that SA involves perceiving the elements in the environment within a specific time and space, understanding their significance, and forecasting their future status (Endsley, 1995).
- In 1999, Bedny and Meister expanded on these ideas by an individual. This reflection not only contemplates past, present, and future but also considers potential characteristics of the situation, incorporating both logical-conceptual and imaginative that help individuals construct mental models of external events (Bedny and Meister, 1999).

It is crucial to consider factors that could undermine situational awareness; most of them come from psychological roots. Key factors that influence SA include boredom, carelessness, focused attention on a single aspect, complacency, overconfidence, distraction, expectation of the human information process, inattentiveness, poor judgment, lack of motivation, failure to follow order pressure technique, and inadequate training. (Melnyk et al., 2022).

Recent studies have emphasised the need for advanced training and cognitive support systems to enhance SA in complex operational settings like maritime navigation. (Naderpour et al., 2015; Sharma et al., 2019b). These studies suggest that improving SA through targeted training, better information

dissemination, and the use of technologies like EEG to monitor brain activity during navigation tasks can significantly enhance operational efficiency. (Kahraman et al., 2023).

2.8.3 Stress

Stress is defined as a force applied to a system that generates pressure, leading to responses aimed at maintaining equilibrium. In biological systems, stress typically refers to factors that demand an organism's physiological or psychological state, prompting an adaptive response (Kranner et al., 2010). Longstanding exposure to stressors can lead to distress when coping mechanisms are overwhelmed. Particularly in the maritime context, work-related stress includes factors like excessive responsibility, monotony, sleep difficulties, long separation from family, noise, vibration, temperature change, and poor organisational communication (Carotenuto et al., n.d, 2012).

A recent study explores mental workload and stress among maritime trainees. The presence of an experienced captain reduces trainees' workload and stress, highlighting leadership's role in managing crew stress. Captains inherently face higher stress due to their responsibilities, while helmsmen reference lower levels (Lim et al., 2018). This study indicates that when OOWs work alone on the ship's bridge, they encounter all the stress factors that adversely affect their performance.

While often seen negatively, stress is an adaptive response. However, it can lead to insomnia, weakened immunity, and high blood pressure. Researchers use both subjective and objective methods to measure psychological stress, including physiological metrics like skin temperature, electrodermal activity (EDA), heart rate (HR), and EEG combined with functional near-infrared spectroscopy (fNIRS). Tools like the Short Stress State Questionnaire (SSSQ) and the Dundee Stress State Questionnaire (DSSQ) are also employed (Alsuraykh et al., 2019).

Another study highlights stress management's crucial role in maritime navigation. Stress and fatigue contribute to up to 90% of maritime accidents and maritime incidents, emphasising the importance of situational awareness and decision-making skills. With its high temporal resolution, EEG technology effectively monitors real-time stress and cognitive state. Using the Advanced Navigation Research Simulator (ANRS), the researcher found that task difficulty correlated with stress levels, and the

experienced pilot managed stress better (Singh Viridi et al., 2022). This study advocates integrating stress management and situational awareness training into maritime education to enhance safety and decision-making. Also, it indicates that more experienced OOWs observe lower levels of stress.

2.8.4 Attention

Attention is an essential psychological aspect for maritime seafarers, involving the capacity to concentrate visual resources on related stimuli, ignoring distraction (Hancock et al., 2013). In the maritime sector, maintaining visual attention is fundamental for situational awareness and hazard detection to avoid accidents (Hetherington et al., 2006a).

Several studies underscore the significance of attention to maritime safety. For instance, Grech et al. (2002) determined that lapses in attention were the leading cause of maritime incidents. Similarly, Fan et al. (2020) pointed out that a lack of attention contributes to a collision between two ships. Therefore, improving seafarers' attention through training and the ergonomic design of ship navigation equipment is essential for enhancing safety and preventing accidents (Hetherington et al., 2006b).

Attention plays a crucial role in maritime navigation, where navigators must handle intricate tasks and high-pressure situations. A recent study explores the development of experimental tools for detecting navigator attention in an erratic system, employing geometric approximation, mathematical models, and a navigation simulator. These tools assess how navigators prioritise and shift their attention, revealing differences in strategies between seasoned and novice navigators. Instruments like eye-tracker and heart rate monitors offer real-time data on stress and attention, which can refine training programs and boost navigational safety by promoting balanced attention strategies and adaptive responses in critical situations (Nosov et al., 2020).

2.9 EEG Application in Maritime Setting

Electroencephalography (EEG) has emerged as a vital tool in understanding seafarers' cognitive and emotional states. It offers a direct measure of brain activity that can enhance safety and performance in maritime operations. EEG-based systems in maritime virtual simulations provide an innovative approach to training and assessing seafarers. These systems enable the real-time monitoring of

seafarer's cognitive states, such as workload and stress, during simulated maritime tasks. This technology allows for a more granular and objective assessment of a seafarer's ability to handle complex navigational scenarios, potentially leading to more targeted training that can address individual weaknesses. Recent studies have utilised EEG to explore various aspects of seafarers' workload, stress, and emotional response during simulators of maritime operations.

A recent study provided a detailed method using EEG to monitor stress levels with high accuracy, employing a combination of fractal dimension, statistical features, and machine learning techniques as support vector machine (SVM) to classify stress methods. The EEG data recorded during these tests revealed that distinct patterns of brain activity correspond to different stress levels, enabling the development of a real-time monitoring system that could be particularly useful for high-stress professions like maritime navigation (Hou et al., 2015).

EEG-based studies have demonstrated the ability to quantify mental workload and stress among crew members in maritime simulators, revealing that experienced captains significantly reduce the perceived workload and stress among less experienced crew members. This supports the importance of leadership and experience in managing crew performance (Lim et al., 2018). Additionally, EEG technology has been applied to assess the emotional states of seafarers during critical operations like collision avoidance by correlating EEG data with ship manoeuvring parameters. Researchers have found that seafarers' emotional states, such as stress and excitement, vary significantly across different navigational scenarios and directly impact operational decisions and vessel trajectories (Wang et al., 2021).

Moreover, developing an algorithm using EEG data to recognise mental workload and emotional states has created a more adaptive and responsive training environment in maritime simulators. These advancements aid in personalising the training program and enhance the predictive accuracy of human errors in maritime operations, thereby contributing to the development of safer practices and procedures. (Liu et al., 2020). Furthermore, using EEG and psychological measures in a virtual simulator offers critical insight into the seafarers' emotional response and cognitive loads, which are crucial for enhancing training protocols and improving maritime safety. The combination of high-

resolution data from EEG and scenario-specific assessment allows for a detailed analysis of how seafarers handle critical situations, potentially transforming training methodologies to focus more on individual needs and capabilities (Ma et al., 2022). These approaches contribute to a nuanced understanding of the interplay between human factors and maritime safety, advocating for a more integrated and technologically advanced framework in maritime training and assessments. This aligns with the ongoing efforts to enhance the effectiveness of maritime simulator training and the need for reliable and innovative assessment methods that cater to diverse learning outcomes and training environments (Tusher et al., 2023).

Overall, integrating EEG technology and other bio-signals into the training and evaluation of seafarers represents a significant advancement in maritime education. This approach enhances our understanding of human factors at sea and supports the reduction of human errors in maritime operations. By providing real-time, objective data on seafarers' mental states, EEG technology helps to bridge the gap between psychological research and practical application. It aligns with ongoing efforts to improve situational awareness and decision-making under stress, contributing to safer maritime navigation and operations. Additionally, this integration ensures that maritime operations are aligned with crew members' cognitive and emotional capabilities.

2.10 Eye Track Application in the Maritime

Eye tracking is a sensor technology that detects and records eye position and movement, identifying where or what an individual is focusing on, also referred to as the point gaze. This point of gaze can be measured across various stimuli, whether on a computer screen, in a real-world environment, or in a virtual reality setting. Eye trackers can function as independent devices or be integrated into other technologies, such as extended reality (XR) headsets, personal computers, or vehicles for automotive applications. Furthermore, Eye tracking has numerous applications, including scientific and medical research, accessibility tools for individuals with disabilities, improving road safety in driving, and enhancing experiences in virtual reality and gaming (Miseviciute, 2024). One of the earliest applications of eye-tracking in the maritime sector was done by Arslan et al. (2005), who utilized eye-tracking technology to assess navigators' sea experience by analysing fixation points during ship bridge

simulator exercises. The study aims to explore differences in fixation patterns based on the different levels of experience and education. The result revealed that there is a significant difference in fixation between those with more experience and those with less experience, indicating that the experience influences the navigator's visual attention. Another study aims to understand the differences in visual scanning between experienced and novice navigators during ship bridge simulator exercises by exploring the use of eye-tracking to analyse how the OOW distributes his visual attention between the external environment and the navigational equipment, highlighting the potential of eye tracking technology to improve bridge design training program, and safety by identifying how visual attention correlates with experience and workload in maritime navigation (Lützhöft and Dukic, 2007). As maritime technologies advance and ship sizes increase. Nowadays, the maritime industry tries to understand human performance by exploring cognitive load, situational awareness, and attention. This growing awareness has driven research to focus more on cognitive and behavioural measurement. eye tracking is a technology tool used to assess and measure attention, workload, and cognitive processes during simulator training. By analysing the eye pupil size with fixation and saccades, a different aspect of the cognitive demand could be measured. A study explores the use of eye-tracking in a ship bridge simulator to evaluate decision-making processes, MWL, and ergonomics. In the experiment, OOW faced an unexpected situation that required immediate decision-making. The data extracted from eye tracking, including fixation and saccades, was used to measure MWL and stress. The results highlight that offices with more experience showed lower MWL and higher decisions, suggesting that eye tracking could enhance simulator training by improving SA and task performance (Muczyński et al., 2013). An additional experiment conducted in a high-speed vessel simulator focused on comparing the eye moment of experts and novices under different sea conditions. The study found that experienced seafarers navigated faster than novices and reduced their fixation duration as the wave roughness increased(Godwin et al., 2013). In recent years, the trend of using eye tracking has been to explore seafarers' cognitive processes and behaviour during tasks. Many studies and training programs utilise simulators to imitate real-world scenarios, particularly high-risk situations, without the danger of causing damage or loss. This shows the importance of the simulation to enhance the performance. An experiment in the ship bridge simulator investigates the MWL during complex scenarios. The study

focuses on the fixation and transition between the navigation equipment. The results illustrate that MWL increased during complex traffic situations, as reflected in more frequent transitions between critical equipment such as ECDIS and RADAR. Furthermore, eye-tracking can be used to investigate SA between the officer and cadet in simulator training using different fixation patterns in BRM training, which reveal significant differences in the SA. In addition, the heat map can be extracted to look at the navigation equipment used in the ship bridge (Arslan et al., 2021; Atik, 2020). Additionally, the researcher applied a machine learning algorithm and was able to recognise navigational tasks such as using RADAR and ECDIS and monitoring the ship heading and speed, revealing that eye tracing can be used as an objective and automated method to evaluate the performance and enhance the safety training (Virdi et al., 2022). Eye tracking can be used to monitor and improve trainee focus, cognitive load, and decision-making in the training, in addition to analysing human behaviour under stress and improving usability and user engagement in the training. Moreover, eye tracking can be used objectively to explore cognitive processes and better understand the user's visual attention to the different points inside a specific area (Luimula et al., 2020; Uflaz, 2023). However, combining the two technologies together will provide valuable insight to understand the human cognitive mentality and behaviour.

2.11 Combining EEG and Eye tracking

The integration of the EEG and Eye-tracking technologies provides significant insight into the human cognitive process, offering a comprehensive understanding approach to studying attention, cognitive load, and mental state. EEG measures brain activity where the cognitive demand can be extracted, while Eye tracking captures visual attention and fixation patterns. This will allow the researchers to analyse and measure the humane mentality, capture human behaviour during different tasks, and find the issues that occurred in real-world scenarios. This combined approach is applied successfully in a different field, including education, medical science, marketing, and image processing (Jamal et al., 2023). However, there is a shortage of studies in the maritime industry that use EEG and eye-tracking together. The integration of both technologies has illustrated the possibility of enhancing vigilance in monotonous tasks, such as surveillance. The participant detected intruders in a simulated environment,

and introducing challenging stimuli, such as rain, led to significant improvement in vigilance. The finding suggests that integrating challenges into tasks can mitigate vigilance decrement and enhance task performance by increasing MWL and attentional resources (Bodala et al., 2016). Moreover, a study approach to emotional recognition involving 44 participants exposed to effective stimuli reveals that EEG alone was insufficient for accurately detecting emotional self-regulation. However, the combination of EEG with biometric measures like electrodermal activity (EDA) and eye-tracking significantly improved emotion detection (López-Gil et al., 2016). More research explores cognitive processes and visual attention using both technologies to analyse behaviour in tasks such as film viewing and map-related information retrieval. In the first study, eye tracking and EEG were integrated to understand how films elicit emotional and attentional responses from viewers. Eye-tracking provided a real-time measure of viewers' focus, while EEG captured their emotional state, revealing a coherence between the two sources of data. Similarly, the second study examines cognitive load in expert and novice map users during spatial memory tasks of varying difficulty. Saccade metrics and EEG power spectrum were key indicators of cognitive load. Saccade metrics show the differences between experts and novices, while EEG data indicate increased cognitive load across all difficulty levels. Although the two groups had no significant differences, performance differences emerged between good and poor learners (Keskin et al., 2020; Szajerman et al., 2018). The use of the Eye-track and EEG will be the trend in the future of research. These methods have emerged as key tools for examining the deeper cognitive process underlying user behaviour. Looking into the future, research will likely focus on multisensory interaction and integration of different physiological measures. Such as skin conductance, respiration, and heart rate, to better address user differentiation needs. (Nolte et al., 2024; Zhu and Lv, 2023). Therefore, with the growing importance of neuroscience and its methodologies, EEG is being increasingly utilised to gain into users' thoughts. The combination of eye-tracking and EEG has become a leading approach to user research. This joint method provides more precise, detailed, and comprehensive user data than subjective reports, allowing researchers to objectively understand both what operators focus on and their cognitive process.

2.12 Summary

The analysis of accident reports provides a comprehensive understanding of the underlying reasons behind maritime accidents, especially those related to human errors. In addition, the maritime industry highlights that the ship size continues to increase, and the number of crew members has been reduced, which has created a new risk, especially in the congested water where the OOW must maintain a high level of attention. The reduction of the crew means the OOW has more responsibility in the ship bridge, which increases the chance of making mistakes in busy water or complex situations, particularly if the OOW navigates solo.

An important aspect addressed in the review of the STCW convention and its amendment is the emphasis on non-technical skills such as situational awareness and cognitive decision-making. As the industry evolves, the requirement of the STCW underscores the need to update the training of the seafarers focusing on developing a navigational skill that is capable of managing the modern and larger ship. It is essential to ensure that the training program produces highly qualified seafarers capable of handling the complexity of maritime operations today. With the evolution of the maritime industry, simulators have become an important approach in seafarer training, offering realistic practising scenarios that imitate real-life situations on the shipboard. Simulators support crew members practice handling emergencies safely, improving their readiness for the actual shipboard challenges.

Using objective tools such as EEG and Eye tracking is a crucial method that changes the understanding of seafarers' performance under pressure. These technologies support the measurement of cognitive processes like MWL, stress, and attention, and they also give us a clear picture of what happens mentally and behaviourally during a critical situation. From this information extracted, the training program can be enhanced by focusing on real human performance and behaviour in safety critical situations.

From the Author's point of view, future seafarer training needs a more advanced approach. However, combining advanced simulation and psychological tools in training with a strong focus on the human factor will lead to more effective seafarers' education. By enhancing simulator training, we can develop

a new training program that prepares seafarers for technical navigation aspects, enhances their ability to manage MWL and stress, maintains situational awareness of the realities of modern maritime operation, and reduces the risk of accidents. However, such training would gain popularity if recognised as part of the seagoing experience officially and certified by the awarding bodies.

Chapter 3 Aims and Objectives

3.1 Problem Definition

There is a lack of standardised maritime simulator training for marine officers, who can conduct practical training that covers different safety-critical situations to improve navigation skills. In addition, there is a lack of evaluation and assessment standards that will allow the officer's performance to be observed and measured during simulator training. Nevertheless, most of the trainers evaluate and assess the trainees subjectively according to their experience (Jinbiao Chen, Tingting Chen, 2011).

However, maritime simulator training is a vital tool to improve the mentality and behaviour in human performance. In the simulator, the trainee will be in an atmosphere that is similar to the real ship's bridge, where the trainee will conduct training based on the scenarios derived from past accidents and near misses. This training will provide the knowledge and navigation skills required on board a ship. The advantage of a simulator is that the trainee has permission to make any mistake and learn from his wrong action without any cost or damage. (Petersen,2016) reported about BIMCO/ICS that there will be a significant shortage of officers by 2025, and training levels should be increased dramatically to avoid the severe shortage. Although STCW's last amendment in 2010 (Manila Amendment) highlighted the importance of training to improve technical and non-technical aspects and mentioned simulator training. However, there is no clear guidance about simulator training and assessment.

The need to design a training scenario in the simulator is a crucial topic in order to provide training that covers all the aspects to improve human performance. However, exploring the seafarers' mentality and behaviour during critical conditions will give us an idea about the issues that officers could face on board the ship. Therefore, the need to have high-quality marine officers raised the idea of this research to enhance the simulator training by developing training scenarios based on real accidents that occurred, aiming to address human errors and improve them.

3.2 Motivation

With the development of technology, the ship bridge simulator training became very advanced, and one can create an almost identical environment similar to real life on board a ship. However, the above-mentioned issues motivate us to develop training scenarios of rear safety-critical events to explore human performance in the ship simulator, find the weaknesses, and develop a training course to improve the weaknesses and enhance overall human performance for individuals and a team.

However, training in full-mission simulators in maritime institutes is not mandatory, except for ECDIS and RADAR training. The existing training scenarios in the full mission simulator depend on the experience of the instructor who creates the scenario. So, the trainee will build up his skills related to the instructor's experience. On the other hand, creating training scenarios based on the accidents that have occurred will allow the simulation of safety-critical/dangerous scenarios, learning from mistakes that have occurred, and developing skills to recognise potential threats and successfully navigate away from the danger. In addition, it will be possible to address human errors and try to improve the performance of the ship's bridge. Moreover, learning from aviation and its standards of training could be the right step towards improving the training. Therefore, creating a standardised training course for safety-critical scenarios in a simulator will shape the skills of seafarers and improve their performance.

3.3 Gaps

The maritime industry shows several vital deficiencies in ship bridge simulator training and preparedness protocols. In maritime institutions, there is no standardised ship bridge simulator training for the officers and cadets that builds situational awareness for emergency situations. Furthermore, the assessment of the performance is subjective, no objective assessment focuses on their mentality and behaviour. In addition, simulator training may not cover all possible scenarios that a seafarer might face on board a ship. Therefore, more scenario-based training must be used to utilise real accident case studies. This limitation means that while simulator training can prepare the trainee for common situations, adding a rare event or unexpected situation will make the training more effective. Therefore, integrating the real accident scenarios and rare events scenarios will ensure that trainees can apply

simulated skills in real-life contexts. In addition, the cost factor can limit the widespread of the simulator system, which leads to outdated training modules. Furthermore, full-mission simulator training is optional in the maritime industry. Unlike the aviation sector, maritime simulator training does not receive equivalent accreditation or recognition. The maritime sector simulator training also needs to catch up to the advanced methodologies employed in aviation. This gap suggests that the maritime industry needs to adopt more rules and policies for successful training practices. However, some predictive reports indicate that, without a considerable increase in training initiatives, the maritime industry will face a future shortage of qualified officers, emphasising the critical need for enhanced and mandatory training programs.

3.4 Aim

The main aim is to identify the seafarer's cognitive demand and performance behaviours using objective instruments and improve human performance individually and as a team in the ship's bridge environment to develop intelligent training programs in a full-mission simulator considering emergencies and accidents that have already happened.

3.5 Objectives

- Review and analyse the maritime accident reports that have occurred using the human factors classification method to identify the human factors involved and create the database of rear events and the underlying causes.
- Create case study scenarios based on previous accidents in the full mission simulator to investigate the cognitive demand of the officer on the watch (OOW) during the training.
- Visit different maritime institutions to see the various types of full mission simulator centres.
- Develop evaluation and assessment methods using objective tools to measure human performance and cognitive demand.
- Propose a framework to accept the full mission ship bridge simulator training as an equivalent to sea-going experience.

Chapter 4 Methodology

4.1 Introduction

Maritime accidents occur due to several factors, including human errors, equipment malfunctions, commercial pressure, technical issues such as equipment or engine failures, etc. However, the primary contributors to these accidents are human factors and equipment failures. In addition, the increasing number of ships in the coastal area and near the ports has significantly influenced maritime accidents. Still, the complexity of maritime navigation has increased further, especially with the evolution of technology. However, expanding ship sizes and increasing the automation in the fleet required highly qualified and skilled navigators. Therefore, the evaluation of navigation skills has become essential. Despite many techniques available for assessing navigation performance during training, most have not changed, mainly based on experts' subjective assessment (Øvergård et al., 2017). Understanding the key factors leading to maritime accidents is not just crucial; it is imperative. This understanding forms the backbone of our research, guiding us towards effective prevention and mitigation strategies. Using an objective method to assess navigator performance, we can identify the factors affecting performance and shape high-standard qualified officers to deal with emergencies. This research has the potential to improve maritime safety and training significantly.

Based on the research issues outlined in the previous chapter and the analysis of the maritime accident, this study will aim to assess the OOW's performance and behaviour during safety-critical situations the primary focus of this research is to understand the cognitive process and behaviour of the OOW, as these are critical areas for enhancing navigational safety and improving officer performance on the ship's bridge. In addition, the objective is also to identify how the OOW interacts with the navigation equipment during high-pressure scenarios, considering how the seafarer distributes their attention in the ship bridge environment. Furthermore, the research will investigate whether cognitive demand affects the performance of OOW in complex scenarios. To achieve this, training has been developed based on a real accident involving two groups of seafarers; the first group is without a lookout, while the other group with an assistant acting as a lookout. The idea of the presence of a lookout is to observe if there

is any improvement in the cognitive load and behaviour during his/her presence. Figure 4.1 outlines the roadmap of our research.

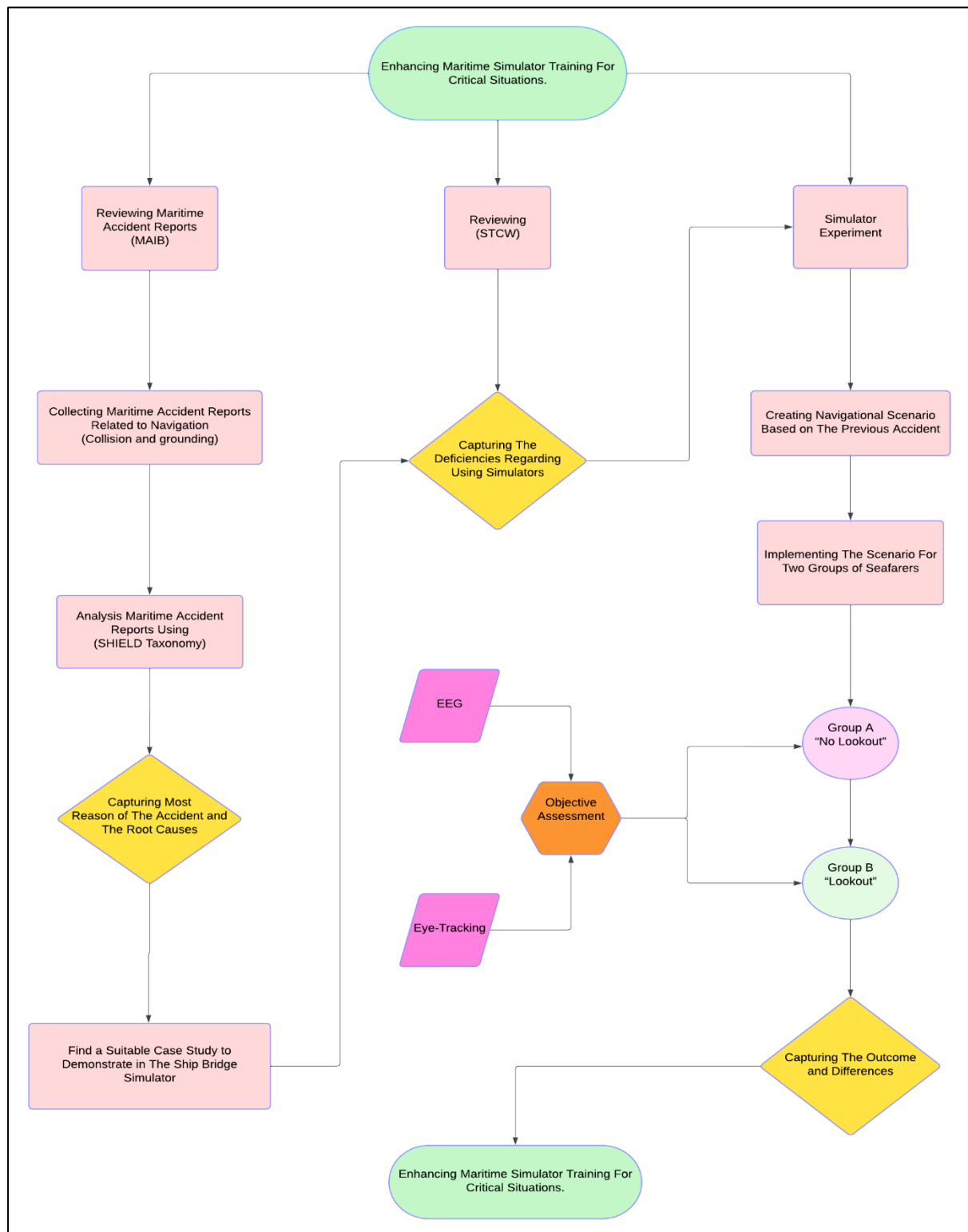


Figure 4.1 Design of the methodology

4.2 Simulation design

The research will utilise a full-mission bridge simulator to recreate the chosen accident scenario. The use of the simulator will allow us to replicate the conditions under which the accident occurred. The scenario is designed to simulate a complex and high-stress environment, which will challenge the OOW's decision-making and attention distribution.

4.2.1 Participants and Equipment

The participants wear both EEG and Eye-tracking as shown in Figure 4.2, while engaging in the simulator training designed to test and explore their visual attention and workload. The experiment is divided into five events that will be explained in Chapter 8. During the experiment, EEG and Eye tracking will be continuously recorded Figure 4.3



Figure 4.2 Participant wearing instruments



Figure 4.3 Laptops recording the signals

4.2.2 Experimental approach

Two experiments will be conducted using the same accident scenario. However, additional targets will be introduced to increase the complexity of the scenario:

- **First Experiment:** the OOW will navigate the scenario solo, as was the case in the original accident. The aim is to identify potential weaknesses in the OOW's performance under high cognitive load and to assess how he/she manages the situation alone.
- **Second Experiment:** in this experiment, a lookout will assist the OOW in evaluating whether the presence of an assistant influences the OOW's performance and behaviour. This will help us understand how teamwork and additional support impact decision-making and attention distribution in a complex situation.

4.3 Assessment tools

4.3.1 Electroencephalography (EEG)

4.3.1.1 Introduction

EEG is a signal that holds valuable information about the condition of the brain. It is a non-invasive technique for recording and interpreting brain activity. The signal is recorded through an extensive collection of electrodes on the scalp that send electrical signals from the brain. (Kannathal et al., 2005). The electrical potentials measurable on the scalp surface originated from the low-frequency summation of inhibitory and excitatory postsynaptic potentials (PSPs) produced by pyramidal neuron cells. These PSPs generate electrical dipoles between the soma and apical dendrites. The cumulative effect of these PSPs in the cortex extends to the scalp surface, where they are recorded as EEG signals Figure 4.4 (Siuly et al., 2016).

The first study published results of using EEG was carried out in 1929 by German scientist Hans Berger. He used an instrument that measures and records brain activity. The instrument is named electroencephalography, commonly shortened as EEG. (Encyclopaedia Britannica, Inc.,2023).

Interpreting EEG signals involves complex mathematics because it deals with a signal that encompasses various evolutions over time and often contains a significant amount of noise.

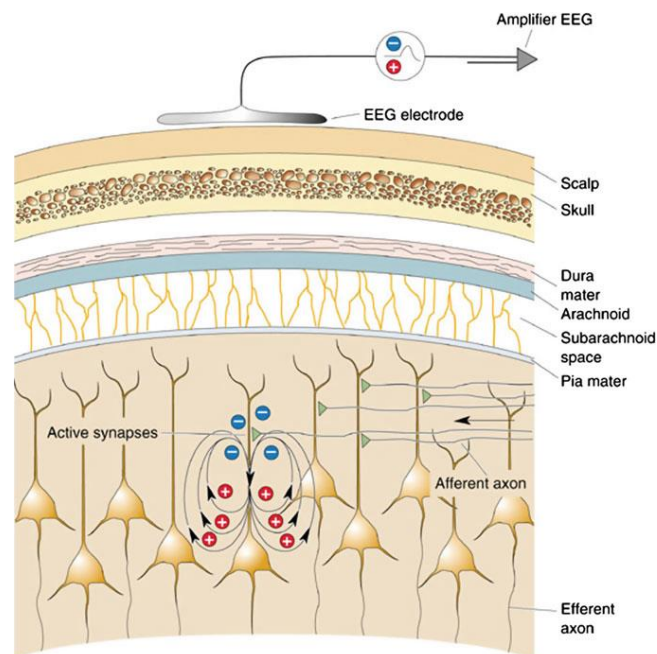


Figure 4.4 Example of the EEG record (Siuly et al., 2016)

4.3.1.2 The brain lobes and function

Each hemisphere of the brain is divided into four lobes: frontal, parietal, temporal, and occipital, as shown in Figure 4.5 . Our EEG focused on the frontal and parietal lobes, and they are responsible for:

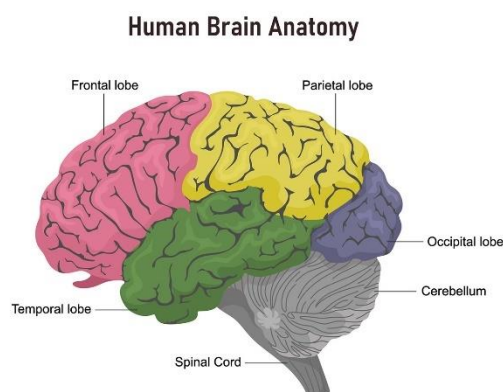


Figure 4.5 Human Brain Lobes (Hopkins, 2024)

- **Frontal Lobes:** the brain's largest lobe, located at the front of the head, is responsible for personality traits, decision-making, and movement. It also plays a role in recognising smells and contains Broca's area, which is linked to speech production.
- **Parietal Lobes:** located behind the frontal lobe and above the temporal lobe. The parietal lobe helps individuals recognise objects and understand spatial relationships, such as the position of their body relative to nearby objects. It also plays a role in interpreting pain and touch. Wernick area, located in the parietal lobe, aids in comprehending spoken language.

4.3.1.3 Type of EEG Device

EEG systems have two types of connection and electrodes, Figure 4.6 (Soufineyestani et al., 2020):

- **Wired or Wireless:** EEG systems use either a wired or wireless connection to transmit brain wave data from electrodes to a recording device. Wired connections use physical cables, providing stable and high-quality signal transmission, which is ideal for clinical and research settings. However, they restrict participant movement and can be heavy, with a higher risk of cable disconnection. On the other hand, wireless connection uses technologies like Bluetooth, enhancing participant mobility and convenience that require movement, such as sports or virtual reality. The downside is that wireless systems can suffer from signal interference and data loss, and they depend on battery power, which may limit the recording duration.
- **Wet or Dry:** EEG electrodes are either wet or dry. Wet electrodes require conductive gel or paste to ensure proper contact between the scalp and the electrodes, providing a more stable and lower-impedance connection and thus, better signal quality. However, applying the gel can be messy, time-consuming, and uncomfortable for the participant, requiring cleaning afterwards. In contrast, dry electrodes do not need conductive gel, allowing for quicker and more comfortable application directly to the scalp. This makes them suitable for situations needing rapid setup. Despite these advantages, dry electrodes generally have higher impedance and may not capture signals as effectively as wet electrodes, potentially affecting data quality.



Figure 4.6 Type of EEG Device

4.3.1.4 Types of Signals and Characteristics.

EEG signals are complex signals, as shown in Figure 4.7. The rhythm of signals is allocated into several frequency bands. EEG waves are classified depending on their frequency, amplitude, and shape, as well as the location of the electrodes on the scalp; the basic unit used for the frequency is (Hertz, Hz) (Kumar and Bhuvaneswari, 2012). Different amplitudes and frequencies of EEG may change due to the different people of different ages. In addition, changes in mental state and behaviour might differ in brain wave frequency response.

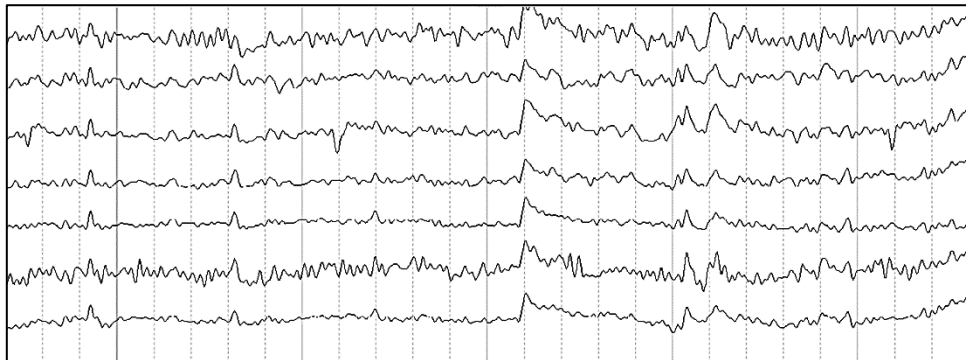


Figure 4.7. EEG signals

The signals transmitted from the brain through EEG instruments have different frequencies. Five types of waves can be identified based on the frequency range. From low to high frequency, respectively, they are alpha (α), theta (θ), beta (β), delta (δ), and gamma (γ) Figure 4.8. Each wave is associated with a different mental state, as shown in Table 4.1

Table 4.1 Mental state and frequency

Name of Wave	Frequency (Hz)	Mental State
Delta (δ),	0 – 4	Deep Sleep
Theta (θ),	4 – 8	Drifting Thoughts, Dreams, Creativity
Alpha (α)	8 – 13	Calmness, Relaxation, Abstract Thinking
Beta (β),	13 - 30	Highly Focused, Highly Alertness
Gamma (γ)	>30	Simultaneous Process, Multi-Tasking

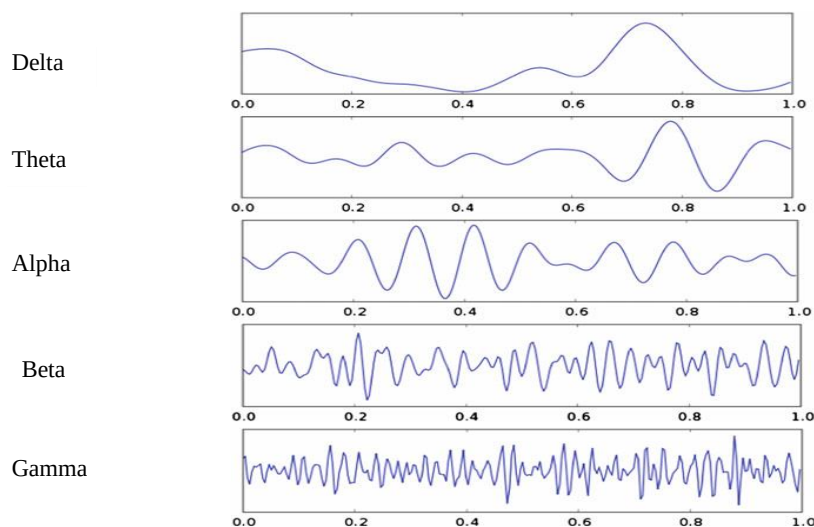


Figure 4.8 EEG signals

- **Delta:** Delta wave, the highest in amplitude and slowest in frequency, represents brain grey matter activity. They are present in all sleep stages and are the dominant rhythm in infants but are rarely seen in experienced meditators. In awake adults, delta waves are abnormal for a wake and associated with growth hormone induction.
- **Theta:** theta waves, ranging between 4 to 8 Hz, are linked to subconscious activity and are common during deep relaxation and meditation. They are normal in children under 13 but abnormal in adults. Theta waves aid in spiritual practices and extrasensory skill development through meditation, and psychotics use them for awareness. They also stimulate the production of human growth hormone, serotonin for relaxation and pain relief, and cortisol for memory and learning.

- **Alpha:** alpha waves, present in all age groups, are common in relaxed, awake adults with closed eyes. They appear on both sides of the head, with higher amplitude on the non-dominant side, and are recorded from the occipital and parietal brain regions. Representing the brain's white matter, alpha waves bridge the conscious and subconscious mind and stimulate serotonin production, promoting relaxation and pain relief. An abnormal occurrence is an alpha coma, caused by hypoxic-ischemic encephalopathy or damage to the pons.
- **Beta:** beta waves are linked to behaviour and sensory perception, including sight, touch, smell, and taste. They appear in the frontal and parietal lobes and simulate cortisol production, which affects aging, learning, and memory. Beta waves are present during conscious activities like talking, problem-solving, judgment, and decision-making and are crucial for cognitive processes.
- **Gamma:** gamma waves, ranging from 30 to 70 Hz, are linked to perception and consciousness. They became analysable with digital EEG, as analogue EEG could not record frequencies above 25Hz. Gamma waves occur during heightened alertness, integrating sensory inputs and combining senses with memory for a complete experience.

4.4 EEG Data Signal Analysis

The EEG signals of the officer of the watch (OOW) were recorded using the DSI-7 device at a sampling of 300Hz, utilising the DSI-streamer v.1.08.60 software Figure 4.9 and Figure 4.10 (Wearable Sensing, 2015). After the experiment is finished, the data will be collected, and EEG signals will undergo various preprocessing steps to ensure clean data for analysis Figure 4.11

4.4.1 EEG LAB

EEG lab is a toolbox and graphical user interface that operates within MATLAB. It can process EEG data across any number of channels and supports various EEG data processing functions. These functions include importing channels and event information, visualising data, and pre-processing data. Additionally, EEG LAB supports independent components analysis (ICA) and time /frequency

decomposition, including channel and component coherence, with statistical methods based on data resampling. (Brunner et al., 2013; Delorme and Makeig, 2004).

4.4.2 Amplitude, EEG

It is a measure of the change of EEG signals with respect to the mean value, usually measured in microvolts (μV), and often expressed as the difference between the maximum and minimum deviation (i.e. peak-to-peak), or in rectified EEG from baseline-to-peak.

4.4.3 Artifact

Artifacts are unwanted signals resulting from external noise, such as that from electrical circuits, rather than brain activity. These artifacts interfere with the signal measurement, complicating analysis. The artifacts are due to the system's impedance and sampling frequency issue because ground loop artifacts usually occur at 50 Hz and 60 Hz (Allen et al., 2000).

4.4.4 Independent Component Analysis (ICA)

Independent Component Analysis (ICA) is a method used to extract source signals from a mixture of signals, assuming the source signals are independent and combined linearly. Recently, ICA has been successfully applied in various biomedical fields, particularly brain imaging techniques like EEG and fMRI. It is particularly effective in removing artefacts, which are presumed to be independent of the brain's underlying processes (Sri and Rajapakse, 2008).

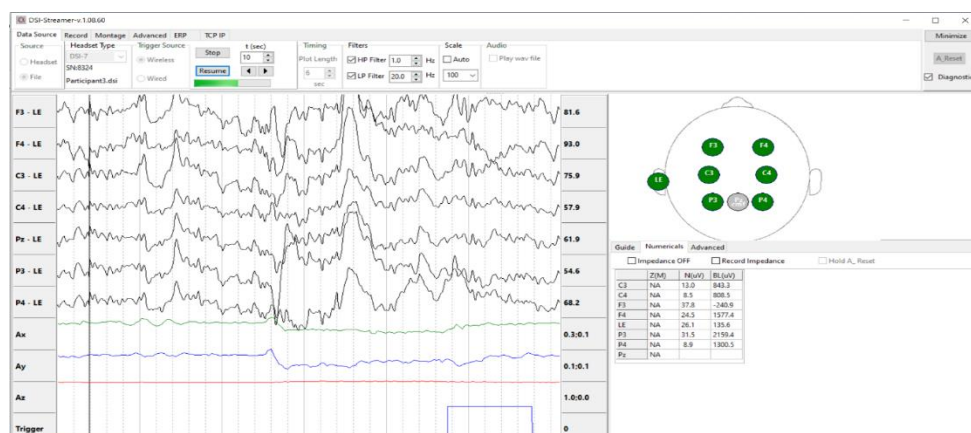


Figure 4.9 Software of the EEG



Figure 4.10 EEG device

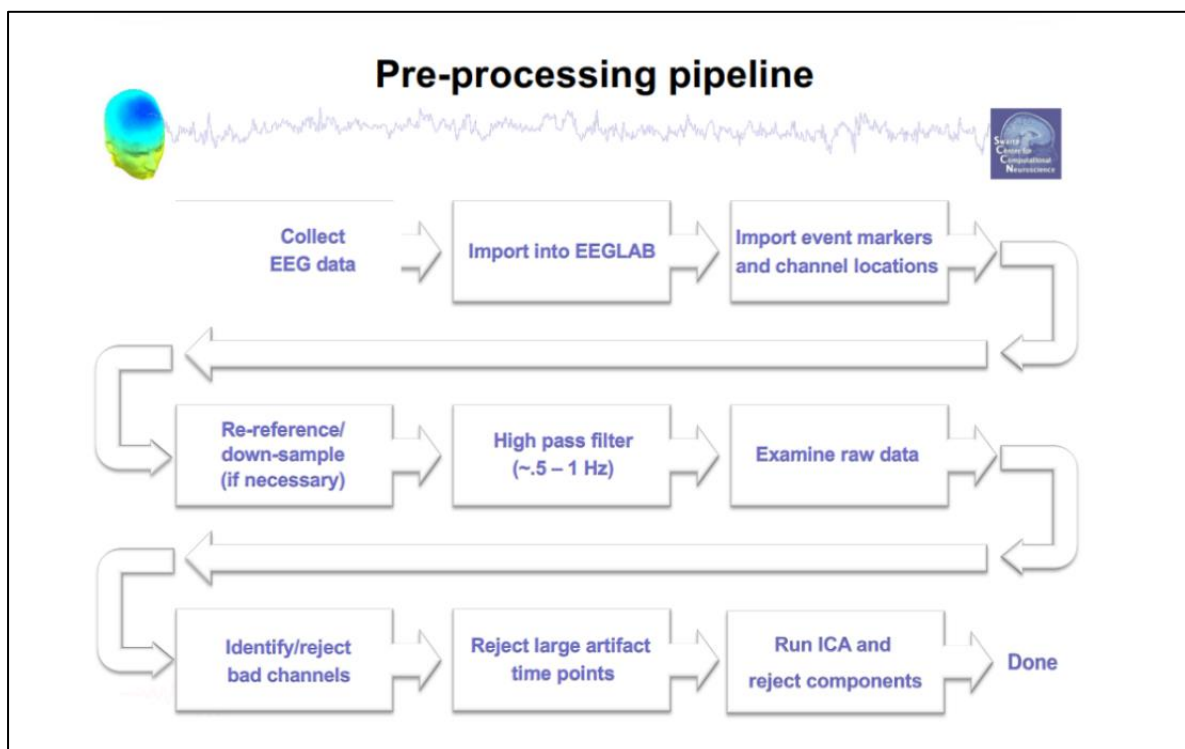


Figure 4.11 EEG pre-processing pipeline (Source: Swartz Centre for Computational Neuroscience)

To analyse the collected data and obtain the result, a code was developed in EEGLAB with the support of Dr. Daniel Kahani (the Author's second supervisor). This code facilitates the data analysis processes and the obtaining of results. Therefore, the Global Field Power (GFP) was calculated from EEG data without artefact, focusing on the Theta, Alpha, and Beta frequency bands, which are relevant for

assessing mental state (Ronca et al., 2023). GFB is chosen as the primary indicator of brain EEG activity due to its capability to represent the level of synchrony or activity in specific cortical areas within the time domain for a particular frequency time.

After preprocessing the EEG data, features derived from EEG-GFP are calculated to identify mental states objectively. Specifically, indices for mental workload, stress, and attention are computed as follows (Ronca et al., 2023):

$$MWL = \frac{Frontal\ Theta\ GFP}{Parietal\ Alpha\ GFP} \quad 4.1$$

$$Stress = Parietal\ Beta\ High\ GFP \quad 4.2$$

$$Attention = \frac{Frontal\ Beta\ GFP}{Frontal\ Theta\ GFP} \quad 4.3$$

After obtaining the result, the neurophysiological – Mental Workload, stress, and attention are normalised using Min-Max scaling to standardize the value within a range of 0 to 1 for all participants. This normalization process ensures comparability and consistency across the data set (Singh and Singh, 2020)

$$X\text{- Normalized} = \frac{(X - X\ Min)}{(X\ Max - X\ min)} \quad 4.4$$

After getting the result, a 3-colour scale is used to show the high, which is red colour, yellow is medium, and low, green to show the variation of the factors with event complexity.

4.5 Eye Tracking Technology

The “eye mind” hypothesis, introduced by Just and Carpenter (1976), suggests that where people look reflects what they are thinking about that moment. This idea was used for the development of eye-tracking technology, which supports pinpointing exactly what someone is looking at, when, and for how long. Eye tracking converts eye movement to data, including pupil size and gaze direction, and specific points of focus by eye fixation. The data need special software for collection and analysis. This technology provides an understanding of a person’s visual attention and cognitive process and is useful in many fields (Just and Carpenter, 1976; Bojko, 2013; Kim et al., 2015)

The eye movement gives important clues about human behaviour for two reasons. The first reason, where we choose to look, shows what we need to focus on at any given time. The second reason, we usually need to pay attention to where we point. Eye movements are a precise and effective method to understand our cognitive function and information needs during any behaviour (Tatler et al., 2014).

4.5.1 Eye tracking concept

To understand how we see and process visual information, psychologists studied the physiology and anatomy of the eye, as well as the cognitive process involved in vision.

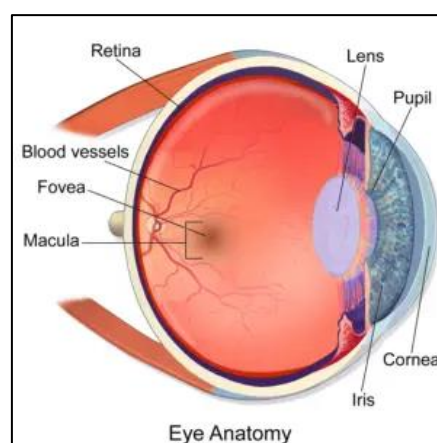


Figure 4.12: Eye concept (Blausen.com staff, 2014)

Figure 4.12 illustrates the eye configuration. The brain processes images through light-sensitive cells in the retina, known as rod and con cells. These cells detect light entering through the pupil and send the visual information to the brain. Although there are fewer cone cells compared to rod cells, cones allow humans to see in high resolution and in full colour. Cone cells are concentrated in the fovea, the central part of the visual field, which is the area of the eye with the highest visual clarity. However, the fovea is quite small, and vision outside this area, in the peripheral region, is much clearer. As a result, the eye needs to move to capture detailed visual information. This combination of high-resolution central vision and low – resolution peripheral vision is what makes eye-tracking technology possible (Eyeware, 2022). Researchers use eye tracking to utilise eye movement and fixation data to study attentional processes, analyse group behaviour, evaluate visual response to stimuli, and explore various other cognitive functions.

4.5.2 Types of eye tracking

There is more than one type of eye-tracking technology depending on what is the application for using eye tracking. However, there are three types of eye-tracking applications:

1. Screen Based Eye Trackers Figure 4.13

Screen-based eye trackers are devices that monitor and measure a person's eye movement and gaze pattern while viewing a screen. This tracker can record and analyse data such as where, when, and for how long an individual focuses on a specific area of the screens, along with details about pupil size and eye blinks. Screen-based eye trackers have a wide range of application (IMotion Online, n.d.)



Figure 4.13 : Screen based eye trackers (I Motion Online, n.d.)

2. Eye Tracking Glasses Figure 4.14

Eye-tracking glasses are wearable devices that track a person's eye movement and gaze behaviour as they interact with the real world. These glasses provide insight into attention, cognition, emotion, and behaviour in a natural environment, they can be applied in a variety of contexts and use.



Figure 4.14 : Eye tracking glasses (I Motion Online, n.d.)

3. VR Eye-tracking, Figure 4.15:

The incorporation of eye-tracking technology into Virtual reality (VR) and Augmented Reality (AR) headsets marks a groundbreaking innovation, revolutionising both academic research and commercial application. By merging the immersive nature of VR/AR with the accurate tracking of eye movements, these headsets offer unprecedented insight into human behaviour, attention, and interaction within a digital environment.



Figure 4.15 :VR eye tracking (IMotion Online, n.d.)

4.5.3 Eye-tracking analysis

4.5.3.1 Eye Pupil Diameter Analysis

Pupil diameter is a known indicator of cognitive load. the raw pupil diameter data was reported from the Tobii Pro lab for further analysis. The average of the pupil diameter for each event and task was calculated, and significant changes in the pupil size were interpreted as marks of cognitive effort or fatigue. Pupil size has been studied and shows that there is a link between the variation of the pupil size and mental workload in both lab environments and real-life (Kramer, 1990). Furthermore, it helps us understand mental demand by measuring pupil size and human behaviour by tracking how long someone focuses on equipment during training. The eye pupil size found that during tasks requiring planning and visual attention, pupil size increased more than during tasks focused on verbal memory, which usually increases with a high workload (Van Der Wel and Van Steenbergen, 2018). However, changes in the illumination can results changing in the size, which should be considered (Pfleging et al., 2016).

4.5.3.2 Area of Interest and Eye Fixation

The key area where the participants focus on some point in the simulator environment was defined as an Area of Interest (AOI). During the preparation of the experiment, critical equipment should be identified in the ship bridge simulator where the tests were performed. The number of hits on this equipment will indicate the area that the participant focused on. The AOIs were mapped in the Tobii Pro lab software, allowing for tracking of participant gaze on a specific object Figure 4.16 . If we calculate the number of hits with the eye fixation on the object, we can get the percentage for each navigation equipment that the participant was interested in. In addition, Table 4.2 Show the layout of the ship bridge with the AOI that is marked as the critical equipment.



Figure 4.16: Area of Interest (AOI)

Table 4.2 Area of Interest (AOI) Definition

AOI	Definition
RADAR	Display information on collision risk with another vessel (CPA/TCPA)
ECDIS	Provide electronic chart data offering environmental information like traffic, reporting area, depth and AIS data
VHF	Facilitate external communication
Display Unit	Allow switching between auto and manual steering, and show own ship information
Top Display Unit	Display general ship information such as course and speed turn of rudder
Engin	Control the ship's speed.
Visualisation	Display the outside environment as seen from the bridge
Visualisation Panel	The panel lets the participant turn the screens to view the surroundings.

4.6 SHIELD Taxonomy

When an accident occurs, we always place the blame based on observable factors, ignoring the investigation of deeper underlying causes. This is similar to an iceberg, where we only see the visible top and ignore the submerged part that holds critical insight, Figure 4.17 Understanding these hidden factors is essential for comprehending why the accident occurred.



Figure 4.17 Iceberg example (Stroeve et al., 2023)

The SHIELD-HF taxonomy functions like an iceberg, revealing the observable factors and the underlying causes behind accidents. It looks into the deeper reasons and factors that could affect human performance. SHIELD taxonomy developed under the European Union's SAFEMODE project aligns with the key component of NASA-HFACS, HERA, and Reason's Swiss Cheese Model (Stroeve et al., 2023). The SHIELD taxonomy is structured into four layers, each layer containing various categories with several factors, Figure 4.18, these layers are:

ACTs: the act describes what occurred and what deviated from the plan and includes 5 categories and 18 factors.

Preconditions: these identify factors influencing performance during operation, including 12 Categories and 61 factors.

Operational Leadership: This covers policies of operational leadership that may impact work arrangements, which include 3 categories and 15 factors.

Organization: which details the influences of the organization and the external business environment and operation, including 4 categories and 17 factors

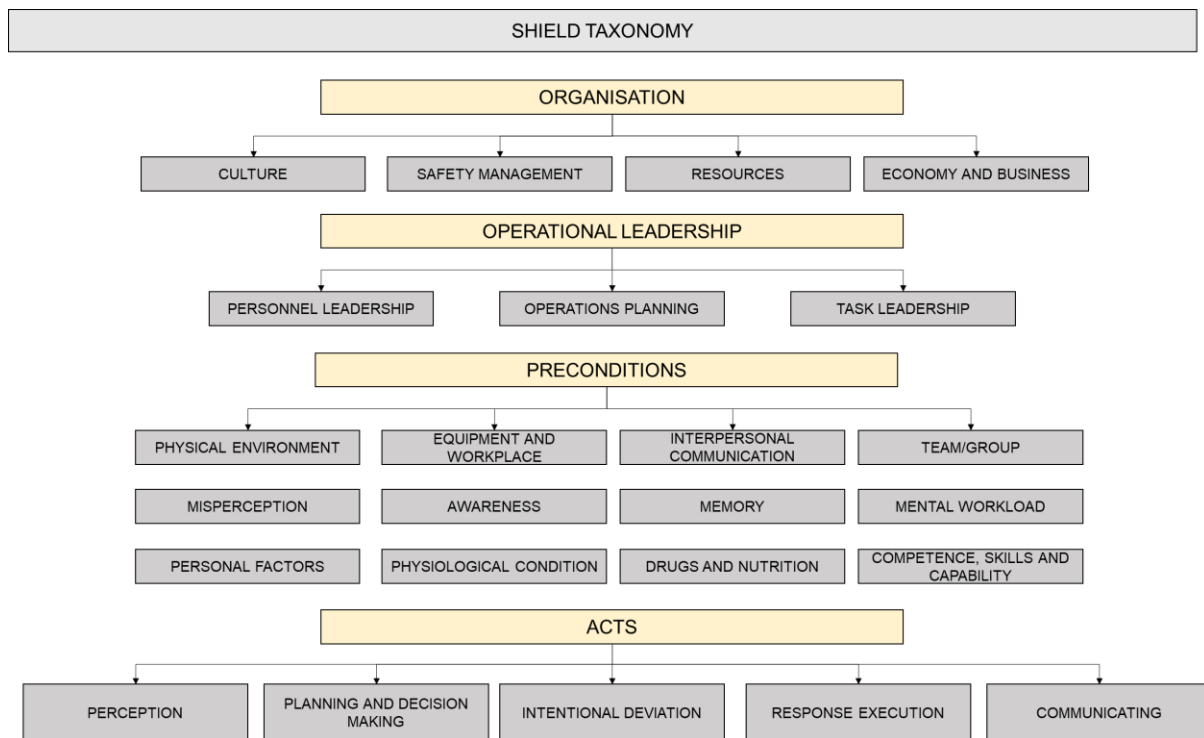


Figure 4.18 SHIELD Taxonomy

SHIELD-HF taxonomy aims to assist the system and operation designer, risk assessor, and manager in efficiently reclaiming and analysing safety occurrence data related to specific human performance influencing factors, safety events, and contextual conditions. This enables learning from reported incident narratives to identify critical contributory factors, compile statistics, and establish a foundation for integrating human elements into quantitative risk models for maritime and aviation operations.

4.7 Summary

The research concentrates on assessing the performance and the behaviour of seafarers during complex situations. The goal is to enhance the performance and improve navigation safety. Therefore, the ship bridge simulator has been done to replicate the real-life maritime accident scenario where the OOW was navigating solo the first time and with assistance in the second experiment. The study used two objective psychological methods, which are EEG and eye-tracking, for assessment. The outcome will be used to identify the weaknesses and evaluate the influence of the lookout's presence on the OOW

performance and behaviour. This will guide us to develop a new training course that focuses on non-technical skills in line with STCW.

Chapter 5 Marine Accident Investigation Branch (MAIB) Accident Data

5.1 Introduction

Human factors remain a critical element in maritime safety. It contributes significantly to the occurrence of maritime accidents despite the advancements in marine technology, education, and training. Many types of accidents can occur onboard ships. However, among the most frequent types of maritime incidents related to navigation are collision and groundings, which often result from human-related deficiencies such as decision-making errors, communication, and situational awareness failure. To better understand and address these issues, this chapter explores human factors in maritime accidents by analysing data from (MAIB), highlighting key human factors trends and their impact on maritime safety. By examining the interaction between human behaviour, organisational practice, and technological factors, the analysis aims to identify opportunities for improvement maritime operation and reduce human errors through enhanced maritime training, improved leadership practice, and the effective integration of new technologies. With this effort, this research will contribute to creating a safer and more resilient maritime navigation system.

5.2 Analysis of Human Factors in Navigational Accidents

The most frequent marine accidents are grounding and collisions, despite the improvement of marine education and training (Martelli et al., 2023). A review of the Maritime Accident reports from an open data source from the United Kingdom MAIB has been done to investigate the human-related factors in ship collisions and try to find a proper solution to improve these factors with the aim of preventing collisions. The accident analysis includes all ships sailing in the United Kingdom water and any ships under the UK flag. Furthermore, the maritime accident reports were reviewed and analysed by the MAIB based on the ships above 100 Gross Tonnage, excluding fishing and pleasure craft because they have special regulations. After uploading more than 200 reports, the reports were classified according to the most common navigational accidents (collision and grounding). After that, a team from Maritime Human Factors Centre, who had sea experience including the authors of this thesis, analysed the accident reports using the SHIELD taxonomy that will be defined later. Our research focuses on the

navigation ship accident especially the Collision in congested waters because it involves two ships and the chance of getting collided in congested water is higher than in open water, and the outcome of the accident could have a massive impact on the environment.

5.2.1 Finding

The research analysed 244 between 2000 and 2021 revealed that 50.82% occurred because of the collision Figure 5.1, with 43.55% of these collisions occurring in congested water Figure 5.2 and we capture most of the HF categories that occurred during these accidents.

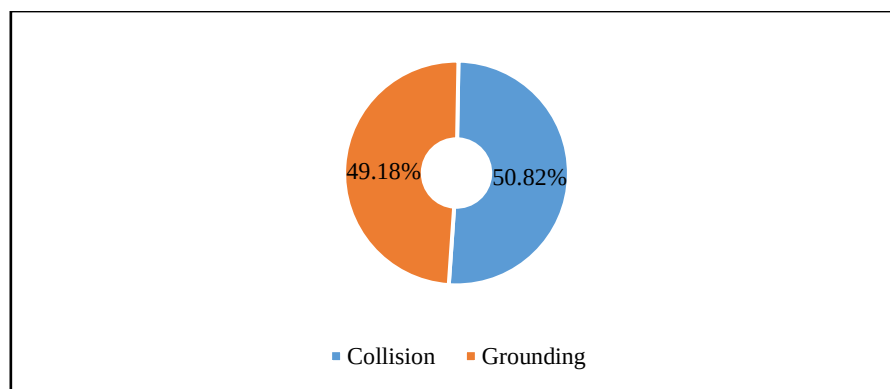


Figure 5.1 Distribution of accident investigation by the type of accident (244 MAIB Reports)

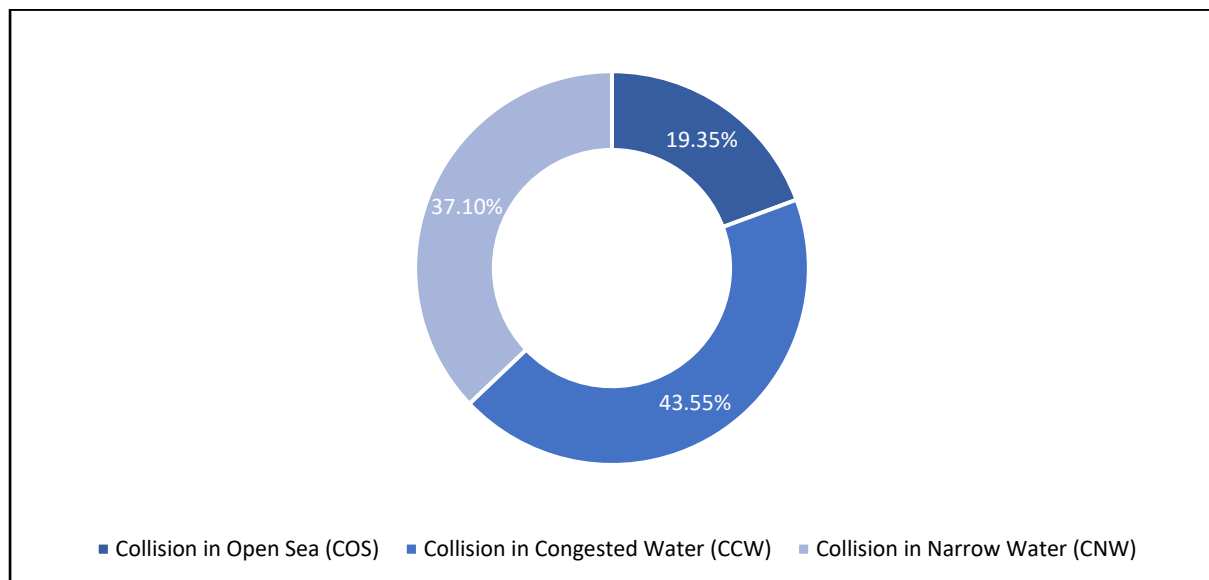


Figure 5.2 : Distribution of collision accidents according to the location (124 MAIB Reports)

Furthermore, utilising SHIELD taxonomy, 807 factors were captured. We categorized the reasons for accidents from the accident reports into four categories: Acts, Preconditions, Operational Leadership, and Organization. The analysis revealed that the most common category was Acts, representing 39% of the reasons with 317 occasions. This was followed by the precondition with 26% and 213 cases, then operational leadership accounting for 19% of the reason with a total of 157 factors. Finally, the organisation contributed to 15% of the reasons with 120 occurrences, Figure 5.3

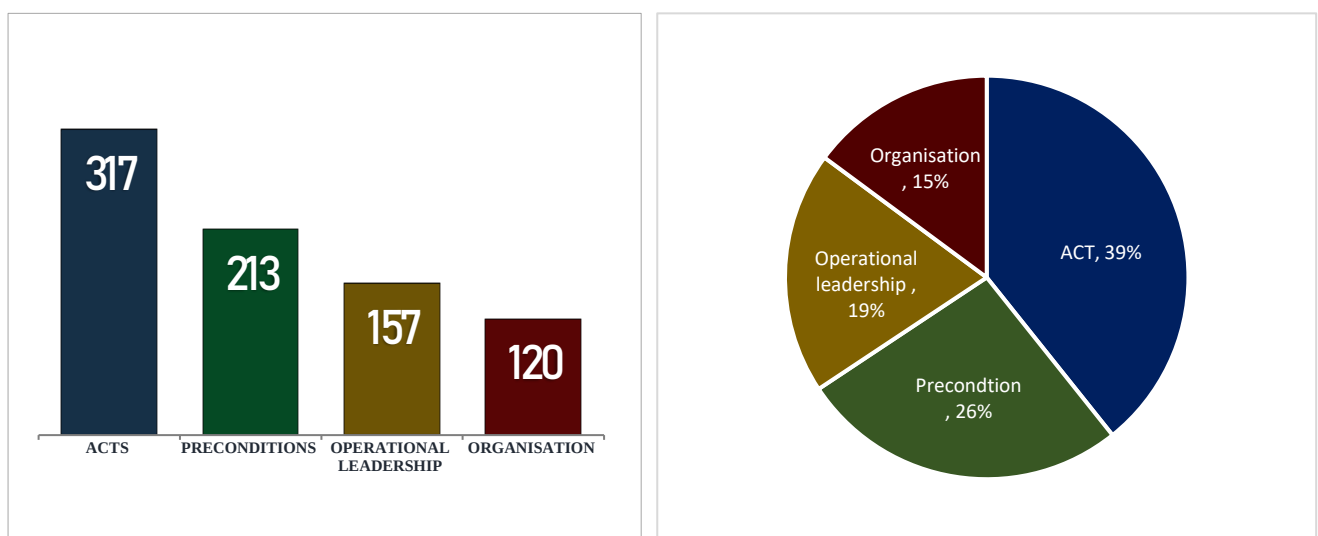


Figure 5.3 Result of congested water accident by classified SHIELD HF Category (IRs=54)

Under each category, there are different codes to show the reasons for the human factors. The code represents various deficiencies contributing to the accident. From the analysis of the maritime accident reports in the collisions in congested water. A corresponding percentage indicates the occurrence of the top ten factors. The collision between a chemical tanker and a trawler ship gives us an example of illustrating the human factor contributing to the maritime accident (MAIB, 2015). The accident underscores deficiencies across the four categories: Acts, Preconditions, Operational Leadership, and Organisation Structure.

Under the Act category, the OS and the OOW made an incorrect decision or plan during a critical moment. When the OOW left the bridge for a period of time, the OS attempted to manage the situation independently but failed to take effective action. Despite observing the approaching vessels and recognising the imminent risk of collision, the OS stopped the engine only one minute before the

collision. This decision was ineffective, as the chemical tanker was still making 10 knots at the time of impact, demonstrating inadequate planning and decision-making.

In terms of Preconditions, distraction played a significant role in the risk of collision. The situation deteriorated when the trawler ship altered its course, coinciding with the OOW's absence from the bridge. Although the OOW intended to leave the bridge for only a brief period, he lost track of time, resulting in a lapse in oversight. This distraction from the critical task of monitoring navigation highlights how cognitive and situational awareness factors contribute to accidents in complex situations.

Under operational leadership, the collision revealed a lack of personal supervision on the bridge. The OOW regular practice of leaving the bridge during watch, in contravention of the STCW regulation was one of the main contributing factors. This deviation from the regulation made the supervision on the bridge weak and leaving the team unprepared to handle the emerging risk.

Finally, at the organisational factor, the deficiencies in the ship structure and policies made the situation worse. Although the OS demonstrated some level of competency, he was neither qualified nor authorised to take avoiding action. The organisation's unclear policy combined with the lack of emergency response planning, left the bridge team without adequate support or guidance during critical moment. This highlights systemic shortcomings in safety management, particularly in providing clear roles, responsibilities, and protocols for emergency scenarios.

This example illustrates how individual, leadership, and organisational levels deficiencies contribute to maritime accidents. Addressing these issues and improving them requires a comprehensive approach, emphasising improved decision-making processes, enhanced situational awareness, more strict safety protocols, and a strong organisational safety structure to mitigate human errors and reduce similar accidents.

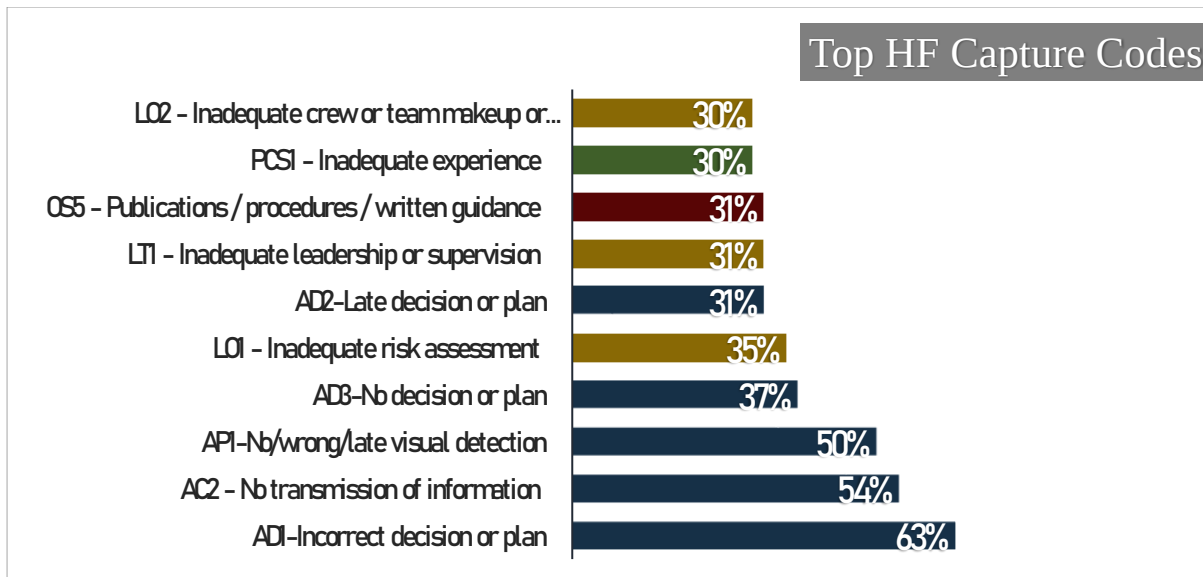


Figure 5.4 Distribution of the HF in collision in congested water (IRs=54)

Figure 5.4 demonstrates the most common HF occurring from 54 maritime accident reports in congested water, which represents the frequency of individual human factor issues observed in the accident. The total result is that multiple human factors deficiencies often contribute to a single collision. In simple words, a single accident can involve several overlapping factors, which collectively increase the accumulative percentage. The analysis illustrates that, with 63%, the most observed factor in 54 maritime accident reports is “Incorrect Decision or Plan,” followed by, with 54%, “No Transmission Information,” and “No/Wrong/Late Visual Detection” indicates 50% of the occurring. The remaining factors included: “No Decision or Plan” (37%), “Inadequate Risk Assessment” (35%), “Late Decision or Plan”, “Publication/Procedures/Written Guidance”, and “Inadequate Leadership or Supervision” (31% each), “Inadequate Experience” and “Inadequate Crew or Makeup” with (30% each).

The analysis highlights the critical areas where human factors contribute to accidents, emphasising the need for improvement in the decision-making process, communication, visual detection, risk assessment, leadership, procedural guidance, and team composition. Table 5.1 shows examples of the most common SHIELD human Factors identified in the collision accident reports. These most common human factors can be utilised as part of scenario building in advanced simulator training and train the OOWs for safety critical situations.

Table 5.1: Examples of the most common SHIELD Human Factors identified in collision accident reports

Incorrect Decision or Plan (Acts)		
	Examples	%
1	The OOW failed to meet minimum standards for manning and maintaining a proper lookout, as they left the bridge unmanned or sole lookout in congested water.	18.4
2	A failure to do correct action in navigation rules and misjudgement in decision-making by the OOW which create concerns for the other target.	16.3
3	The OOW did not adjust to a safe speed while navigating in a high-traffic area	14.3
4	The OOW executed complex navigational decisions without sufficient planning or situational awareness.	12.2
5	The OOW incorrectly assumed that other vessels would pass clear.	6.12
6	The OOW failed to escalate a critical situation by notifying the Master when it was necessary.	6.12
7	The OOW failed to maintain a safe distance from other vessels	6.12
8	The actions taken by the OOW did not comply with the requirement of the COLREGs	6.12
9	The OOW made an incorrect alteration of course, which increased the risk of collision with the other ships	4.1
10	The OOW navigated through a route that was unsuitable for passage.	4.1
No Transmission of Information (Acts)		
	Examples	%
1	The OOW failed to notify the Master despite night orders mentioned clearly for consultation in case of doubt.	21.7
2	The OOW did not inform the master about deteriorating visibility during the watch.	8.7
3	The OOW transmitted unclear information to other ships while taking action and this was inconsistent with the requirement of the COLREGs.	8.7
4	The lookout made an inappropriate decision and took action individually without informing the Master.	8.7
5	The OOW agreed to a manoeuvre proposed by another ship but failed to provide a clear response.	8.7
6	The VTS did not provide adequate traffic and emergency information to the ships as required by the VTS manual.	8.7
7	Essential ship navigation data was not recorded	8.7
8	There was no exchange of critical navigational information between the Master and the Pilot.	8.7
9	The pilot failed to effectively communicate passing arrangements between vessels resulting in confusion and heightened collision risks.	8.7
10	The OOW had the option to use light signals as an additional method to clarify intention but failed to take this precautionary measure.	8.7
No/ Wrong/ Late Visual Detection (Acts)		

	Examples	%
1	The bridge team failed to detect the presence of the other vessel either visually or on radar before the collision.	11.5
2	The bridge team did not detect the other ships because they were preoccupied with other tasks.	11.5
3	The bride team was unable to detect other ships due to environmental obstacles such as fog, and sun glare.	11.5
4	The bridge team failed to detect the other targets using both visual observation and radar, indicating inadequate monitoring of navigation equipment.	11.5
5	The OOW misinterpreted the direction and navigation lights of other ships.	11.54
6	The bridge team initiated course alteration without identifying other targets in a timely manner, increasing the risk of collision.	7.7
7	The OOW failed to detect the other vessels until was dangerously close, reducing the chance for corrective action.	7.7
8	Although the OOW was aware of the presence of the other ships, they did not take any corrective action to prevent a hazardous situation	7.7
9	Watchkeepers on the vessels exceeded the work hour limits described in STCW which impacted their ability to visually detect other vessels.	7.7
10	The OOW failed to recognise that the other ships were engaged in specific operations.	7.7
No Decision or Plan (Acts)		
	Examples	%
1	The bridge team failed to sound any warning signals during a critical situation.	16.7
2	The OOW did not take timely or appropriate action when required.	12.5
3	The bridge team failed to take corrective action because they were unaware of the presence of the other ships, highlighting the lack of situational awareness.	12.5
4	The pilot and another member of the bridge team were distracted by unrelated tasks and failed to focus on critical navigational duties delaying necessary action.	12.5
5	The OOW did not call the Master as mandated in the master's standing orders,	12.5
6	The ships were operating at unsafe speeds that were inappropriate for the prevailing circumstances and environmental conditions.	8.3
7	Despite noting the presence of another vessel 15 min before the collision and correctly assessing the risk, no action was taken to mitigate the hazard or prevent the collision.	8.3
8	The bridge team failed to adhere to the IMO-recommended route, which compromised the vessel's safety	8.3
9	After becoming aware of the risk posed by the other targets, the bridge team failed to reassess the situation or take corrective action.	4.2
10	At the time of the collision, the vessel's doors were not secured, compromising the integrity of the low-freeboard ship and increasing the risk of flooding.	4.2
Inadequate Risk Assessment (Operational Leadership)		
	Examples	%

1	The Master failed to conduct a proper risk assessment to determine the safe speed of the ship under the prevailing circumstances and conditions.	17
2	The bridge team did not reassess the risk when changes in the situation occurred, despite the need for immediate action.	11.4
3	The avoidance actions have been done but it was too late to effectively prevent the collision, demonstrating delayed decision-making.	11.4
4	The OOW failed to use ARPA to evaluate the approaching danger, resulting in inadequate delayed decision-making.	8.6
5	There was a lack of effective risk assessment and onboard instructions, compounded by the Master's failure to sign and verify the passage plan.	8.6
6	The pilot and bridge team did not sufficiently consider forecasting winds and tidal streams, leading to misjudged navigational decisions.	8.6
7	The absence of comprehensive briefing to both Masters before unmooring resulted in unclear procedures and confusion in the event of operational failure.	8.6
8	Although the OOW was present on the bridge, they failed to visually or by radar check for nearby traffic before altering the ship's course.	8.6
9	The crew was unprepared to respond effectively to the ship's emergencies. Which contributed to the collision.	8.6
10	The pilot and OOW did not recognise that the other ships were making headway over the ground, resulting in a misinterpretation of the manoeuvre and associated risks.	8.6
Late Decision or Plan (Acts)		
	Examples	%
1	The bridge team attempted to take collision avoidance measures, but their actions were delayed and insufficient to prevent the accidents.	18
2	The OOW detected the risks and initiated action, however, the detection and response occurred too late to avoid the hazard effectively.	18
3	The OOW made several course alterations, but these actions did not comply with the COLREGs and were executed too late to prevent the escalating situation	11
4	The OOW assumed that other ships would take action at a later stage, resulting in inaction and increased risk.	11
5	The OOW's actions were inadequate, as they failed to account for the uncertain movement of the other ships, leaving insufficient time for collision avoidance.	11
6	Despite deteriorating environmental conditions, the bridge team failed to take immediate corrective action.	7
7	The Master made a delayed decision due to confusion regarding the intentions and manoeuvre of the other ships, which impacted timely navigation	7
8	The OOW used the ship's whistle as a warning during the final minute before the collision, but this measure was insufficient as a last-resort precaution.	7

9	Two ships navigating near the northern separation limit experienced delayed actions due to restricted manoeuvring space, increasing the opportunity of collision.	7
10	The aster ordered a significant helm adjustment of 20 degrees only after recognising the inaction of the other ships, highlighting the delayed response to the risk.	7
Inadequate Leadership or Supervisor (Operational Leadership)		
	Examples	%
1	The masters' lack of oversight in reviewing and approving the passage plan resulted in the appropriate allocation of BRM hazardous conditions and failure to adjust bridge manning.	15.1
2	The OOW failed to adjust and verify the radar set to accurately detect and track targets.	12.1
3	The bridge team failed to maintain effective communication, leading to misinterpretation and delayed response during a critical situation.	12.1
4	Poor watchkeeping practice and relaxed navigation management were evident after passing the Dover strait, despite the restricted visibility requiring high vigilance.	9.1
5	The master left the bridge to engage with the onboard services manager during a critical period, neglecting the main responsibility for navigation oversight.	9.1
6	The OOW was distracted by phone calls during a critical situation, neglecting their duty to monitor and respond to navigational tasks.	9.1
7	The master failed to establish an effective lookout organisation and was absent from critical communication, resulting in the misidentification of targets and subsequent collision.	9.1
8	The master allowed non-essential personnel to remain on the bridge during a critical period, leading to distraction and engaging in non-work conversation.	9.1
9	A poorly executed handover of responsibilities between watchkeepers created confusion and an unsafe situation, highlighting inadequate bridge team coordination.	6.1
10	The master performed actions that violated the COLRGs, demonstrating a lack of adherence to navigational rules and insufficient leadership in managing the situation.	6.1
Publication/ Procedure / Written Guidance (Organisation)		
	Examples	%
1	The master's night orders lacked clear instructions and procedures, leaving the bridge team without adequate guidance for decision-making during critical situations.	13.2
2	The bridge manning levels on both ships were inadequate to the prevailing circumstances, failing to meet the demands of effective navigation and situational awareness.	13.2
3	Actions taken were contrary to the requirement of the COLREGs, due to the absence of instruction provided by the master.	10.5
4	The handover and familiarisation process between the OOWs from different nationalities lacked of proper guidance, leading to ineffective communication and operational inefficiencies.	10.3
5	SMS requirements outlined by the ship's management were ignored, undermining established safety protocols.	10.3
6	The absence of clear recommendations for bridge watchkeepers to notify the master early hazardous situational resulted in delayed and inappropriate actions.	10.3

7	The use of VHF radio for collision avoidance caused confusion between ships, despite this practice being discouraged under established maritime guidelines.	8
8	Watchkeepers had exceeded the STCW-mandated working hours over the previous two days, contributing to fatigue and reduced performance.	8
9	The lack of predefined failure procedures created delays in resolving problems during critical situations.	8
10	Misleading information in navigational publications contributed to errors made by the OOW during the passage planning process, increasing the risk of navigational errors.	8
Inadequate Experience (Precondition)		
	Examples	%
1	The OOW demonstrated a lack of experience and familiarity with the ship's radar systems, compromising the ability.	16
2	OOW was inexperienced and unqualified for night watch duties in the Dover strait and was unfamiliar with the ship's manoeuvring characteristics and their authority to reduce speed when required.	13
3	The OOW failed to appropriately adjust and assess radar controls to manage clutter, reducing the effectiveness of radar monitoring in identifying risks.	9.6
4	Despite a minimal CPA, the OOW incorrectly assumed that the situation was under control without obtaining a clear agreement and did not escalate the matter to the master	9.6
5	The master was new to both the company and the ship, having assumed command only a few hours earlier. In addition, some masers are first time navigating in the Dover strait, contributing to unfamiliar with the operational environment.	9.6
6	Avoiding actions was delayed due to the inexperience of the OOW and the master being distracted, increased by a lack of practical ship-handling experience.	9.6
7	The OOW displayed unfamiliarity with critical bridge equipment, affecting their ability to operate systems effectively during navigation	9.6
8	Despite possessing knowledge of the COLREGs, the OOW made unfounded assumptions, leading to incorrect actions and failure to mitigate risk.	6.5
9	The OOW failed to adequately monitor the action of the give-way ship and did not maintain a proper lookout, violating basic watchkeeping responsibilities.	6.5
10	A 17-year-old deckhand, inexperienced and underqualified, was assigned to manage navigation in busy and hazardous TSS, raising serious concerns about competency and safety.	6.5
Inadequate Crew or Team Makeup (Operational Leadership)		
	Examples	%
1	The master deemed it unnecessary to maintain a dedicated lookout on the bridge, undermining the principle of effective watchkeeping.	12.7
2	Bridge personnel was poorly utilised, and there was an evident lack of proper BRM, contributing to ineffective decision-making and situational awareness.	12.7

3	The master adheres to routine practices by delegating navigation responsibility entirely to the OOW, without considering the increased workload in high-density traffic areas or ensuring the provision of a proper lookout.	12.7
4	The master allowed OOW to independently decide bridge manning levels during their watch, which proved inadequate under the circumstances leading to the incident.	12.7
5	The absence of personnel with proficiency in English to monitor VHF communications reduced situational awareness and delayed effective response, highlighting inefficient manning practices.	10.7
6	The OOW failed to call for assistance during periods of heavy traffic, despite company policies mandating such action in high-risk situations.	7.7
7	There were no established protocols for determining when additional personnel were required on the bridge during navigation in high-traffic density areas.	7.7
8	The OOW did not utilise available personnel effectively for lookout duties, neglecting a critical element of safe bridge operation.	7.7
9	Insufficient rotation among bridge team members reduced their ability to perform effectively under the stress of prolonged operations, contributing to fatigue and diminished performance.	7.7
10	The SMS lacked specific directives for bridge manning during the challenging navigational condition, leaving the team without clear guidance for high-risk situations.	7.7

The examples in Table 5.1 showed the most reasons for the accident under different layers. However, most layers were under the “Acts” layer which highlights how the OOW can directly impact to the accidents. These examples provide a useful checklist to identify common causes of accidents and help design a comprehensive framework to address common issues and improve performance through targeted training programs. These examples serve as a foundational checklist to identify the root causes of accidents and implement effective solutions in OOW training.

For example, several accidents occurred because there was a lack of a lookout or the OOW left the bridge unmanning during critical times. To address this, simulator training can demonstrate the importance of proper bridge manning and show the consequences of insufficient monitoring. The scenario can focus on effective bridge resource management (BRM), and the right number of personnel needed for safe navigation.

Another issue is lack or poor use of the ship bridge equipment such as ECDIS and the radar, usually due to lack of familiarity or insufficient training. In some situations, the OOW may be new on board

the ship and unfamiliar with the system. To address this, simulator training should include scenarios that focus on the proper use of navigational equipment under different conditions. These scenarios can also provide opportunities for the OOW to become proficient in interpreting radar and ECDIS data. Managing clutter and understanding their limitation.

Furthermore, simulator training can recreate real-life environments to enhance decision-making, communication, and situational awareness. For example, scenarios involving high-density traffic, reduced visibility, or equipment failure can be implemented to help OOW practice and internalise proper procedures, including compliance with COLREGs, effective communication with other vessels, and timely escalation to the master when required.

By addressing the issues illustrated in the examples, we can design training programs that enhance the OOW performance. This approach ensures that OOW gains experience in a controlled environment, reducing the likelihood of critical errors in real-life navigation. This aims to improve safety, minimise human error, and promote more effective bridge operations.

5.2.2 Decision-making

Maritime navigation is a complex process involving a series of decisions made under different environmental and operational conditions. These decisions, usually made in high-pressure situations, are critical to ensure the safety and efficiency of a ship's passage. Effective decision-making in maritime navigation requires a combination of situational awareness, communication, experience, and proper training. Understanding these processes is key to enhancing maritime safety and reducing the risk of human errors, which is still one of the main reasons contributing to maritime accidents. Decision-making in maritime navigation involves making real-time choices to respond to different maritime conditions, including weather, sea conditions, traffic, and navigation hazards (Xue et al., 2023). In simple words, it means making quick decisions based on the changing conditions. Furthermore, the OOW will be the decision-makers on board the ship to deal with any condition. The main role of a decision-maker in any situation is to find the best or at least a good way to achieve the desired result. Individuals with knowledge or experience know the most effective approach, making knowledge a key

factor that can distinguish between skilled and less skilled decision-makers (Byrnes, 2002). However, the OOW must deal with many navigation equipment on the ship bridge during critical situations. Furthermore, cognitive and behavioural performances have become the most focused topics for researchers in maritime studies (Ay et al., 2024; Brooks and Greenberg, 2022). The lack of knowledge about the use of equipment can cause wrong decision-making. Using a simulator in maritime training is crucial for improving the decision-making abilities of OOW under different levels of stress and complexities (Xue et al., 2023).

5.2.3 The Impact of Teamwork, Communication, and Automation

When examining maritime accidents, the factors influencing navigation on the ship bridge are significantly impacted by several human factors, as detected from accident reports. Situation awareness, encompassing perception failure and projection, is a primary contributor to navigation errors (Sandhåland et al., 2015). However, with the rise of automation, human-machine interaction created different issues, such as poor design and inadequate training with the new technology, leading to improper use of equipment (Balfe et al., 2015; Lützhöft and Dekker, 2002). Furthermore, a critical issue in maritime accidents is the lack of transmission of information. This will impact the navigation performance and the bridge team. The information includes different data such as weather updates, maritime safety information, and traffic data from another vessel. Without all this information, the bridge team will navigate with blind spots. And they will be unable to predict and respond to the maritime conditions. One issue that can cause the lack of the transmission of information is a technical failure in the radio and navigation equipment (Karahalios, 2018). Another crucial issue relating to the human factor is inadequate teamwork. Procedural issues between bridge teams where important information is not accurately transmitted can lead to poor communication and, therefore, poor situation awareness. This deficiency in communication may prevent the bridge team from predicting imminent hazards or necessary navigation changes, which leads to an increase in the risk of collision. The key factors include misunderstanding among bridge team members, deficiencies in communication, and insufficient coordination are the main reasons for inadequate teamwork (Mansson et al., 2017). In addition, a study indicated that the lack of communication and trust among team members, influenced

by their roles within the team, skill levels, competence and primary language, reduces teamwork effectiveness (Lutzhof et al., 2009). Furthermore, the absence of strong leadership, poor distribution of roles and responsibilities and misallocation of duties contribute to complications within the bridge team, leading to weak teamwork performance (Brodje et al., 2013).

5.2.4 Summary

Despite improving marine education and training, collisions and grounding are still the most common marine accidents. The review reveals the highest frequent issues were poor decision making, lack of communication, and late or incorrect visual detection. The reasons for this problem could be the interaction with the equipment, teamwork, and poor training on new technologies. Combined with the weak leadership and language problems, it further contributes to maritime accidents. The recommendation is to do better training focusing on humans mentally and behaviourally in safety-critical situations to reduce these problems, which are the reasons for human errors. Focused training will improve the leadership and communication practice on the ship, which will enhance the decision-making and interaction with the new technologies.

Chapter 6 Design of Experimental Study

6.1 Introduction

Reviewing the maritime accident reports revealed that most accidents occur in internal and coastal waters. This is a vital discovery from the (EMSA) data analysis of accidents between 2014 and 2022. It is important to note that despite the prevalence of accidents, there is currently no organised methodology for categorising navigation areas based on traffic density. These areas are generally classified as congested, narrow, or open water.

6.2 Collision in congested water

Congested water, a term used to describe areas within a Traffic Separation Scheme (TSS) overseen by Vessel Traffic Service (VTS), is a global concern. These areas include port approaches, high-traffic zones, and regions where ships enter, exit, or cross TSS lanes. Notable examples are the Dover Strait, the Strait of Gibraltar, and the Malacca Strait. Narrow waters, on the other hand, encompass regions like the Istanbul Strait and the Suez Canal. Given the global significance of congested waters as some of the busiest navigation areas, examining the factors that potentially heighten the risk of collision, particularly within these regions, is imperative.

6.3 Problem Statement

Despite technological advancement in the maritime industry, accidents continue. The maritime industry has recently focused on implementing high technologies and advanced equipment to mitigate these incidents. Previous research has utilised quantitative and qualitative methods to measure human factors, while traditional techniques, such as analysing accident reports and statistical databases, remain prevalent. Over the last decades, frequent emergency situations, including collision, grounding, fire, and explosion, have resulted in significant loss of life, property, and environmental damage. The role of the crew (humans) and their response is crucial in mitigating these consequences. Even when accident

reports attribute incidents to human error, quantifying the extent of these errors' impact on the accident remains challenging.

In addition, if we explore STCW, the mandatory simulator training used for the navigation equipment is only RADAR and ECDIS. The full mission simulator training is not mandatory, which is an advanced technology where the crew can imitate their duty on the ship's bridge, including interaction with the other bridge team members, and correct their mistakes without any detrimental impact on life, property, or the environment. It is a free-risk location. Furthermore, full mission simulators in maritime are not standardised. However, they are certified if they are used for certified courses, unlike the training for the crew in the flight simulator in aviation, where the training is standard and credentials.

In this thesis, human responses to collisions in congested water were analysed using subjective analysis and the SHIELD (Safety Human Incident and Error Learning Database) taxonomy approach, as reported in Chapter 4. SHIELD taxonomy was founded on the SAFEMODE project, which is a European-funded project (SAFEMODE, 2020). The SAFEMODE project (Strengthening synergies between Aviation and maritime in the area of human Factors towards achieving a more Efficient and resilient MODE of transportation) aims to capture human element interaction with other components/elements of the system in order to enhance safety on maritime and aviation operations. Furthermore, the selected scenario from maritime accident reports was simulated in the ship bridge full mission simulator to analyse human cognitive responses and behaviours by using objective data from an Electroencephalography device (EEG) and Eye-tracking glasses.

6.4 The scenario selected from the maritime accident reports dataset

As mentioned in section 2.2.5, the biggest concern in the maritime industry now is the ship size and how the operator handles such a huge ship in congested waters. Controlling this massive object is not easy, especially in congested waters. The primary casualty event type from 2014 to 2022 was a collision, and human action was the main contributing factor, with 67.6% of all the factors. (EMSA, 2023), resulting in loss of life and damage to the property and environment. Research in collision avoidance has increased because of the high-frequency occurrence and detrimental consequences. To choose a

scenario and apply it in our experimental thesis, 278 different accidents were analysed between 2001 and 2021 using the SHIED taxonomy, 126 collision accidents were captured in the analysis, and almost half of them were in congested water, which is 54 accidents, Figure 6.1. The accident reports were retrieved from the Marine Accident Investigation Branch (MAIB).

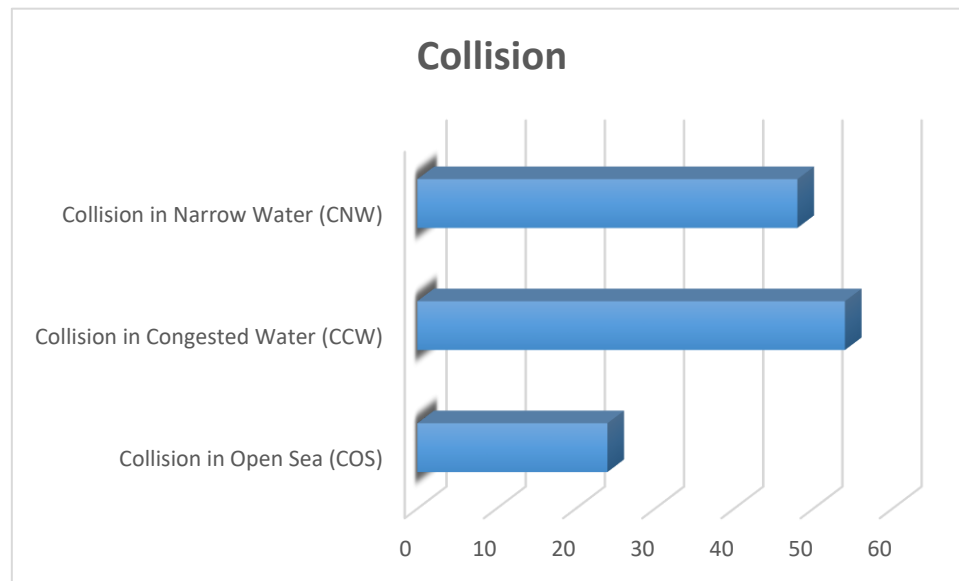


Figure 6.1 Location of collision

This thesis evaluates the human contribution factor that led to the accident in congested water. The key motivation behind this research is to examine the human response to such a scenario using advanced neuroscience tools, including EEG and eye-tracking, within a ship bridge simulator, which is one of the most innovative methods in maritime studies.

The experimental design centres on developing and selecting appropriate scenarios that accurately simulate real-life conditions. A collision scenario was carefully created using the same across different actions required by the participants to ensure consistency and reliability in the data. The scenario development was informed by a detailed review of past accident reports, with the selected report chosen based on its location, the type of accidents, and contributing factors such as lack of manning and communication. These elements provide a realistic framework to observe how participants react to and manage collision situations, capturing their cognitive performance and interaction with the ship bridge

environment and equipment. The background and details of the chosen accident will be illustrated in the next section.

6.5 Background of the selected scenario.

Table 6.1 shows detailed information about the ships and the consequences of the accident.

Table 6.1 Detailed information about the ships

Type	Information
Time and date	0449 am, 29 October 2008
Location of the accident	Dover Strait
Injuries/Fatalities	No
Vessel 1	MV Scot Isles
Route	Rochester to Antwerp
Type	General cargo (Loaded condition)
Length overall	89,95 m
Gross tonnage	2595 GRT
Service speed	10,5 knots
Damage	Extensive damage to starboard side shell plating, frames, and bridge wing
Pollution	60 tonnes of marine gas oil spilt into the sea
Vessel 2	MV Wadi Halfa
Route	Egypt to Bremen
Type	Bulk Carrier (ballast condition)
Length overall	184,9 m
Gross tonnage	22895 GRT
Service speed	14,2 knots
Damage	Material damage to port side shell plating
Pollution	No

In October 2008, a collision occurred in the Dover strait at 0449 hours between a bulk carrier, MV Wadi Halfa, and a general cargo ship, MV Scot Isles. The visibility was good, the weather conditions were calm, and the navigation area was congested with traffic. The MAIB accident report provides a detailed account of the events leading up to the accidents. Figure 6.2 illustrates the collision on a chart obtained from the accident report (MAIB, 2008).

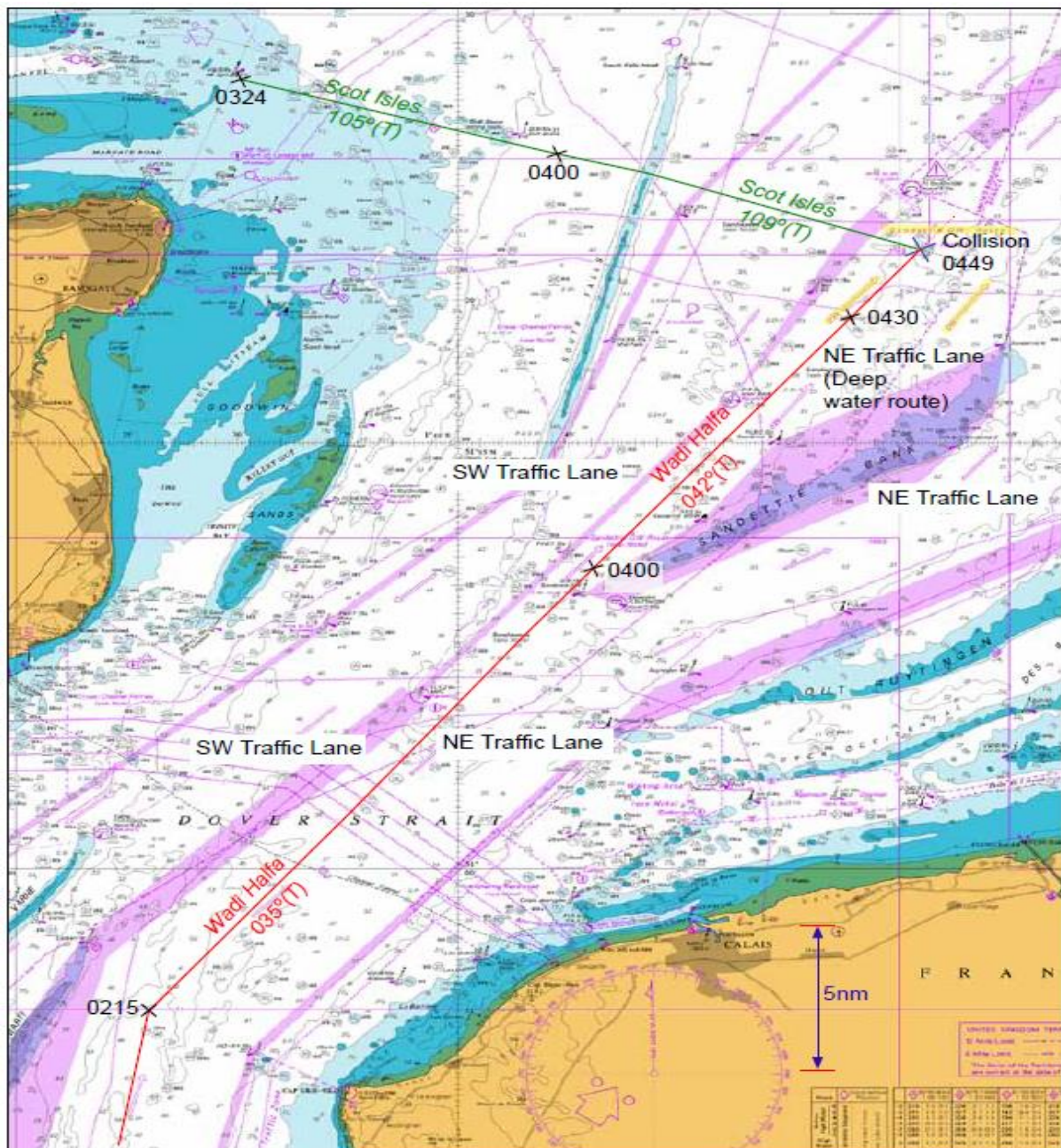


Figure 6.2 MV Wadi Halfa & MV Scot Isles collision (MAIB, 2008)

- **General Cargo Ship Background:** The MAIB report provided the details of the events and the following text is taken directly from the MAIB report.

“The general cargo vessel MV Scot Isles had departed from Rochester en route to Antwerp. The chief officer was navigating the ship through the northeast traffic lane of the Dover Strait Traffic Separation

Scheme. After exiting the pilotage area at 0150 hours, the second officer took over the navigation from the master but did not activate the bridge watch alarm system. At 0400 hours, the chief officer resumed his watch, adjusting the starboard ARPA radar to a 6-mile range scale with a ship's head up and relative motion, while the port RADAR remained unused. Despite the presence of multiple objects on the RADAR screen, none were tracked using ARPA to assess collision risks. The automation identification system (AIS) listed six nearby ships, but they were not monitored.

At 0410 hours, the ship began crossing the southwest traffic lane of TSS. The lookout reported the vessel at 0435 hours and subsequently left the bridge to conduct a safety round without delivering his report to the chief officer. The chief officer became aware of the other vessel just before the collision and attempted a port-side helm manoeuvre, which was insufficiently late to avoid the collision at 0449 hours. Post-collision, the master and second officer observed that the vessel was on autopilot, proceeding at full engine speed.”

- **Bulk Carrier Background.**

“The bulk carrier MV Wadi Halfa was navigating a northeast course in the northeast traffic lane of the Dover Strait, heading for Bremen, Germany. The chief officer took over the watch from the second officer, accompanied by a cadet and lookout on the bridge. At 0435 hours, the lookout left the bridge for a restroom break, and the cadet was preoccupied in the chatroom. The ARPA was set on a 6-mile range scale with relative motion and north-up orientation but without plotting any targets. At 0448 hours, the chief officer noticed the approaching vessel on the port side and immediately executed a hard starboard manoeuvre, while the cadet alerted the master.

The collision resulted in significant shell plate damage to the starboard side of the general cargo ship, leading to a spill of 60 tonnes of marine gas oil into the sea. The bulk carrier sustained less severe damage to its port side. Fortunately, there were no fatalities or injuries. The report identified critical failures in the proper utilization of radar and other bridge equipment, with no lookout present on either bridge at the same time of the incident. Additionally, there was a lack of communication between the

chief officer and the lookout on the general cargo vessel, and the master failed to issue night orders regarding the navigational area and the potential risks of congested water.

In addition, environmental conditions reported in the accident included northerly winds at force 3 on the Beaufort scale, slight to moderate sea conditions, good visibility, occasional rain showers, and slack tide. The conditions did not pose significant risks to navigation; the accident occurred at the early dawn, as daylight was beginning to emerge”.

6.6 Collision Analysis Based on the SHIELD Taxonomy

To apply the SHIELD HF taxonomy in the analysis of Maritime accidents, a sequence of steps needs to be followed as some studies applied the taxonomy (Navas De Maya et al., 2022). Table 6.2 shows the steps below:

Table 6.2 Steps to be followed to conduct the analysis

No.	Step	Description
1	Selection of the data	This step filters and selects the accident that will be further analysed using the SHIELD taxonomy.
2	Pre-Analysis: Provide a description of the event and create a timeline.	This step aims to capture and record information from an accident report to provide an overview of the accident process, which aids in the subsequent identification of the contributing factors.
3	Analysis: Coding of the event in the accident	This step intended to identify all the factors from four layers of the SHIELD HF taxonomy that contributed to the development of the accident.
4	Post-Analysis: Presentation of the result	This step presents the analysis process, including tracking and trending data.

6.6.1 Step 1: Data Selection and Description.

The selected accident was summarised in section 1.6. the information on the accident report was acquired from the real accident report conducted by the UK Marine Accident Investigation Branch

(MAIB,2009). MAIB is a UK government organisation authorised to investigate all global maritime accidents involving UK vessels and any vessels operating in UK territorial waters.

6.6.2 Step 2: Pre-Analysis, Creating Timeline

Creating a timeline is very useful and essential to provide an understanding of the causes that led to the accident. Furthermore, it can also be used to compare with other accidents to find common patterns and identify key points to find a method to reduce the probability and enhance maritime safety overall. Consequently, a timeline of the collision between Scot Isles and Wadi Half is presented in Figure 6.3, where each ship's crew has taken action since its departure.

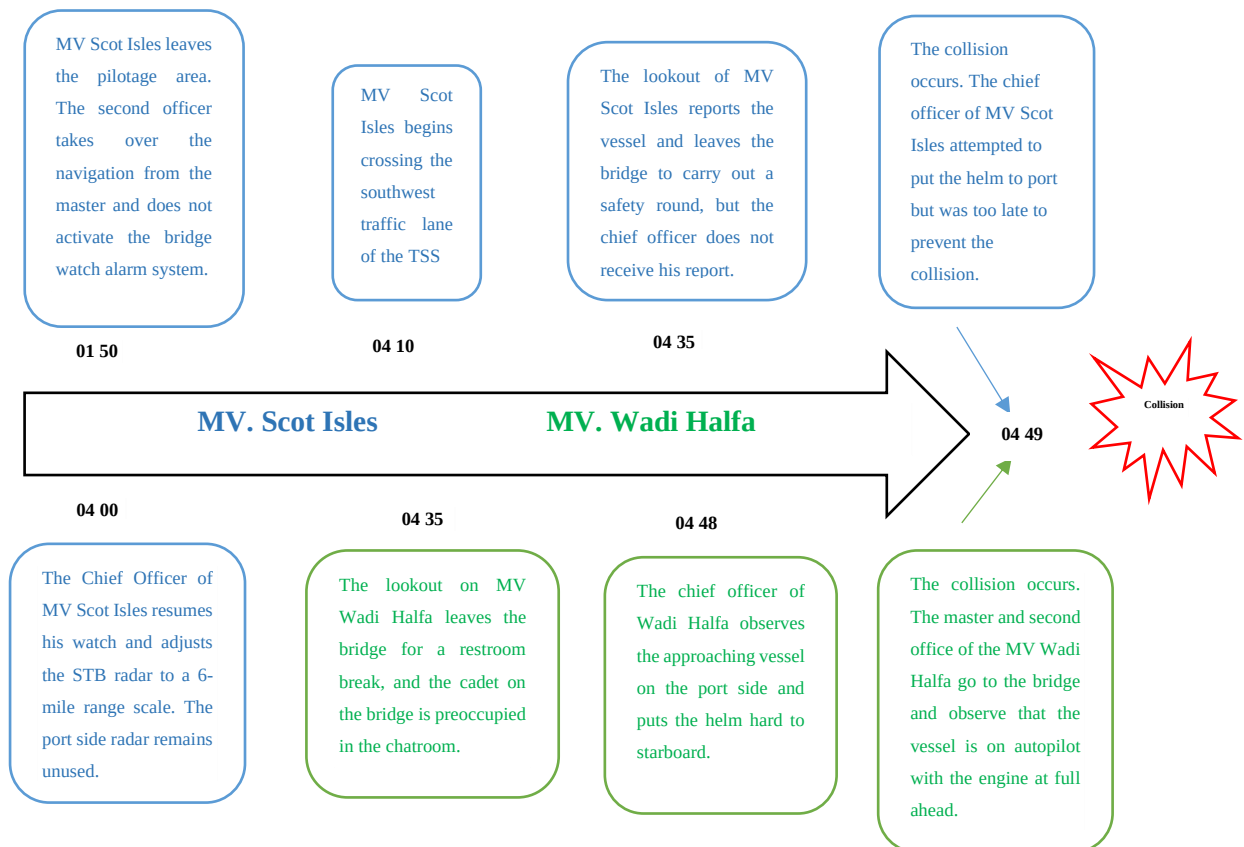


Figure 6.3 Timeline for the collision between Scot Isles and Wadi Halfa

6.6.3 Step 3: Analysis, Coding and Accident Events

Applying the SHIELD-HF Taxonomy to the accident report can be done by an individual or as a group task, and it requires an expert with adequate knowledge in the maritime field, particularly in navigation. For this report, several experts, such as chief officers, have worked onboard the ship for 7 years, and researchers in the human factors field participated in analysing the accident, and the result is illustrated in [Table 6.3](#); the No.1 represents MV. Scot Isles and No. 2 represent MV Wadi Halfa.

Table 6.3 Identification contributing factors

LAYER	CODE	REASON	VESSEL
ACT	AI3 - Workaround in exceptional conditions	Although bridge equipment was available to assist both chief officers in keeping a proper lookout in the absence of a dedicated lookout, this was not used effectively.	No.1
PRECONDITION	PPF7- Risk underestimation	The master had become complacent.	No.1
OPERATIONAL LEADERSHIP	LO1 - Inadequate risk assessment	The master left the second officer as the sole watchkeeping officer	No.1
ORGANISATIONAL	OR1 - Personnel	The need to maintain a proper lookout should determine the basic composition of the navigational watch. A dedicated lookout should be an integral part of the bridge team	No.1
LAYER	CODE	REASON	VESSEL

ACT	AI3 - Workaround in exceptional conditions	Although bridge equipment was available to assist both chief officers in keeping a proper lookout in the absence of a dedicated lookout, this was not used effectively.	No.2
PRECONDITION	PCS2 - Lack of proficiency	Effective bridge resource management was lacking in this case	No.2
OPERATIONAL LEADERSHIP	LO2 - Inadequate crew or team makeup or composition	The chief officer was then the sole lookout	No.2
ORGANISATIONAL	OR1 - Personnel	The need to maintain a proper lookout should determine the basic composition of the navigational watch. A dedicated lookout should be an integral part of the bridge team	No.2
LAYER	CODE	REASON	VESSEL
ACT	AC2 - No transmission of information	He did not sound the alarm or carry out a full safety muster.	No.2
PRECONDITION	PPF7 - Risk underestimation	Wadi Halfa's master, like Scot Isles', had become complacent.	No.2
OPERATIONAL LEADERSHIP	LT1 - Inadequate leadership or supervision	The master did not leave night orders	No.2

LAYER	CODE	REASON	VESSEL
ACT	AC2 - No transmission of information	He did not sound the alarm or carry out a full safety muster.	No.1
OPERATIONAL LEADERSHIP	LP2 - Inappropriate behaviour affects learning	It was the master's custom not to post a lookout during his bridge watches.	No.1
LAYER	CODE	REASON	VESSEL
ACT	AP1 - No/wrong/late visual detection	The chief officer failed to maintain a proper lookout by sight or use of the navigational equipment available to him.	No.2
OPERATIONAL LEADERSHIP	LP2 - Inappropriate behaviour affects learning	Master did not engender best practice in his bridge watchkeeping personnel	No.2
LAYER	CODE	REASON	VESSEL
ACT	AR4 - Wrong action on the right object	The chief officer was sitting in front of a radar fitted with ARPA, but this facility was not used to acquire and plot any of the radar targets.	No.2
LAYER	CODE	REASON	VESSEL
OPERATIONAL LEADERSHIP	LO2 - Inadequate crew or team makeup or composition	It was the master's custom not to post a lookout during his bridge watches	No.1
LAYER	CODE	REASON	VESSEL

ACT	AI3 - Workaround in exceptional conditions	The vessel's passage through the Sandettie deep water route to the NW of the Sandettie bank was contrary to the advice given on the chart.	No.2
LAYER	CODE	REASON	VESSEL
OPERATIONAL LEADERSHIP	LT1 - Inadequate leadership or supervision	The master did not leave night orders	No.1
LAYER	CODE	REASON	VESSEL
ACT	AC2 - No transmission of information	the lookout was unaware that the chief officer had not registered his report.	No.1

6.6.4 Step 4: Post-Analysis, Presentation of the result.

In the end, after all the contribution factors have been clarified in the previous section. The most important factors that have been identified for both ships were clustered and illustrated in Figure 6.4.

Table 6.4 presents the frequency of the main contributors at the sub-layer level.

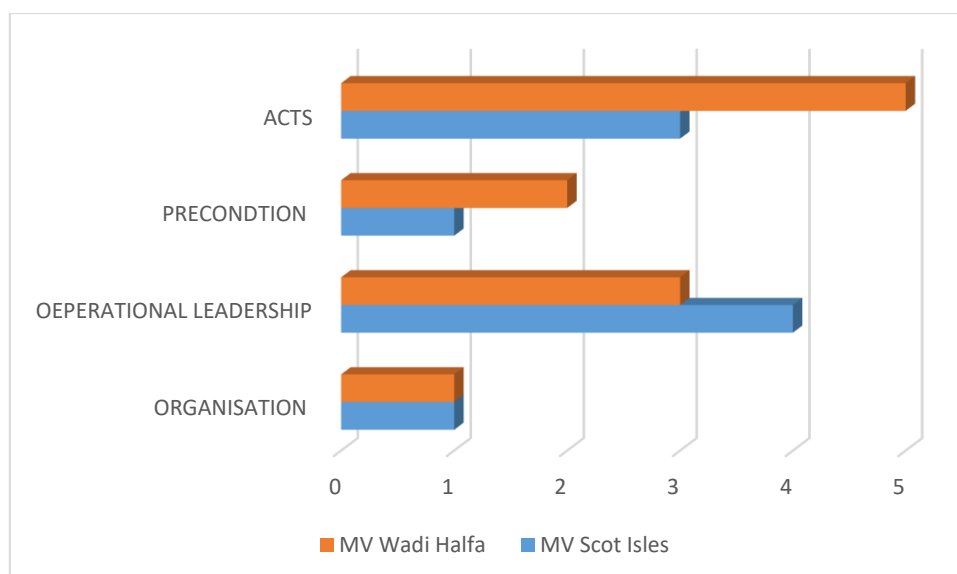


Figure 6.4 Frequency of the contributing factors at the layer level

Table 6.4 Frequency of the contribution at the Sub-layer level

Sub Layer level	MV Scot Isles	MV Wadi Halfa	Total
COMMUNICATION	15.00%	4.55%	19.55%
RESPONSE EXECUTION	0.00%	4.55%	4.55%
PERCEPTION	0.00%	4.55%	4.55%
INTENTIONAL DEVIATION	5.00%	9.09%	14.09%
PERSONAL FACTORS	5.00%	4.55%	9.55%
COMPETENCE, SKILLS AND CAPABILITY	0.00%	4.55%	4.55%
PERSONNEL LEADERSHIP	5.00%	4.55%	9.55%
OPERATIONS PLANNING	10.00%	4.55%	14.55%
TASK LEADERSHIP	5.00%	4.55%	9.55%
RESOURCES	5.00%	4.55%	9.55%
Total	50.00%	50.00%	100.00%

6.7 Discussion

Maritime accident reports consistently provide detailed information about the accidents; however, they often lack focus on the core issues and underlying causes. Despite the existence of a prescribed structure

for investigators to follow, the framework for acquiring accident information does not fully address the needs of maritime safety professionals. By applying the SHIELD-HF taxonomy, it was determined that the majority of contribution factors linked to the collision between MV Scot Isles and MV Wadi Halfa were associated with the Act Layer (40%), followed by the operational leadership (35%), and precondition (15%), and last layer was organisational with (10%)

A deeper analysis revealed that communication was the most critical issue, as evidenced by its importance in the sub-layer analyses (19.55%). There was a significant lack of communication both among the crew and between the two ships, highlighting the need for enhanced communication skills training. The deficiency likely reduced the performance of the officer of the watch (OOW), resulting in missed information contributing to the accident. Additionally, operational planning and intentional deviation issues were significant, accounting for (14.55% and %14.09) respectively.

One of the most critical findings in the accident analysis was the absence of a lookout, which is a direct manning issue and falls under the precondition, operational leadership, and organisation category of errors related to the wrong utilisation of crew resources and lack of proficiency. Both ships; lacked a proper lookout assigned by the bridge team, leaving the OOW to navigate solo in congested water. This is also against rule 5 in COLREG which is “ *every vessel shall at all time maintain a proper look-out by sight and hearing as well as by all available means appropriate in the prevailing circumstances and conditions to make a full appraisal of the situation and the risk of collision*” (COLREG, 1972). This absence likely increased the OOW's mental workload and stress, reducing their ability to focus on duties among the numerous surrounding targets and tasks during the watch. The lack of an additional lookout highlights a deficiency in bridge resource management proficiency, which should have ensured an effective distribution of tasks and personnel to maintain situational awareness.

The SHIELD-HF taxonomy provides a systematic analysis, offering a comprehensive understanding of the issues and potential solutions to find a proper idea to prevent a similar accident in the future. The accident analysis identified the “ absence of the lookout” as the most critical human-related factor, particularly when the OOW navigated solo in congested water. To investigate this further, our study will implement a scenario in the full-mission simulator to evaluate participant performance under two

conditions: navigating solo and increased manning by adding a lookout as an assistant; the objective is to determine whether the presence of a lookout enhances the efficiency and performance of the OOW, particularly in high-a risk situation.

Chapter 7 The Simulator Experiments

Chapter 2 presents an analysis of maritime accidents, indicating that a significant number of these incidents occur in internal water, particularly in congested areas. Furthermore, there is a shortage of empirical studies examining participants' cognitive processes during collision accidents.

To address this gap, two sets of experimental studies were conducted to evaluate cognitive processes using a full mission ship bridge simulator aimed to measure seafarers' cognitive abilities and limitations. The experimental studies utilised an EEG and eye-tracking instrument, including the description of the video recordings to collect data; in the first experiment, participants navigated the Dover Strait in a “Sole Lookout”. While in the second experiment, a designated lookout was present under the same accident scenario. Both scenarios were designed to assess the impact of the lookout’s presence on the participants’ workload and cognitive process when navigating congested waters with multiple targets.

Designing EEG and eye-tracking experiments in this context presents several technical and methodological challenges. The technical challenges involve calibrating and using the EEG device with eye-tracking, ensuring signal accuracy and quality, and processing the collected data. Methodological challenges include defining the research objective, selecting appropriate participants, determining tasks and scenarios, choosing suitable psychological measures, and deciding on evaluation methods and data analysis techniques.

This chapter addresses the technical and methodological challenges within the context of maritime experimental design and underscores the progress made. The lessons learned from the pilot study and the issues discussed here were acknowledged and integrated into subsequent experiments' design. This approach ensures a robust and reliable understanding of the cognitive process and participants' interaction with equipment in maritime navigation, marking a significant step forward in our research.

7.1 Application of the Scenario

Scenario design is a critical aspect of simulator studies, requiring thorough testing and adjustment to replicate real-world accidents accurately. This process has proven to be one of the most challenging

components of the thesis. After an extensive review of the literature and accident reports, a collision incident in the Dover Strait was chosen as one of the busiest maritime regions for the simulation in the full-mission ship's bridge simulator. The instructor meticulously configured the scenario to faithfully replicate the exercises detailed in the incident report. This includes environmental conditions, the manoeuvrability characteristics of the simulated vessels, and all necessary parameters to represent the incident circumstances accurately. Figure 7.1 illustrates the scenario design process for the ship bridge simulator.

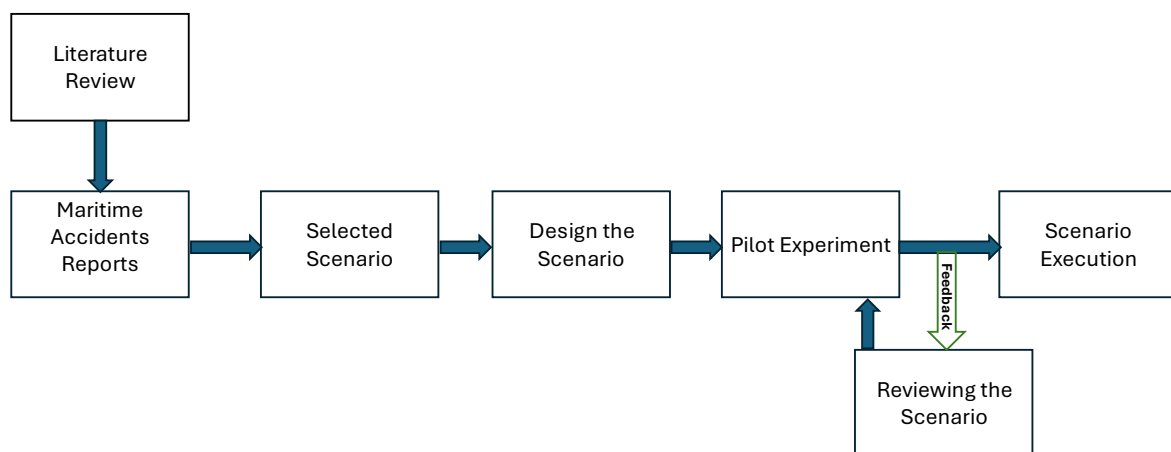


Figure 7.1 Methodology

The vessels used in the experiments were selected from the Wartsila ship simulator library in the instructor room, closely matching the types and sizes of the ships involved in the reported collision. The main ship, controlled by the participant, allowed for environmental monitoring and ship control using all electronic bridge equipment. Target ships were integrated into the scenario with determined courses and speeds to create a realistic simulation of the Dover Strait environment. These target ships were navigated automatically but could be controlled by the instructor as needed. Table 7.1 provides detailed information about the primary and target ship used in the experiment.

Table 7.1 Information about the target ships

Ship	Speed	CPA	TCPA	ID in Library
MV Wadi Halfa	14.2	-	-	-
MV Nowa	15	0.35	10:02	Car Carrier 7 (Dips.68229t)
MV Diamond	18	1.075	11:42	Container ship 20(Disp. 211405 t.)
MV Scot Isles	10.5	0.074	17:16	Bulk carrier 12 “CSL Niagara”
MV Tana	0	0.577	18:32	Container ship (Disp. 211405 t)
MV Clyde	13	0.389	16:01	LNG 7 (Disp. 81549t) bl
MV St Alex	13.5	4.065	18:28	LNG 7 (Disp. 124706t) bl.
Royal Glasgow	20	1.05	26:53	Passenger cruise ship 4(Disp.24841 t)
MV Anadolu	14.3	-	-	Bulk carrier 5(Disp. 142600t) part load
MV Golden Horn	13	-	-	Oil Tanker 4 (Disp. 77966 t)

In the scenario, the MV Wadi Halfa was designated as the main ship, while the MV Scot Isles served as a target vessel. The routes were designed to simulate a collision course between these vessels, ensuring an accurate and realistic representation of the accident scenario for the study.

To ensure a consistent environment for each experiment, identical vessels and operational parameters were utilised and pre-programmed into the simulation software. The selected ship for the experiment was a bulk carrier, MV Wadi Halfa, travelling at a speed of 14.2 knots on a course directly to 042 degrees. The vessel’s autopilot was set to maintain this position. These settings were designed to create a collision risk with the Scot Isles, as per the marine accident investigation report. Additionally, other vessels were incorporated into the simulation to establish realistic maritime traffic surroundings.

When the experiment was established in normal conditions, the participant initiated the experiment with specified parameters, intending first to encounter a collision with MV Nowa approaching from the Starboard side. Afterwards, MV Diamond was programmed to overtake MV Wadi Halfa. All these ships were incorporated into the scenario to maintain the main ship on a collision course with MV Scot Isles. Figure 7.2 illustrates the scenario design, including the main target ships, as captured from the Wartsila ship bridge simulator software in the instructor room at the University of Strathclyde.

The scenario went through testing and trial manoeuvres, demonstrating that it takes around 20 minutes to result in a collision if the main ship takes no action. The scenario includes several uncontrollable parameters, particularly after the collision risk is recognised, due to variations in participants' decision-making process, risk perception, and reaction time. To address this, participants were informed to keep their course and speed by other targets to see their reaction when detecting the risk of collision. Additionally, fixed setting parameters for RADAR, ECDIS, and other equipment were utilised to create a consistent environment and minimise uncontrollable variables. [Table 7.2](#) outlines the specific parameters used in the scenario design to ensure all participants meet the same experimental condition.

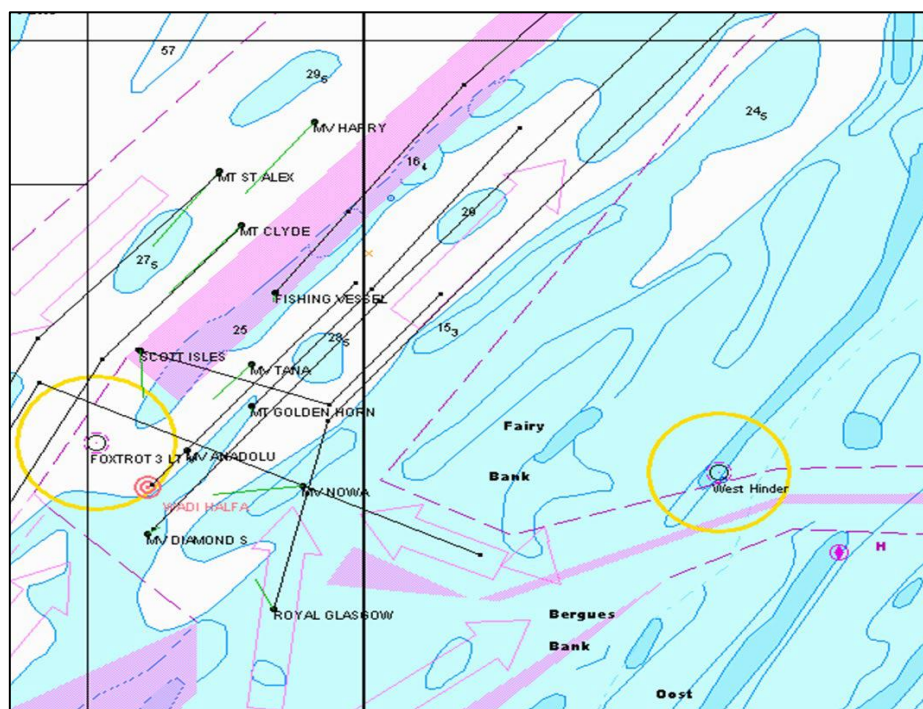


Figure 7.2 Scenario Design

Table 7.2 Own ship information

Parameter	Setting Parameter
Main Ship	MV Wadi Halfa
Time	05:45 am
ECDIS	Dark Mode, 1:200.000, off-centre
RADAR	Dark Mode, 6 miles, North-up,
Speed	14.2 knot

Course	042
Area	Dover Strait, NE course in the NE traffic lane
Condition	Loaded
VTs	Dover Coast Guard
Wind	Northerly, Force 3 (Beaufort scale)
Sea	Slight to Moderate
Weather Condition	Good
Tide	Occasional rain shower
Visibility	Good
Current	Used TRANSAS area model
Engine Telegraph	Full Ahead
Steering Mode	Autopilot

7.2 Experimental Research Question

After assessing the selected accident reports from many accident reports, it is apparent that human factors and the response from the crew have a vital role in reducing the consequences of the accidents and their impact. The “lookout” was the common factor in the accident occurrence from the chosen maritime accident report. The lookout issue (lack of it) was also identified as a main problem in several collision accidents. In order to evaluate Lookout’s impact on improving the safe operation of the ship, an experiment was conducted in a real-time full-mission bridge simulator to examine the significance of human factors and investigate human response in critical conditions. Through simulation, the behaviour and responses of participants during emergency situations were examined, and potential consequences were identified. Two experimental studies were conducted in this research; in the first experimental study, the participant navigated as a solo OOW (acting also as a lookout at the same time) on the bridge, while in the second experimental study, the OOW was accompanied by a lookout with defined tasks. The following research questions were formulated in alignment with the research objective.

Q1: Do psychological factors such as mental workload or stress impact the concentration of the officer on the watch (OOW) during emergencies?

Q2: Does “lookout” influence the cognitive workload of the officer on the watch (OOW) so that the performance will be improved?

Q3: How can we use EEG and eye-tracking devices to explore human cognition and behaviour to improve it in the future?

7.3 Pilot study

Fifteen deck officers and masters with good health and experience were selected and invited to the pilot study, where their performance was assessed under high-traffic conditions in Dover Strait. Pilot studies are preliminary explorations conducted on a smaller scale to determine the feasibility of an experiment. They help identify potential difficulties and bottlenecks early in the research design and data analysis phases. This pilot study identified and addressed weaknesses in the experimental design, leading to its improvement.

Many variables influence EEG and eye-tracking devices in experimental studies; therefore, a pilot study is crucial for laying the basis for the main experiment. Participants executed the simulator scenarios on different days. Each participant received ethical principles and was given 20 minutes to familiarise themselves with the bridge navigation equipment. Following the pilot study, essential modifications to the design were identified. The findings from the pilot study significantly contributed to enhancing the actual experiment conducted in the bridge simulator. Effective experimental design features are crucial for ensuring high-quality data analysis and results. [Table 7.3](#) outlines all the identified weaknesses of the design, along with the reasons and solutions.

Table 7.3 Outline of the accident

Design Concept	Improvement
Duration of the Familiarisation	Each participant initially takes a 20-minute familiarisation exercise. However, it was observed that this time needed to be increased, and the participant had difficulties, especially using RADAR, ECDIS, engine telegraph, and auto-to-hand steering mode. For that reason, the familiarisation duration was set to 60 minutes with the structured design.

Key Person Define	Following the pilot study, it was decided to equip the OOW with an EEG device. In the second set of the experiment, a bridge team was formed, and it was established that the OOW held initial responsibility for all decision-making.
Participants Calling	An invitation text was prepared to recruit participants, ensuring that individuals with the same skills and experience were invited. Given the several variables in the experiment, it is crucial that participants acquire similar characteristics to ensure the reliability of the results.
Essential Events	In experimental studies using an EEG device, it is crucial to identify significant events for participants and to identify the critical time periods that include these events, particularly for the analysis process. Therefore, a timeline was established for the scenario.

7.4 Full Mission Ship Bridge Simulator (Research Testbed)

With increasingly advanced technology, simulator training become a vital approach among researchers. Full-mission bridge simulators are designed to replicate the physical environments and controls of a ship's bridge. The system in the University of Strathclyde for the ship's bridge simulator is WARTSILA NTPRO-5000, which includes a bridge simulator and instructor room. This system is primarily utilised for research in accident analysis, human factors analysis, and critical ship operations such as ice navigation, search and rescue, and high-speed craft operation. The system features over 100 ships and around 50 sailing areas simulating the busiest ports, including a diverse fleet of ships. This extensive range of ship models and sailing areas facilitates a broad spectrum of training, assessment, and research opportunities, enabling the creation of highly realistic scenarios in high-density traffic areas, such as collision or grounding. The simulator allows for the configuration of realistic environmental conditions, including wind, waves, and swell, to mimic real-life conditions, worst-case scenarios, or accidents that occurred in the past. Another critical component of the simulator is the instructor station. The system provides the instructor with tools and facilities for total control over all stages of simulation operation, including design, modification, and editing of the scenario. The instructor can monitor and check the participant's performance during the simulator experiment. Also, the simulator record can be shown for further discussion during the briefing and debriefing. The simulator system has a comprehensive bridge with electronic equipment such as RADAR, ECDIS, engine telegraph, steering wheel, VHF, and display

unit. Figure 7.3 and Figure 7.4 show the general view of the simulator that was used in the experiment and the instructor room.



Figure 7.3 Full mission simulator

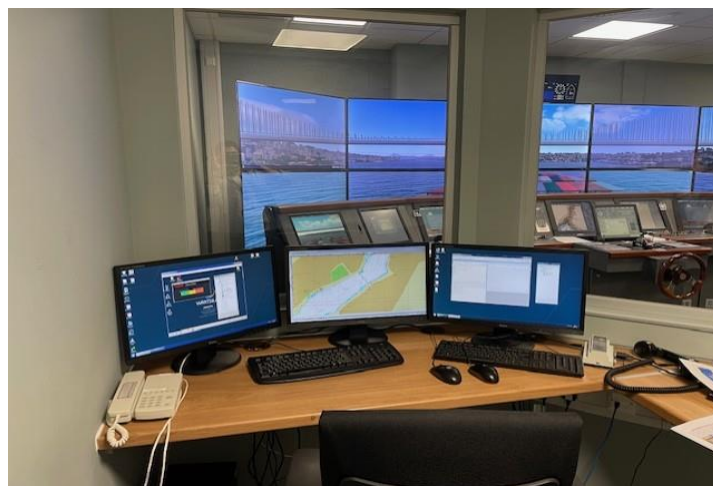


Figure 7.4 Instructor room

7.5 Recruiting Participants

An online call was prepared and distributed to specify the characteristics required for the key participant in the scenario. As the chief officer (OOW) was designated as the key person in the scenario derived

from the accident report, participants were required to possess at least the qualification of a chief officer. Individuals with specified skills and experience were invited to participate. Participants were selected from volunteers holding at least a chief officer's qualification to ensure consistency in the result due to the variables in the experiment.

The bridge simulator presents certain limitations, such as the time and resources needed to execute the scenario. Additionally, the use of EEG and eye-tracking requires special attention and operators with relevant experience.

7.6 Roles/Responsibilities in the Experiment

There are some roles were assigned to the team during the simulator as follows:

- Two operators with expertise in simulator systems managed the simulator, designed scenarios, provided bridge familiarisation, conducted briefing and debriefing, and created the study environment (including weather and VHF communication)
- Operator experienced with the EEG and eye-track system handled and installation, synchronisation, and data extraction of the EEG device.
- One marine expert evaluated the participant based on predefined parameters.
- The simulator was filmed for research purposes.

7.7 The first set of experiments design

Participants signed a consent form and reviewed the orientation script outlining the experiment design. All ethical considerations were addressed during the briefing session. Each participant then goes through familiarisation to ensure proficiency in using the equipment. During the first run of the conduct experiment, participants were navigating solo on the bridge.

7.7.1 The participants

Before the experiment, participants were recruited through a participant call detailed in the Appendices, and subsequently, a schedule was created for the sessions. Participants received information via e-mail

regarding the study and the necessary consideration. The first set of experiments was established with 15 male and female participants who participated in the study. None of the participants had a previous experience with EEG and eye-track devices. However, through the participants' EEG analysis, some of the participants' signals in the EEG device were unclear and insufficient for the study, resulting in the study being conducted with 13 participants.

7.7.2 Research Testbed

The experiment study was conducted in a full mission ship bridge simulator at the Maritime Human Factors Centre in Naval Architecture, Ocean Marine Engineering Department at the University of Strathclyde. To provide the same environment for the participants, all the navigation bridge equipment was set to the same parameters. EEG signals were recorded by the DSI-7 system with a sampling frequency of 300 (Hz) using (DSI- Streamer-v.1.08.60 software in addition to the eye track system Tobii Glass 3.

7.7.3 Experimental Procedures

Participants were instructed during the briefing session, and the scenario was established following the calibration of the EEG and eye tracking. A countdown was used before starting the scenario to synchronize the EEG, eye tracking, and video records. In addition, an additional person helped the author press the button to mark each event in EEG recording software. Each participant was informed of their duties within the scenario and the differences that would occur during the experiment. The duration time of the experiment was defined as 20 minutes. The initial 3 minutes of the scenario were designated as the baseline period, during which participants did not see any targets. Following the baseline period, participants encountered all designated targets. The critical events that will be expected to happen are shown in [Table 7.4](#). The time of the events shown in the table may differ based on the participant's action due to various uncontrollable parameters on the navigational areas for the OOW. In particular, decision-making process in a collision scenario can differ according to each participant's risk perception and reaction time.

Table 7.4 Scenario of the first experiments

Time	Operation	Target	Condition	Action
05:45	Starting	-	-	
05:48	Baseline	-	3 minutes baseline without targets	The simulator will start in the same environment without targets.
05:49	ARPA Target	MV Nowa	CPA 0.4nm TCPA 8 mins 32 sec	COLREG Rule15- crossing situation under normal conditions, MV Wadi Halfa should give way to MV Nowa but increase the workload of the pointed person (to keep her ship on the same course and speed). MV Nowa will agree on passing her aft side.
05:50	ARPA Target	MT Golden Horn	No action needed	
05:51	VHF Comm.	MV Nowa		(Wadi Halfa should call MV Nowa)
05:51	Agreement of passing	MV Nowa		MV Nowa will agree on passing on the aft side of the Wadi Halfa
05:51:48	ARPA Target	MV Diamond	CPA 0.5nm TCPA 14 min	COLREG Rule 13 overtaking situation, in this case, MV Wadi Halfa should keep her Course and speed.
05:51	ARPA Target	MV Anadolu	No action needed	
05:53	ARPA Target	MV Tana	No action needed	MV Tana is Not Under Command, but MV Wadi Halfa should check her status.
05:50	VHF Comm. By Inst.	MV Wadi Half	Calling as MV Diamond for overtaking	MV Diamond will agree on passing on her STB side (No course or speed alteration)
05:50	ARPA target	MV Soctt Isles	CPA 0.1nm TCPA 16.2 min	(Wadi Halfa should call MV Nowa)
05:54	VHF Comm.	MV Soctt Isles	No Reply	The instructor will not reply
05:55	VHF Comm.	MV Soctt Isles	No Reply	The instructor will not reply

05:53	VHF Comm.	MV Soctt Isles	No Reply	The instructor will not reply
05:56	Auto to Hand Steering Mode			MV Wadi Halfa should take action to STB side (Rule 15, MV Scot Isles should give way to MV Wadi Halfa, but there will be no communication at that time, MV Wadi Halfa should take action to prevent collision). There are two options (Altering Course to STB side with big angels and/or reducing speed)
05:58	VHF Comm.	MV Diamond	Callin for A/C to STB	MV Wadi Halfa should call MV Diamond to agree on altering the course to STB side.
06:02	Hard to STB			To steady as she goes
06:02	Midship	MV Scot Isles	CPA 0.9 nm, TCPA 9.4 mins	Steady of the vessel.
06:03	A/C to port			Steady of the vessel.
06:05	Closing			

7.8 The Second Set of Experiments Design

Participants signed a consent form and reviewed the orientation script outlining the experiment design. All ethical considerations were addressed during the briefing session, and the participants went through familiarization to train using navigation equipment. However, in the second experiment, a lookout was assigned as an assistant for the participant.

7.8.1 The participants

The procedures used in the first experiment were applied to the participants taken part in the second experiment. A total of 19 participants were involved, with an experienced officer on watch from our team participating as a lookout. However, through the participant's analysis period, it was discovered

that EEG data and eye track from some participants were unclear for the analysis, and one of the participants could not wear the EEG for personal reasons, resulting in 13 participants being recorded.

7.8.2 Research Testbed

All the participants took part in the experiments at the same location and used the same method and device, which is a full mission ship bridge simulator at the Maritime Human Factors Centre in Naval Architecture, Ocean Marine Engineering Department at the University of Strathclyde.

7.8.3 Experimental procedures

During the scenario simulation, an assigned lookout was pointed with a well-time reporting table, consistently reporting all the targets at the same interval for each session. The same lookout was present during all sessions to ensure a consistent environment for all participants. According to the accident report used to simulate the experiment, both ships had a lookout during the night watch. However, before the accident, both officers of the watch permitted their lookouts to leave the ship bridge for different reasons, such as toilet breaks or safety rounds. The critical situation expected to happen in the second scenario is in [Table 7.5](#). In assessing the collision between the vessels, we established a reporting order based on the Closest Point of Approach (CPA) and Time to Closest Point of Approach (TCPA) values. Specific times for each reporting stage along the route were determined accordingly.

Table 7.5 Scenario of the second set of experiments

Time	Condition	Actions
05:45	Baseline Start	
05:48	Baseline End	
05:49	MV Nowa Reporting.	Lookout report: (there is a vessel on crossing situation with a red light)
05:49:10	Mv Anadolu Reporting.	Lookout report: (there are two ships ahead of us with yellow light (stern light))
05:49:50	MV Golden Horn Reporting.	
05:50	Call as MV Nowa (if the participant did not	Instructor report: (calling MV Wadi Halfa x 2 times). This MV Nowa, information, I am on your starboard side, I will pass on your stern; please keep your speed and course, over.

	recognize the risk of collision)	
05:52:05	MV Scot Isles Reporting.	Lookout report: (there is a ship on our port side with a green light, it is approaching)
05:52:25	Mv Tana reporting.	Lookout report: (the ship has two red lights at the top of the bridge.
05:52:45	MV Diamond reporting.	Lookout report: (there is a ship behind us at a close distance)
05:53	Call as MV Diamond (if the participant did not recognize the risk of collision)	Instructor report: (MV Wadi Halfa x2 times, this is MV Diamond, information, my speed is 17 knots, I will overtake on your starboard side, please keep your speed and course, over.

7.9 Collection Data

Each scenario experiment team was assembled to reflect the actual bridge manning as shown in the accident report. The instructor's room included four operators: a simulator operator, an EEG and eye-tracking specialist, and a navigation specialist. Fifteen participants participated in the first set of experiments, while nineteen were involved in the second. Due to technical issues, some participants were excluded to ensure a comparable distribution of subjective and objective data statistics. Therefore, twenty-six deck officer participated in the two experimental scenario runs with their respective teams for data analysis. The EEG and eye-tracking were fitted to the participant's head, and the operator provided information regarding the experiment and compliance with the General Data Protection Regulation (EU Regulation 2016/679).

Participants were required to sign an informed consent form and orientation script after consenting to the use of their personal information and confirming their participation. During the briefing session, participants were introduced to the scenario and experiment in detail and were asked to read and sign the consent form. An additional interactive familiarization session was conducted, where the participants were introduced to the familiarisation scenario to explain the equipment, vessel, and sailing area to them. The session lasted for 60 minutes.

During the scenario, the first three minutes are baseline with no target, and the following 15-minute participants will face various targets. After the scenario ended, participants engaged in an open-ended

discussion about the recording and the manoeuvres conducted. During the debriefing, they were also required to complete a NASA TLX form **Appendix C** and a demographics questionnaire .

All collected data, including EEG and eye tracking recording and raw data, simulator logs, recordings from external cameras, and questionnaires, were securely stored in a database. The data was anonymised and processed by the University of Strathclyde, which is responsible for data treatment and protection.

Chapter 8 Analysis of the Experiments and EEG and Eye Track Data

8.1 Introduction

In maritime operations, the capacity of seafarers to perform under different conditions of Mental workload (MWL), stress, and attention is paramount to ensure safety and efficiency. Bridge simulator training is critical in preparing seafarers for the demanding environment they will face at sea. With advancements in neuroscientific analysis, the use of electroencephalography (EEG) has become increasingly prevalent in understanding and enhancing cognitive performance within this simulation. Moreover, eye tracking gave us an understanding of the mental demand through eye pupil size and human behaviours through the focus duration on the equipment in the training simulation. Most of the studies mentioned that the increase in the eye pupil diameter tends to increase the workload (Van Der Wel and Van Steenbergen, 2018). However, it is important to consider that the changes in the lighting condition during the tasks could affect the eye pupil dilation (Pfleging et al., 2016). Moreover, the pupil size increased when attention was directed toward the target stimulus, reflecting enhanced cortical processing associated with attentional engagement (Binda and Murray, 2015; Morita et al., 2015).

This research aims to interpret the cognitive profile of OOW during bridge simulator exercises through EEG data and eye-tracking analysis. By studying the changes in MWL, Stress, and Attention across different experimental conditions (Participants navigate solo versus navigating with a lookout). We aim to explore the dynamic interplay between individual cognitive processing and the presence of the lookout.

In this study, the data presented originated from two types of experiments. The first experiment involved 13 participants navigating the ship in a simulator solo. The second experiment involved 13 participants with a lookout. The first and second experiments used the same scenario. By comparing both data extracted from EEG and eye track for each participant, we aim to identify issues that affect the performance to develop future training protocols and potentially unveil strategies for cognitive optimisation in the maritime training environment.

To provide a clear and interpretable framework, we developed a value scale that categorised each cognitive factor into three levels represented by colour coding. For MWL and Stress Table 8.1 provides the criteria while Table 8.2 provides the criteria for attention. It represents the value of the cognitive state, as shown, but it should be taken into consideration that attention is the opposite in the colour code than MWL and stress.

Table 8.1: Value for MWL and Stress

MWL and Stress	
The Value	Scale
(0.0) to (0.3)	Low
(0.3) to (0.6)	Moderate
(0.6) to (1)	High

Table 8.2 Value for Attention

Attention	
The Value	Scale
(0.0) to (0.3)	Low
(0.3) to (0.6)	Moderate
(0.6) to (1)	High

This colour scale is a practical tool for visually representing participants' cognitive load, stress, and attention level during critical tasks, providing insight into performance and decision-making during simulator exercises. In addition, the pupil diameter represents the workload during the critical task. Most studies show that increases in the eye pupil diameter are related to increased workload (Van Der Wel and Van Steenbergen, 2018). However, it is essential to consider that the changes in the lighting condition could affect the pupil's dilation.

The scenario was recorded and divided into five events, Figure 8.1. Each event shows the performance of the participant during the training scenario, and each event is described as follows:

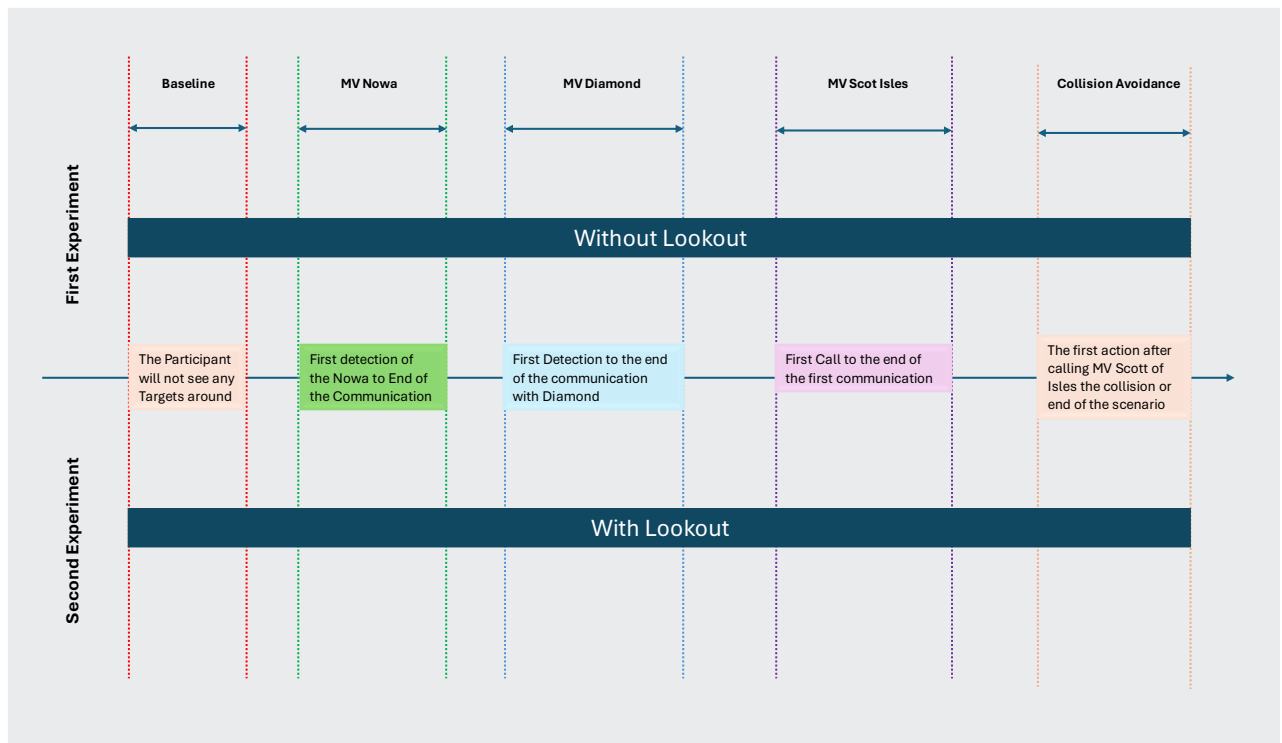


Figure 8.1: Event during the scenario

8.1.1 Event 1: Baseline

This event is designed to provide a clear environment for the participant, with no target or radar-detected target in the area. The purpose of this event is to allow the participant to familiarise himself with the surroundings vicinity without any external pressure. This phase is to keep the participant's cognitive state calm and focused before any operational tasks begin.

8.1.2 Event 2: MV Nowa Approach

This event begins when the participant detects the approaching MV Nowa visually or by acquiring the ship on radar. The participant monitors MV Nowa as it approaches from the starboard side and passes safely from the stern. The event ended when the first communication with MV Nowa ended.

8.1.3 Event 3: MV Diamond Approach

This phase also begins when the participant detects MV Diamond visually or on the radar. However, in this case, MV Diamond approaches from a stern and overtaking from the starboard side. The participant

in this event encompasses the detection, monitoring, and communication with the MV diamond until the end of this event, when the first communication ends.

8.1.4 Event 4: MV Scot Isles Approach

In this event, the participant is required to detect the Scot Isles visually or by radar. The ship approaches from the port side. The participant attempted to communicate with the ship Scot Isles, but no response was received from Scot Isles. This event ends when the participant makes their last attempt to communicate with the ship, and the ship passes or becomes a navigational concern to the participant.

8.1.5 Event 5: Collision Avoidance

This event illustrates the collision scenario where the participant identifies a risk of collision with the Scot Isles. This event starts when the participant detects the risk of collision and must take action, which includes altering course or reducing the speed to avoid collision. The event ends either with a successful manoeuvre to pass clear or a collision if the participant fails to prevent the collision.

8.2 First experiment

As mentioned in the previous section, the first experiment included 13 participants that were analysed. However, the participant was sailing the ship solo, assigned with code (P No.)

8.2.1 Participant No.3 Performance (P3)

During the simulator experiment, Participant 3 was navigating solo with the ideal course, which is the green line Figure 8.2, but it culminated in a collision with the ship Scot Isles. The accident occurred during the participant's interaction with five events:

- **Event 1 Baseline**

During the baseline phase, no targets were present during this event, and this period resulted in the participant having a low cognitive load. The participant took the opportunity to check the navigation equipment and familiarise himself with the surrounding environment through visual observation.

- **Event 2 MV Nowa**

After the baseline, the participant detected the MV Nowa within a few seconds of the ship appearing on the radar. Upon noticing the ship visually, the participant checked the radar to acquire the MV Nowa and continued to monitor the surrounding area for other targets. After maintaining visually and on the radar, the participant received a call from MV Nowa instructing him to maintain his course and speed. The participant confirmed with the instructions and did not feel any risk posed and proceeded without taking any action.

- **Event 3 MV Diamond**

In this event, the participant visually detected MV Diamond at (9m:21s) after turning the visualisation equipment to scan the area, even though the ship had appeared on the radar earlier. Despite the ship being present, the participant had not acquired the MV Diamond on the radar before visual detection. After detecting the ship, the participant received a call requesting the participant to maintain the course and speed. The participant agreed and informed MV Diamond that MV Nowa was ahead of him, which means he still monitored MV Nowa. Throughout this event, the participant showed that he remained calm and did not observe any immediate risk, and he still maintained the same course and speed as advised by the other targets.

- **Event 4 MV Scot Isles**

At (11m:12s), the radar highlighted MV Scot Isles with a red circle, indicating a potential target. The participant quickly checked the radar and visually detected the ship. Then, the participant adjusted the radar scale and acquired Scot Isles to check its CPA and TCPA information. When he realised the increasing risk of collision based on the radar information, the participant attempted to communicate with MV Scot Isles twice, and he did not receive any response. After the second call, the participant prepared to take action when he realised the situation had become critical.

- **Event 5 Collision Avoidance**

Following the failed communication with Scot Isles, Participant 3 took action by reducing speed after (3m:12s) from the last call with Scot Isles. During this period, the participant

communicated with the Dover Coast Guard to report his situation and explain his attention. This communication took around (01m:30s), and the participant's reaction was delayed. In addition, after terminating the call with the Dover Coast Guard, Participant 3 also called MV Diamond to inform them of his action. Although the participant successfully reduced the speed, the action was taken too late, and the collision with the Scot Isles occurred. Participant 3's decision to communicate before taking immediate action contributed to the delayed response. The participant should prioritise taking collision avoidance action before attempting to communicate with others.

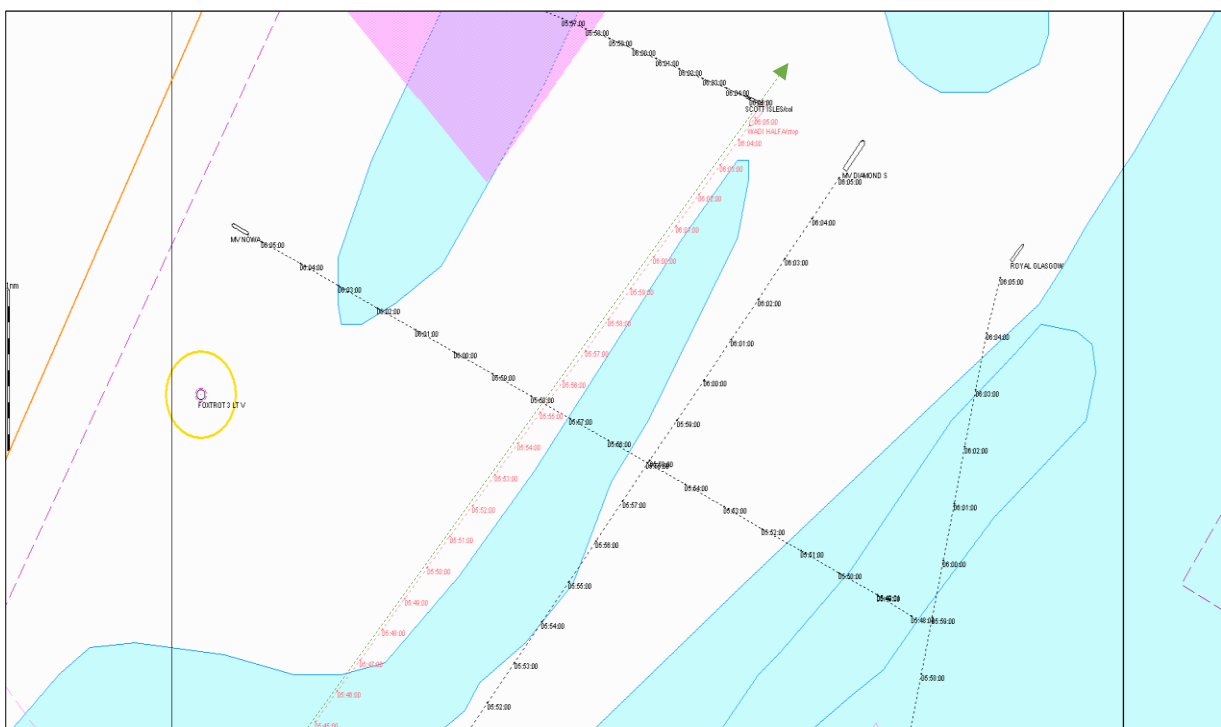


Figure 8.2: P3 Navigation chart

Also, the heat map provides Participant 3's visual attention distribution during the ship bridge training simulation in Figure 8.3, which offers a clear visual focus throughout the events. The red zones indicate the area with high focus, suggesting that Participant 3 concentrated heavily on the radar and the port side when he noticed the risk with Scot Isles. Also, the central navigation display shows the participant was focusing on the Scot Isles approaching a head. The green regions show less intense focus, indicating

that the participant was aware of his surroundings, but he spent less time monitoring these targets, which are MV Nowa and MV Diamond.



Figure 8.3: Heat map for P3

Table 8.3: P3 EEG Data

Time		Event	Duration	MWL	Stress	Attention
00:00.0	03:02.7	Baseline	03:02.7	0.00	0.41	1.00
03:20.2	07:07.6	Nowa	03:47.5	0.15	0.01	0.25
09:21.7	10:14.9	Diamond	00:53.2	0.10	1.00	0.41
11:12.3	13:19.0	Scot Isles	02:06.6	1.00	0.03	0.34
16:31.4	20:11.6	Collision Avoidance	03:40.2	0.43	0.00	0.00

Based on the EEG result and participant's performance metrics illustrated in

Table 8.3 and Figure 8.4, we can observe how the cognitive demand (MWL, Stress, and attention) differentiation across the different events in the simulator experiments as follows:

- **Event 1 Baseline:**

During the baseline, Participant 3 showed no mental workload while stress level was moderate and attention high. This suggests that the participant was calm and engaged with high attention because there were no targets, and no immediate risk existed.

- **Event 2 MV Nowa:**

Moving to event 2 MV Nowa, there was a slight increase in the MWL and a very low level of the stress and attention. This is when the scenario starts and targets appear, and the participants begin to monitor the radar which shows that cognitive demand starts to increase. However, attention could become very low due to multitasking by the participant the same time such as, observing the targets and receiving communication

- **Event 3 MV Diamond:**

The next event, MV Diamond, shows significantly high stress with low MWL and moderate attention, indicating that the sudden detection of the MV Diamond and when the communication commenced may have created stress for Participant 3, despite there is still no risk of collision.

- **Event 4 MV Scot Isles:**

In the Scot Isles event, the MWL increased significantly, which might be due to the detection of the risk of collision and failure in communication attempts. However, the stress level becomes low, and a moderate attention level suggests the participant is still alert with a high cognitive load.

- **Event 5 Collision Avoidance:**

In the last event, collision avoidance, after taking action, there was a moderate MWL while the stress and attention levels dropped significantly, which reflects that the participant was over-reliance on the equipment and got a cognitive overload that delayed his reaction, which led to the collision.

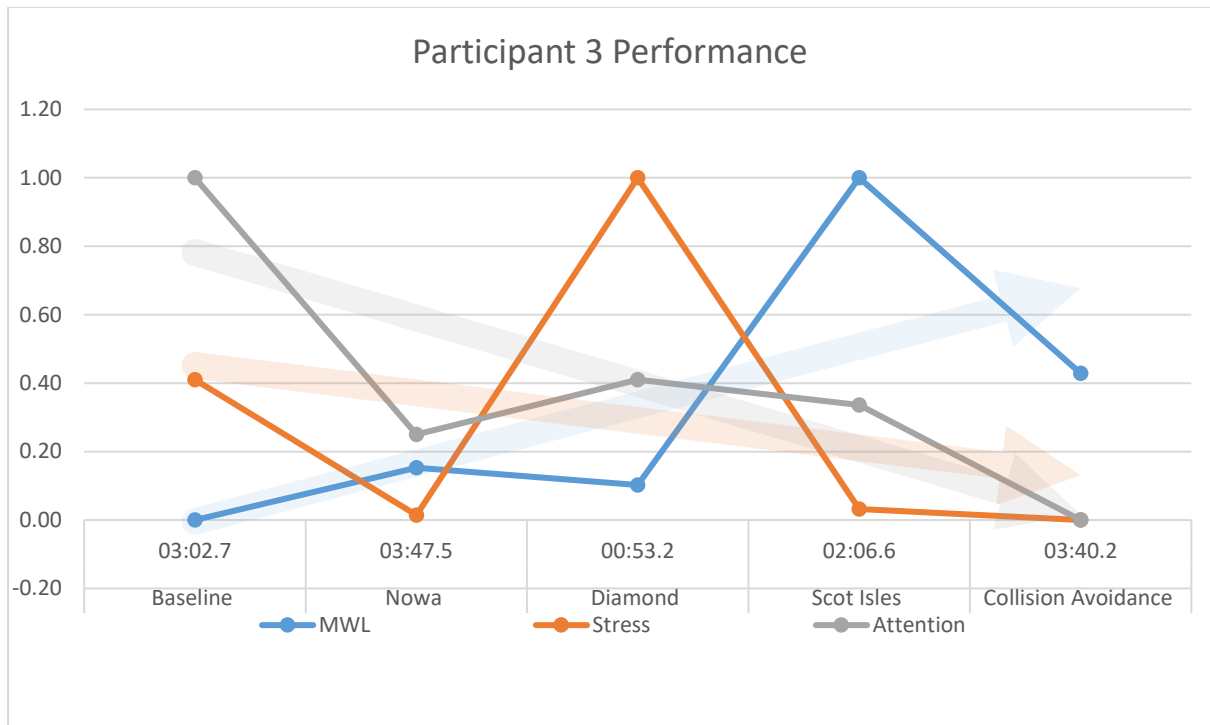


Figure 8.4: P3 EEG data

The pupil diameters for both eyes show a constant increase during the event of the MV Diamond. After that, during the Scot Isles, the eye pupil decreased slightly and stayed until the end of the Collision indicating that the MWL was increasing with the difficulties of the situation as presented in Figure 8.5. The participant eye pupil dilation was changed as shown in Figure 8.5, Figure 8.11 and with each event as follows:

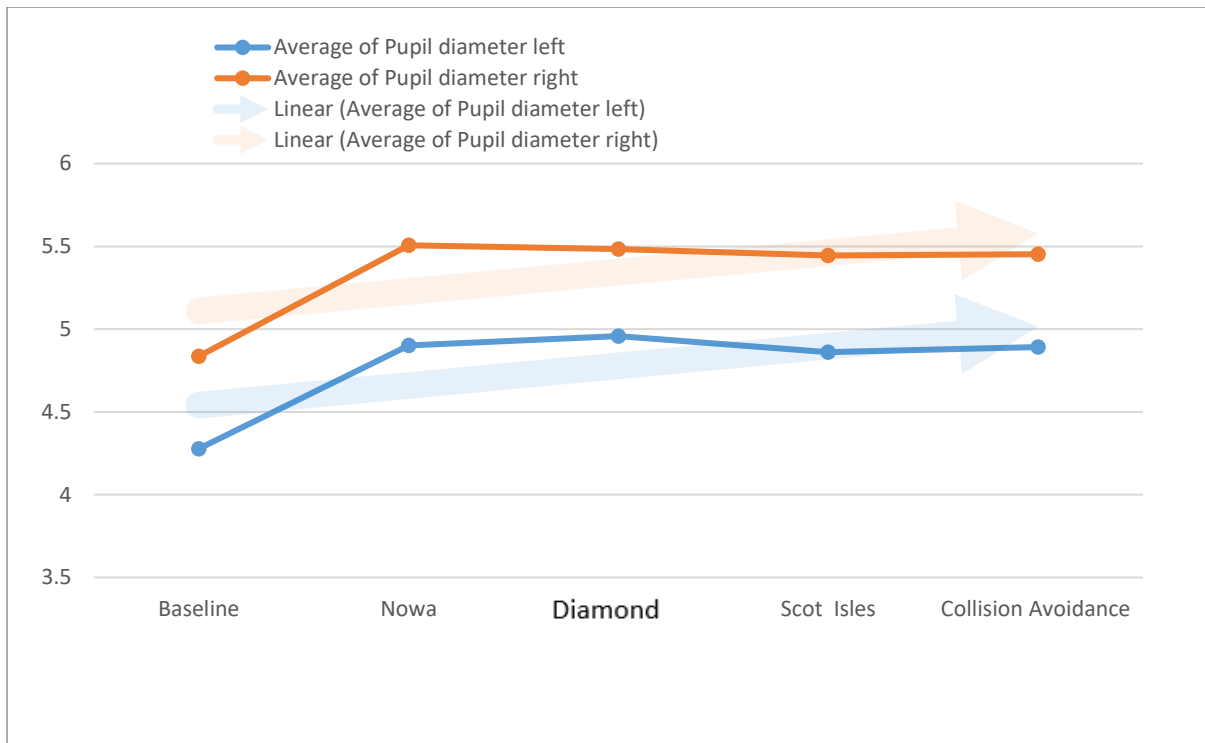


Figure 8.5 P3 Eyes pupils' diameter

- **Event 1 Baseline:**

During the baseline event, Participant 3 demonstrated the smallest average pupils with (4.28) and (4.84) for the left and right eyes, respectively. The participant was not under pressure as there were no external targets to deal with, which made him calm and in a low MWL state. The baseline duration is around (22%) of the scenario time, and the participant in the baseline event spent around (37%) of the event time focusing on the radar and (18%) of the event on ECDIS, which indicates that the participant used this time to get familiar with the navigation equipment, and around (31%) of the event time was visually scanned the surrounding area to check the situation in the surrounding area. Additionally, a small amount of attention was put on the display unit and top display unit, which is (6%) and (7%) of the event, indicating an initial information check before the targets appear. In addition, the heat map showed how the participant distributed his visual attention during the baseline event, Figure 8.6.



Figure 8.6 P3 Heat map for baseline event

- **Event 2 MV Nowa:**

As the MV Nowa appeared on the radar and was visually detected, Participant 3's eye pupil diameters increased to (4.90 mm) and (5.51mm) for the left and right sides, respectively. This was due to the participant showing high cognitive engagement and an increase in the MWL during the experiment, maybe because of the sudden appearance of the MV Nowa. In addition, the participant spent around (28%) of the experiment time observing the MV Nowa . The participant has shown a strong reliance on radar, with (59%) of the event time in this event and (6%) of the event time on ECDIS, indicating that he prefers to use the radar as a navigation system to monitor the target. Also, the participant spent around (34%) of the event time observing on the visualization screens. Figure 8.7 illustrated that the participant relied on the radar and various visual attention on the visualisation screens.



Figure 8.7 P3 Heat map for MV Nowa event

- **Event 3 MV Diamond:**

During this event, pupil dilation increased slightly to (4.96 mm) and (5.48 mm), indicating that Participant 3 got more MWL when the MV diamond appeared. This event took around (7%) of the experiment time. The participant remained focused on the radar for (61%) of the event time. However, (36%) of the event time, he also focused on screens for visualisation when the MV Diamond communicated with the participant, who tried to observe visually to ensure the location of the MV Diamond and have the situation awareness. In addition, there was a small amount of attention (3%) during the event time, indicating that the participant was focusing on different systems during communication. The MV diamond event duration was shorter because the participant failed to detect the target until receiving a call from MV diamond. Immediately, the participant checked the radar and the screen for visualisation, which suggests that the participant did not pay attention to the Radar for monitoring the targets and used his visual for observation. Figure 8.8 shows that Participant 3 used his visual attention and the radar during the MV Diamond event. It shows there is a concentration on the visual panel, which indicates that the participant turned to the screens to observe the MV Diamond and improve his situational awareness.



Figure 8.8 P3 Heat map for the MV Diamond event

- **Event 4 MV Scot Isles:**

Still with this event, the participant's eye diameter slightly decreased but remained high compared to the baseline at (4.89 mm) for the left eye and (5.45 mm) for the right eye, indicating that Participant 3 continued to have high MWL, especially when the participant communicated with the Scot Isles and assess the risk of collision. This event took around (16%) of the experiment time. The participant focused approximately (67%) of the event time on the radar during this event to assess the situation with the Scot Isles, which still indicates that the participant relied on radar to monitor the situation. However, participant 3 also checked the situation visually, with (24%) of the event time checking the external environment through the screen visualisation and (8%) of the event time using the ECDIS to support navigational checks. It shows that the participant relied on the radar and improved his awareness by visual observation and then confirmed the information using the ECDIS, which indicates an effective assessment to improve his situational awareness, Figure 8.9. This suggests that the participant distributes his attention in the ship bridge environment between the navigation equipment and the external observation, indicating he is aware of the situation.



Figure 8.9 P3 MV Scot Isles event heat map

- **Event 5 Collision Avoidance:**

The pupil diameter remained elevated at (4.89 mm) on the left and (5.45 mm) on the right, demonstrating a high MWL when he took action to avoid the risk of collision. The collision avoidance action took around (27%) of the experiment time. During this event, the participant distributed his attention more widely across the bridge systems. The participant focused this time less on the radar (17%) of the event time while (50%) of the event time on screen for visualization and (18%) of the event time on the ECDIS, which indicated that the participant was aware of the situation visually and keep monitoring the navigation equipment, Figure 8.10. This means that the participant relied on the external environment when he saw the risk of the collision to monitor the target and tried to take imminent action. Unfortunately, the delay in the decision to take action resulted in a collision.



Figure 8.10 P3 Collision avoidance heat map

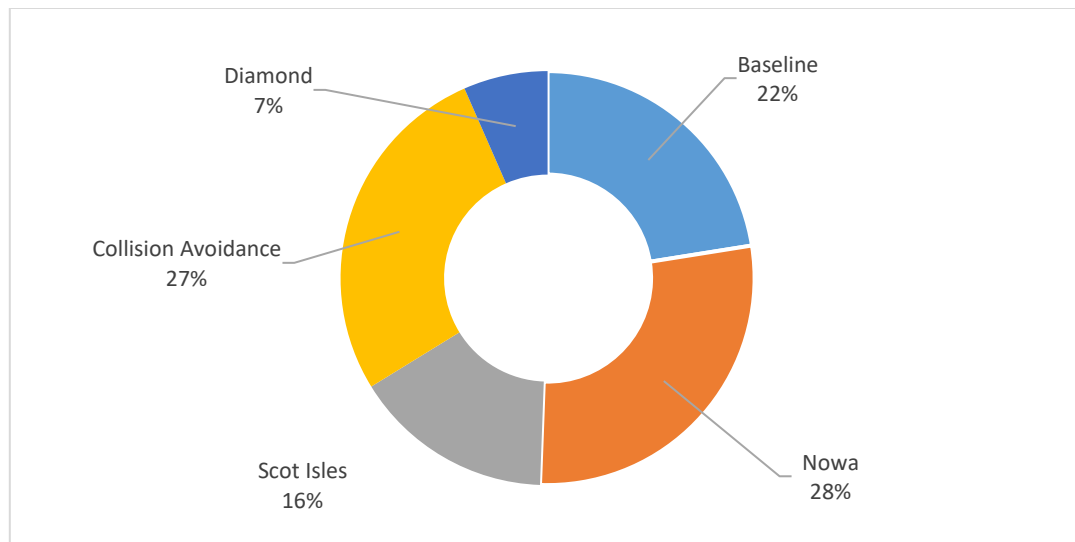


Figure 8.11 P3's duration for each event

Table 8.4 P3's point of focus at different scenario events

Row Labels	Display Unit	ECDIS	Engine	VHF	RADAR	Visualization	Top Display Unit
Baseline	6%	18%	1%	0%	37%	31%	7%
Nowa	0%	6%	0%	0%	59%	34%	2%
Diamond	0%	0%	0%	3%	61%	36%	0%
Scot Isles	0%	8%	0%	0%	67%	24%	0%
Collision Avoidance	7%	18%	0%	0%	17%	50%	8%

The combined analysis of EEG and Eye tracking data provides a comprehensive view of Participant 3's performance and cognitive demand during the simulator experiment, as shown in the recording. Both results for Participant 3 offer a valuable understanding of how the participant responded to each event and the complexity of the scenario from the baseline to the collision avoidance as shown in Figure 8.12, which demonstrates the brain activity across four channels (F4-PZ, P4-Pz, P3-Pz, and F3-Pz) that illustrate the cognitive demand.

The EEG data reveals cognitive engagement, especially the MWL, increased as the complexity of the scenario progressed, while attention levels decreased and the stress fluctuated. Starting with the baseline, the brain activity across the channels was low and calm.

Moreover, during the MV Nowa event, the activity remained stable until the participant received a call from the Nowa. At this point, around (10m:10s) of the experiments, a change in the EEG signal indicated a rise in MWL.

Moving to the MV Diamond event, an increase in the spike was pronounced in the F4-Pz and P4-Pz channels, which is linked to the cognitive engagement of Participant 3. This spike occurred because Participant 3 noticed MV Diamond after receiving the call from MV Diamond, prompting sudden awareness of the situation.

The next event, MV Scot Isles, reflects a significant increase in MWL, as shown by the sharp spike in EEG activity, which was around 16m:40s in the experiments. This might have resulted from the failure to communicate with the Scot Isles and the perceived risk of the collision.

In the final event, the risk of the collision made the participant take immediate action, resulting in a moderate level of MWL and lower stress and attention. However, due to the delay in response, the ship collided despite the participant's effort to avoid the situation.

Similarly, the pupil diameter from eye tracking is closely aligned with EEG findings. During the baseline, the pupil diameter was small and stable, indicating that the participant was calm and relaxed. As the scenario proceeded to the MV Nowa event, the eye pupil began to increase, reflecting greater cognitive engagement. During the MV Diamond and Scot Isles, the eye pupil peaked, reflecting

the highest MWL load during these events. This increase in cognitive load was due to a sudden call from Diamond and the participant's attempt to communicate with Scot Isles, which resulted in no response, further elevating the participant's MWL and affecting his attention.

Following this, the pupil diameter remained elevated during the collision avoidance event, indicating continued MWL but less than the Scot Isles event. This might be because the participant believed he had made the correct decision to avoid the collision, but the delay in action led to the collision. This suggests that the participant was not fully aware of the ship's manoeuvring characteristics, or he relied on the ship's engine that would give a response immediately. This also suggests that the participant did not have experience or need more familiarisation with the ship's characteristics.

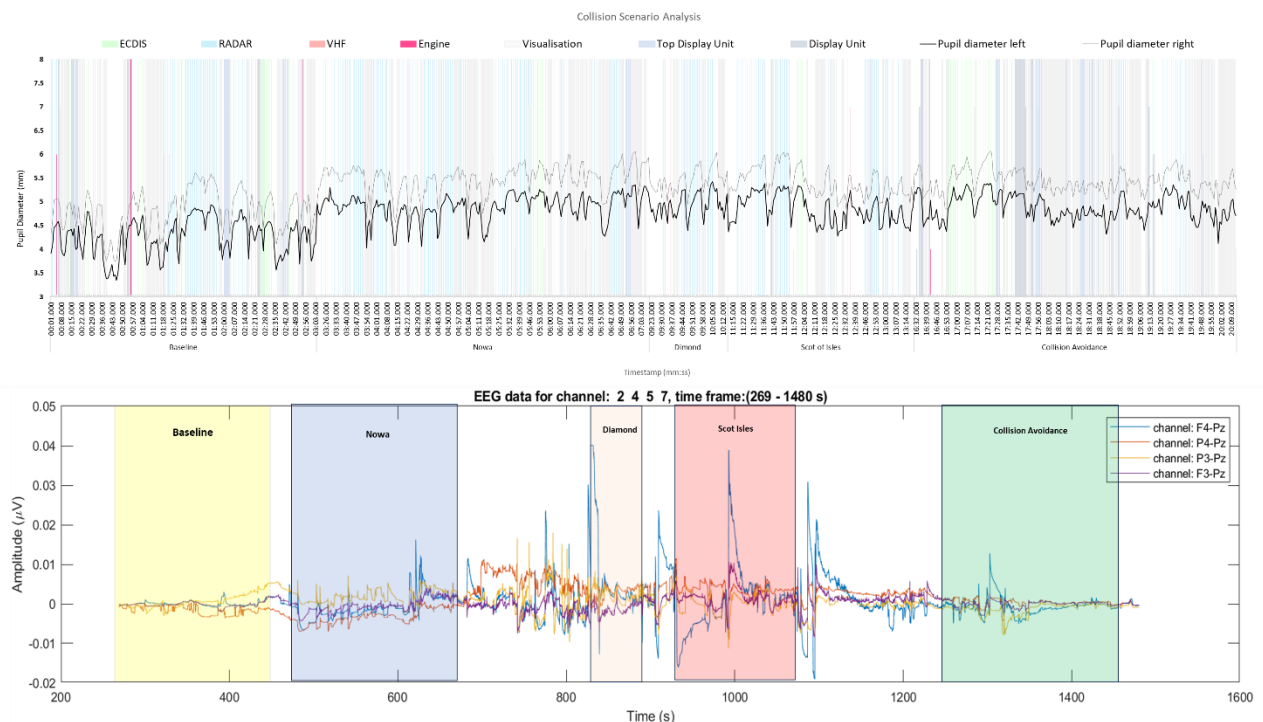


Figure 8.12: P3 EEG and Eye Track

In addition, Figure 8.13 shows significant activity in the delta (the blue signal) and some activity in the theta, particularly in the frontal lobe more than the parietal lobe. These lobes play a crucial role in cognitive function, and high delta power suggests active cognitive processing, possibly related to working memory and decision-making during the experiment. The fluctuations in EEG amplitude,

especially in the frontal lobe, might be linked to high cognitive demand at certain points, such as the significant spike during MV Diamond and MV Scot Isles events.

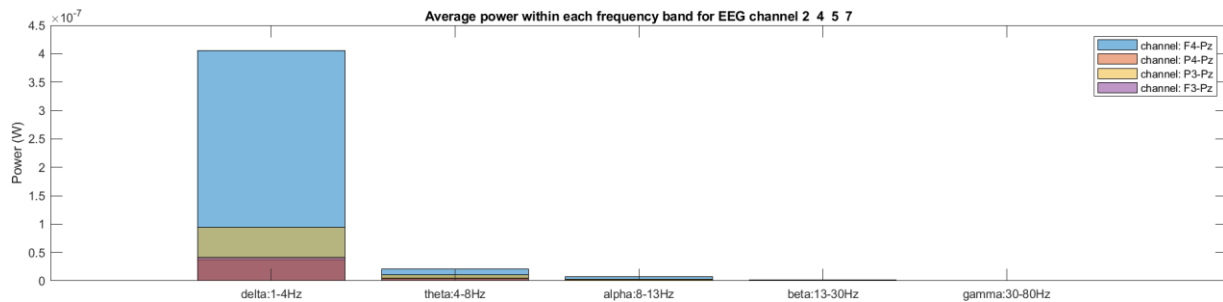


Figure 8.13: P3 Power band

8.2.2 Participant 5: Performance (P5)

During the simulator experiment, Participant 5, as a solo navigator, was navigating the ideal course, which is the green line, Figure 8.14. The participant passes clear, but
with a near miss with the ship Scot Isles. P5's performance is classed as a near-miss performance with actions during the following five events:

- **Event 1 Baseline:**

Participant 5 in this event checked the radar and the ECDIS most of the time to familiarise himself with the bridge equipment. He looked to the external environment only a few times, particularly at the buoy on the starboard side and returned his attention to the navigation equipment. This event has no target, and therefore, Participant 5 has low cognitive demand.

- **Event 2 MV Nowa:**

After the baseline ended, Participant 5 mentioned that he changed the radar scale verbally. Then, Participant 5 detected the MV Nowa a few seconds later by acquiring it on the radar. The participant used the visualisation panel to check the MV Nowa visually and, he used the binocular to look at the ship in front of him. After that, the participant returned to the radar and monitored the MV Nowa until he received a call from Nowa instructing him to maintain the same course and speed. During the monitoring of MV Nowa, Participant 5 glanced at the

MV Scot Isles visually but did not give the Scot Isles attention and did not feel any risk posed, so the participant proceeded without any action.

- **Event 3 MV Diamond:**

After the MV Nowa terminated the communication, Participant 5 scanned the surrounding area by using the visualisation panel and visually detected the MV Diamond. After that, Participant 5 went to the radar to monitor the targets. Participant 5 attempted to acquire a target other than MV Diamond. Participant 5 could not acquire the targets successfully, so he requested assistance from one of the instructors to learn how to acquire the targets on the radar to get the information. Afterwards, Participant 5 received a call from MV Diamond instructing him to maintain course and speed, which the participant confirmed without taking any further action.

- **Event 4 MV Scot Isles:**

After the MV Diamond call finished, Participant 5 used the screen visualisation panel where he could control the screen rotation Figure 8.15, and the binoculars to confirm the location of the MV Nowa and MV Diamond. Participant 5 noticed the MV Scot Isles from the MV Nowa event without being aware of the risk. Participant 5 acquired the MV Scot Isles and the radar at (12m:30s) and went immediately to the ECDIS for more information. The participant monitored the MV Scot Isles visually and also used the port side bearing for monitoring with the radar. The participant used communication and said “Officer of the Watch” which is not understandable who Participant 5 wants to call.

- **Event 5 Collision Avoidance:**

At (17m:47s), Participant 5 changed the steering to manual and took action by altering the course to the starboard side. During collision avoidance action, the participant used the steering manually and monitored the Scot Isle visually. There was no attempt for communication and Participant 5 passed clear with a distance of less than (0.2 nm) which is a near miss and the opportunity of collision is high with the delay of the decision.

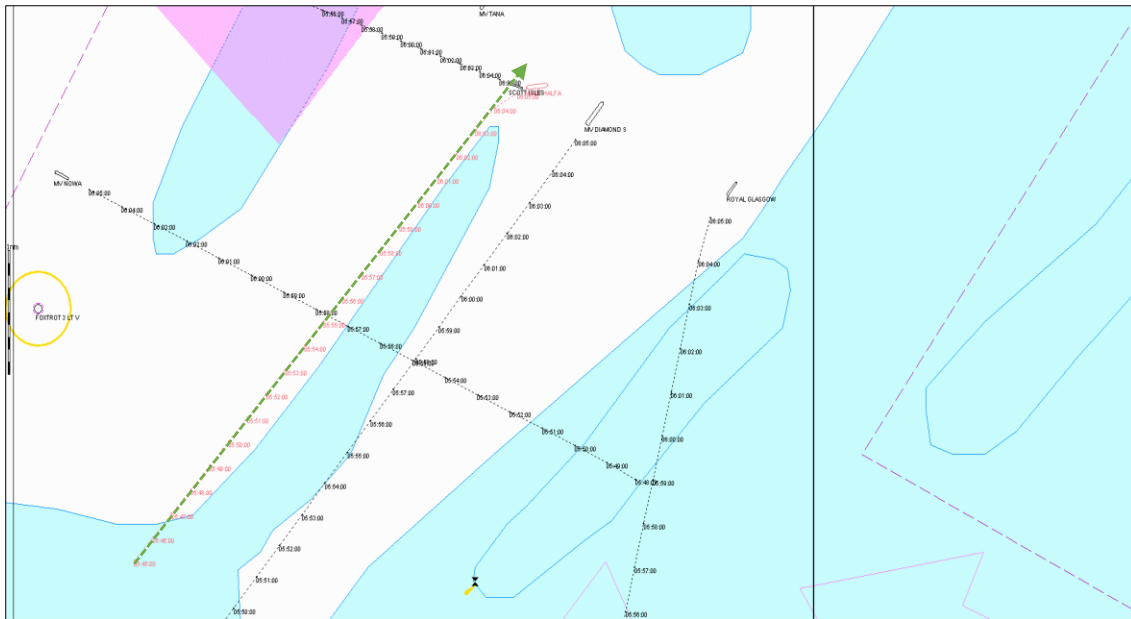


Figure 8.14 P5 Navigation chart

The heat map demonstrates Participant 5's observation distribution throughout ship bridge simulator experiment, Figure 8.15. The heat map illustrates a low visual focus during the events, which indicates that Participant 5 over-relied on the automation and did not observe screens visually consistently at the end of the experiment when Participant 5 monitored the Scot Isles. The red zone suggests that the participant focused most of the time on the radar to monitor the targets in the surroundings. In addition, the participant used the ECDIS and other equipment with low to moderate focus to support his attention and situation awareness, as shown in the heat maps.



Figure 8.15 P5 Heat map

Based on the EEG result and Participant 5's performance metrics illustrated in Figure 8.16, we can observe the differences between each participant how the cognitive demand (MWL, Stress and attention) differentiation across the different events in the simulator training as follows:

Table 8.5 P5 EEG data

Time		Event	Duration	MWL	Stress	Attention
00:00.0	03:00.0	Baseline	03:00.0	1.00	0.2974	0.0833
03:23.0	00:07	Nowa	03:36.6	0.89	0.2237	0.0000
07:14.0	10:17.6	Diamond	03:03.6	0.00	1.0000	0.1456
10:17.6	17:46.9	Scot Isles	07:29.3	0.03	0.0000	1.0000
17:46.9	20:50.6	Collision Avoidance	03:03.7	0.97	0.2901	0.4491

- **Event 1 Baseline:**

During the baseline, Participant 5 shows high MWL and low stress and attention, which is the opposite of Participant 3. This indicates that each participant's reaction may be significantly different, and this could be related to the individual differences in personalities and the training they received. Participant 5 focused most of the time on the radar and ECDIS during event 1, which suggests that the participant increased his cognitive focus to get familiar with the environment.

- **Event 2 MV Nowa:**

The next event, MV Nowa, Participant 5 demonstrated the same criteria as the baseline which is high MWL and low stress and attention. In this event, the participant also concentrated on the navigation equipment and noticed the Scot Isles but did not pay attention to it, which suggests that the cognitive load was still high until the call from MV Nowa.

- **Event 3 MV Diamond:**

In this event, Participant 5 detects the MV Diamond visually. The participant illustrates high Stress, no MWL and low attention. The stress might have increased because Participant 5 suddenly realised he did not know how to acquire the target on the radar. Therefore, the participant asked for support on how to use the radar.

- **Event 4 MV Scot Isles:**

During Scot Isles Monitoring, Participant 5 put all his attention on Scot Isles. Participant 5 utilises the radar and ECDIS and observed Scot Isles visually, and he did not attempt to communicate with Scot Isles, which indicates that his attention is high with low MWL and no stress.

- **Event 5 Collision Avoidance:**

During this event, Participant 5 altered the course manually to avoid collision. The target ship, MV Scot Isles, was very close. As a result, the MWL becomes high, and his attention is moderate with low stress.

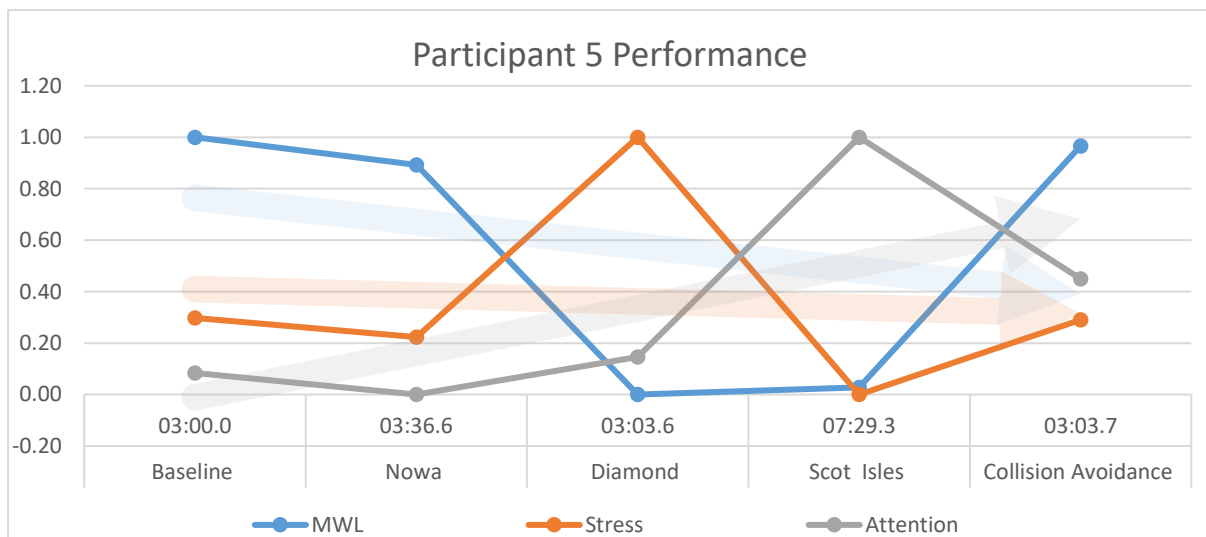


Figure 8.16 P5 EEG data

Pupil diameters for both eyes show a variation during the events. Participant 5 began with low MWL and increased slightly until reached the Scot Isles event. During the Scot Isles event, there is a notable decrease in pupil diameter and an increase again in the Collision event, indicating the variety of the MWL with the difficulties of the situation. The participant's eye pupil dilation was changed as shown in Figure 8.22, Figure 8.23, and Table 8.6, with each event as follows:

- **Event 1 Baseline:**

During the baseline, Participant 5 started with a normal eye pupil with an average (of 5.76mm) and (5.87mm) for the left and right eye, respectively. Since there were no targets in the

surroundings, the participant was calm with the low MWL. The baseline event lasted around (16%) of the scenario time. During this event, Participant 5 spent around (56%) of the event time focusing on the radar and (38%) of the event time on the ECDIS. In addition, (5%) of the event time in this event, Participant 5 checked the surrounding area through the screens. This indicates that Participant 5 was trying to get familiar with the navigation equipment and the external environment. Figure 8.17 shows that Participant 5 concentrated on the radar and ECDIS during the baseline.



Figure 8.17 P5 Heat map for baseline event

- **Event 2 MV Nowa:**

The targets started to appear, and the participant detected the MV Nowa immediately on the radar. The eye pupil increases slightly to (5.80 mm) and (5.90mm) for the left and right eyes, which indicates that the participant received cognitive load and increased the MWL. The duration of this event was approximately (19%) of the experiment time. However, Participant 5 used the radar around (52%) of the event duration, while (26%) of the event time was on the ECDIS and (3%) of the event time was on VHF for communication. Also, the participant looked around using the visualisation for around (19%) of the event time. This indicates that the participant relied on the radar for monitoring and used the visualization for observation as to ensure the appearance of the target.



Figure 8.18 P5 Heat map for Mv Nowa

- **Event 3 MV Diamond:**

In this event, there is a contrast in the pupil diameter. The left eye increased slightly to (5.85mm) and the right decreased to (5.89mm). This occurred because Participant 5 suddenly stopped using the radar and looked to the right side, asking for support to show him how to acquire the target on the radar, which affects eye movement. This event took around (16%) of the experiment time. Participant 5 spent around (85%) of the event time using the radar and (10%) of the event time scanning the screen for visualisation. Participant 5 was less focused on the ECDIS with (1%) of the event time and (4%) of the event time for VHF when he received a call from MV Diamond. In this event, Participant 5 relied on the radar especially after one of the instructors explained the acquirement on the radar Figure 8.19.



Figure 8.19 P5 Heat map for MV Diamond event

- **Event 4 MV Scot Isles:**

There was a notable decrease in eye pupil size during this event. The left eye decreased to (5.62mm) and the right eye decreased to (5.68mm). The decrease in eye dilation could be because of fatigue as mentioned in the section 8.1. However, Participant 5 spent around (33%) of the experiment duration monitoring Scot Isles. During this event, as shown in the recording, Participant 5 moved across the bridge visibly. In addition, Participant 5 focused on the radar for around (59%) of the event time, on the ECDIS (26%) of the event time, and scanning the visualisation for around (13%) of the event time. This long-time focus and moving around could cause mental fatigue, resulting in a decrease in the eye pupil size. Figure 8.20 shows how Participant 5 was focused on the radar and also monitored the Scot Isles visually approaching from the port side.



Figure 8.20 P5 Heat map for MV Scot Isles

- **Event 5 Collision Avoidance:**

The pupil diameter in this event increased again when Participant 5 took action. The eye pupil increased to (6.1mm) for the left eye and (6.06mm) for the right eye. This indicates that when Participant 5 noticed the risk of collision, he took action immediately and altered the course, which increased the workload, leading to the increase in the eye pupil. This event took about (16%) of the total experiment time. It shows that Participant 5 spent most of the time looking at the screen visualisation and the display unit at (42%) of the event time and (33%) of the event time, respectively. In comparison, the participant used the radar and ECDIS less than the other events, with around (22%) of the event time and (2%) of the event time. This occurred, as shown in the record when Participant 5 was navigating solo and used the steering manually, which distracted him from using the navigation equipment. Figure 8.21 shows Participant 5 was focused on the display unit while he was steering and observed the Scot Isles visually until it passed clear.



Figure 8.21 P5 Heat map for collision avoidance

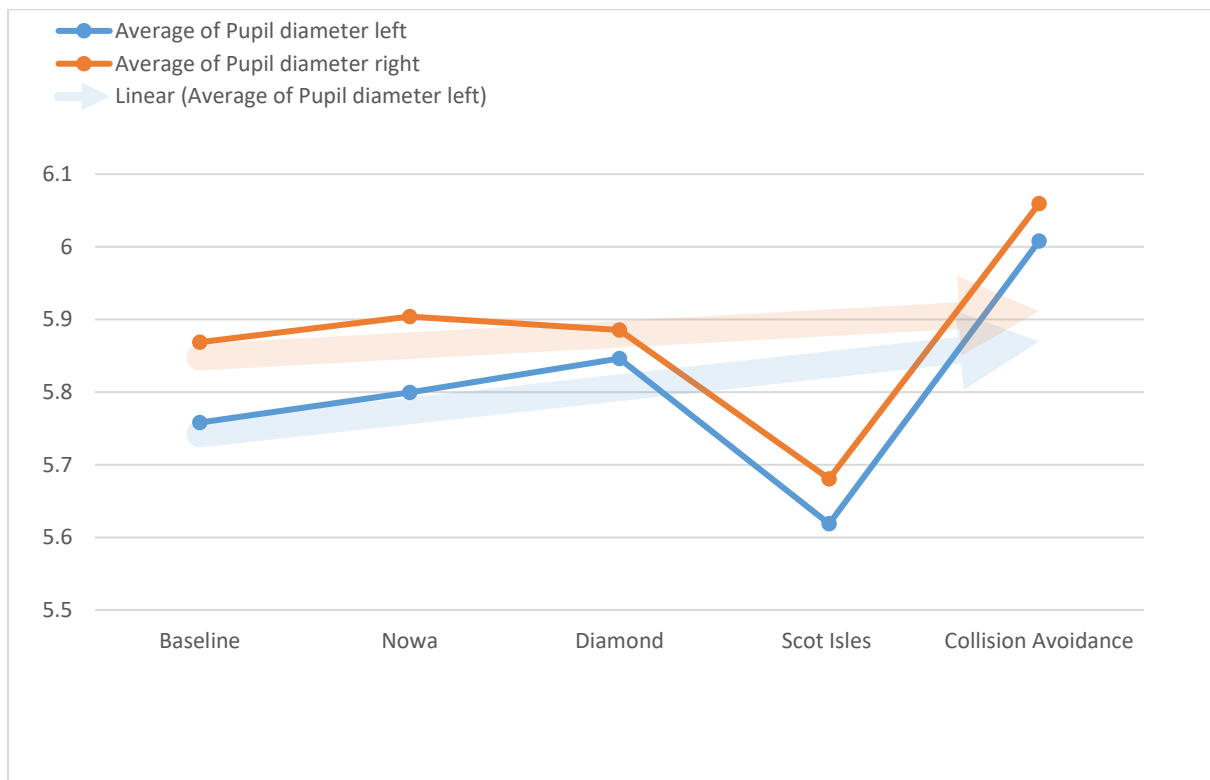


Figure 8.22: P5's Eye pupils diameters

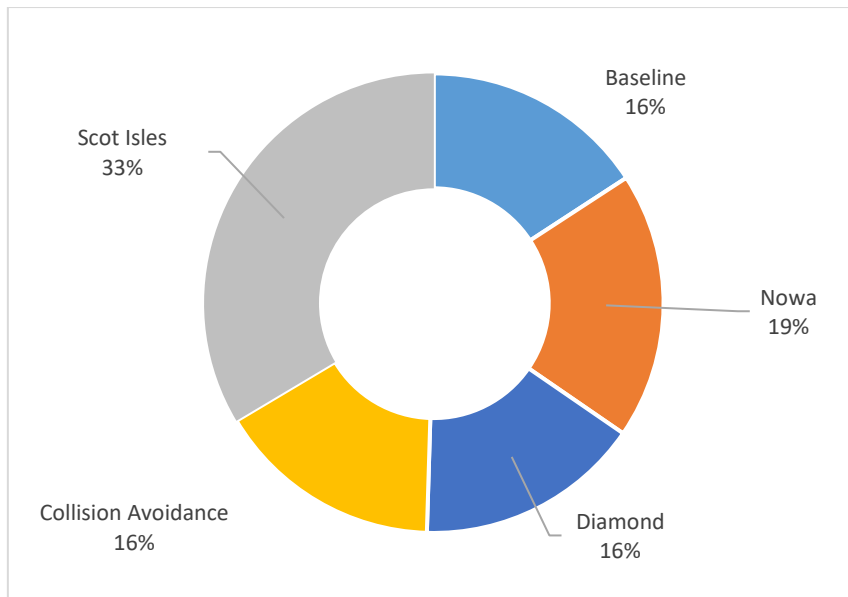


Figure 8.23: P5 Events duration

Table 8.6 : P5 point of focus at different scenario events

Row Labels	Display Unit	ECDIS	Engine	VHF	RADAR	Visualization	Top Display Unit
Baseline	0%	38%	0%	0%	56%	5%	0%
Nowa	0%	26%	0%	3%	52%	19%	0%
Diamond	0%	1%	0%	4%	85%	10%	0%
Scot Isles	0%	26%	0%	2%	59%	13%	0%
Collision Avoidance	33%	2%	0%	1%	22%	42%	2%

The combined analysis of EEG and eye-tracking provides a comprehensive view of the participant's behaviour throughout the simulator experiments. Figure 8.25 demonstrates Participant 5's brain activity across the EEG channel and eye tracking. In this scenario, the channels (P4-Pz) and (P3-Pz) are more active than the other signals. The parietal channel (the channels located on the back) is more related to sensory processing or spatial awareness.

At the beginning of the scenario, the baseline shows a low activity occurring in the brain where all the EEG signals show low amplitude. With the MV Nowa's appearance, the brain's signals started to become active, which means that Participant 5 started to react, evidenced by the high cognitive load shown during the MV Diamond and Scot Isles events. Particularly around (12m:40s) there is a high spike where the participant asked for support to use the radar, and in the event Scot Isles, the signals

were more active where the participant moved around the ship bridge and touched and used most of the navigation equipment to check the surrounding area and improved his situation awareness to increase his attention. During the collision avoidance, the signals became more stable because the participant stopped to move and steer the ship manually to avoid collision where his MWL increased, and the attention started to decrease.

Similarly, the changes in pupil diameter across various events in a ship bridge simulator show the participant's cognitive load and attention levels. In the baseline, the pupil began small and increased during the baseline when the participant used the radar to get familiar. As the targets began to appear, the participant was engaged, and the eye pupils started to get bigger, which indicated that the MWL of the participant increased and started to focus. However, there was a notable decrease during the event. This could be because the participant started to feel fatigued, and when the participant received the call, his attention was back to continue monitoring. In the MV Diamond, the decrease of the eye pupil diameter indicated fatigue as the participant lost his attention and asked for support to use the radar. In the Scot Isles event where the participant spent most of the training time, the variation of the eye pupil indicated the participant's movement in the ship bridge because the eye pupil was not stable at some point. Taking action to avoid the collision increased the eye-pupil which is related to engagement in the tasks and increasing the MWL or attention.

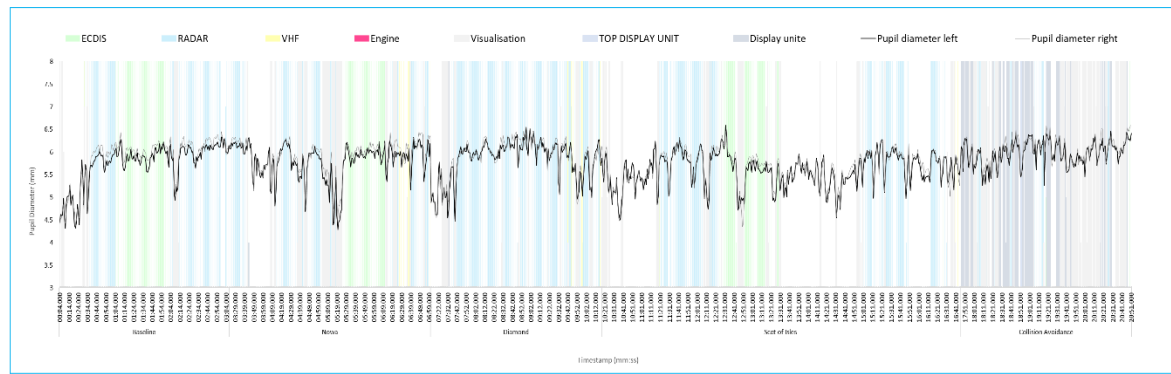


Figure 8.25: P5 EEG and Eye Track

Furthermore, as the EEG shows more activity in the parietal channels, this is because the participant was most of the time speaking to himself (loud thinking) to be aware of the situation as the parietal lobe reflects the sensory process or spatial awareness. Moreover, increasing the delta band in the parietal lobe supports the idea of ongoing cognitive processing, potentially related to the detection of stimuli and the execution of event-related tasks. Also, as theta band is present, this indicates attentional involvement, Figure 8.26.

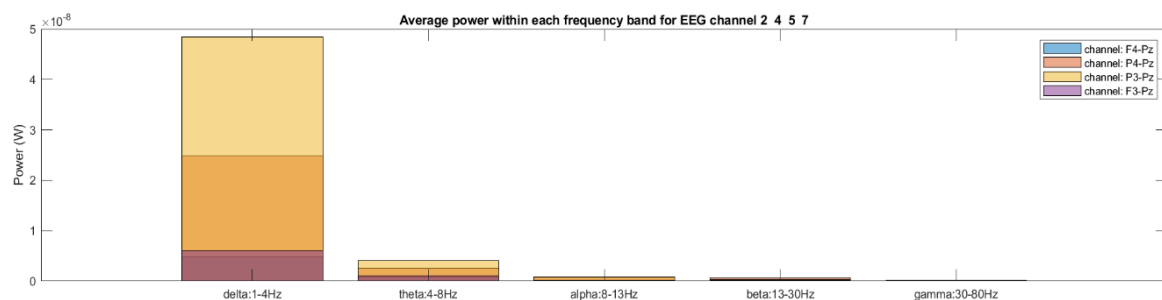


Figure 8.26: Power band

8.2.3 Participant 6: Performance (P6)

During the simulator training, Participant 6 navigated the ideal course, which is the green line, and started to alter the course to avoid a collision, Figure 8.27. The participant passed clear without any risk of collision with the ship Scot Isles. From the author's point of view, the participant's performance in this experiment as a solo navigator was one of the best performances observed. Participant 6's performance was classed as a clear-pass performance with actions during the following five events:

- **Event 1 Baseline:**

In the baseline, clear environment with no targets around. Participant 6 checked the radar and asked if she could acquire the target. Then, Participant 6 looked at the screen for visualisation most of the time until the target ships appeared. This event aimed to keep the cognitive load low and stable.

- **Event 2 MV Nowa:**

After the targets were present, Participant 6 started to acquire the targets one by one. Participant 6 immediately acquired the MV Nowa on the radar and checked the CPA and TCPA. After (00m:30 s), during this event, Participant 6 acquired MV Diamond and became aware of the Diamond and the traffic. Therefore, Participant 6 reduced the speed, which indicates appropriate situation awareness. Then, Participant 6 received a call from MV Nowa and confirmed that MV Nowa would pass by a stern.

- **Event 3 MV Diamond:**

After the MV Nowa call ended, the participant detected the MV Scot Isles during this event. Participant 6 checked the MV Diamond on the radar and kept monitoring the MV Scot Isles, too. After 1 minute, Participant 6 contacted Scot Isles before receiving a call from MV Diamond, which indicates that Participant 6 was aware of the risk very early at (07m 20sec). Participant 6 did not get a response from Scot Isles and received a call from MV Diamond confirming to overtake from the Starboard side.

- **Event 4 MV Scot Isles:**

After the communication ended with the MV Diamond, Participant 6 kept monitoring the Scot Isles on the radar and tried to communicate twice but still did not get a response. Therefore, Participant 6 decided to take action.

- **Event 5 Collision Avoidance:**

Before taking action, Participant 6 communicated with MV Diamond to confirm altering the course to the starboard and make them aware of his action. After that, Participant 6 altered the course to starboard using manual steering and then returned to autopilot and kept monitoring the radar until the ship passed clear.

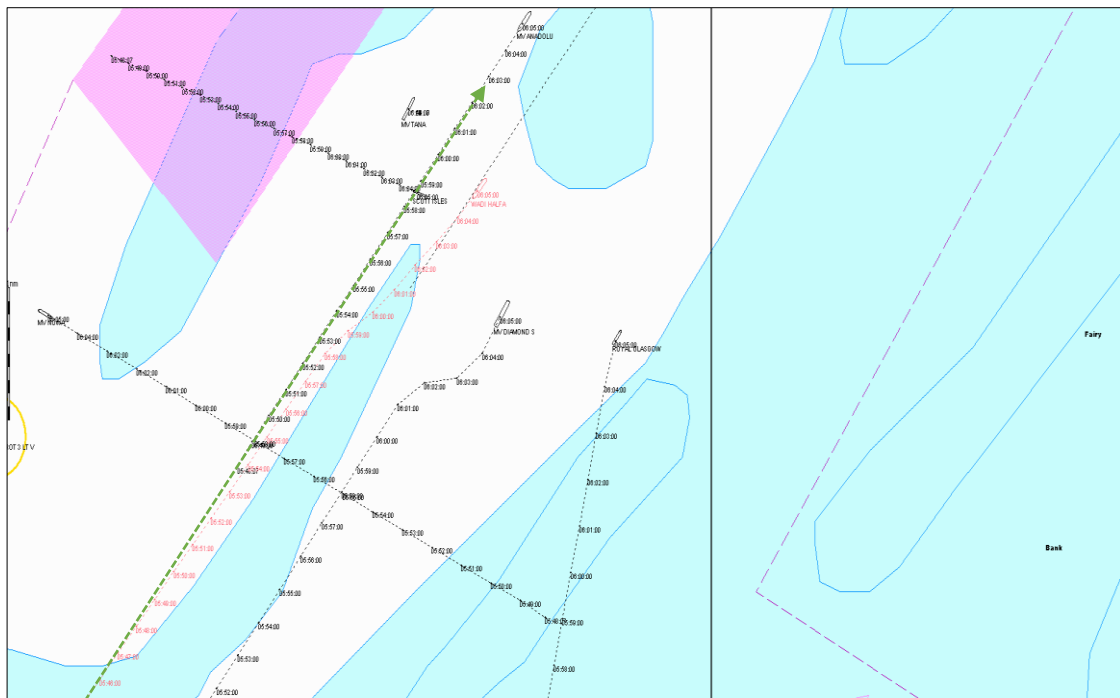


Figure 8.27 P6 Navigation Chart

The heat map illustrates clearly how Participant 6's visual focus is distributed throughout the various events, Figure 8.28. Participant 6 was constantly constrained on the radar during each event. However, the map shows how the participant kept his attention on MV Scot Isles as shown in the green zone on the port side of the visualisation, and gradually became darker ahead of the ship, which indicates that the participant kept monitoring the MV Scot Isles visually also.



Figure 8.28: P6 Heat map

Table 8.7: P6 EEG Data

Time	Event	Duration	MWL	Stress	Attention
00:00 - 03:01	Baseline	03:01	0.79	0.1036	0.3175
03:37 - 06:03	Nowa	02:26	1.00	0.1845	0.0000
06:03 - 08:32	Diamond	02:29	0.84	0.2283	0.0265
08:32 - 09:37	Scot Isles	01:05	0.26	1.0000	1.0000
11:56 - 20:02	Collision Avoidance	07:06	0.00	0.0000	0.9050

Based on the EEG result, as shown Table 8.6 and Figure 8.29, Participant 6 in the first event of the experiment demonstrated high MWL, Moderate Attention, and low stress. Throughout various events, Participant 6 improved his MWL and attention with stable stress most of the time. The cognitive demand was changeable in each event as follows:

- **Event 1 Baseline:**

In the baseline, Participant 6 showed high MWL and moderate attention, while stress levels were low. This indicates that even though there are no targets and no task engagement, the participant's MWL could be elevated, probably because of the situational awareness and preparation for upcoming events.

- **Event 2 MV Nowa:**

When the targets were present, the MWL peaked, suggesting that Participant 6 was engaged in acquiring and assessing the situation. The stress level was still low but increased slightly while the attention dropped. The reduced attention might be because Participant 6 was highly focused on processing information and, therefore, experienced cognitive overload and reduced his overall concentration.

- **Event 3 MV Diamond:**

Participant 6 has high MWL, low stress, and low attention. This duration proposes that Participant 6 was still struggling with maintaining situational awareness with multiple targets, which made the MWL remain high with low focus.

- **Event 4 MV Scot Isles:**

This event showed a significant reduction in the MWL, but the stress level increased sharply with the attention. This might have occurred because while the participant faced low MWL, the stress level increased due to the failure to receive a response from Scot Isles, which meant he needed urgent decision-making. Therefore, Participant 6 was highly focused on the task despite the high level of stress.

- **Event 5 Collision Avoidance:**

During Participant 6's action to avoid the collision, the MWL and stress dropped to low levels while the attention remained high. This suggests that Participant 6 focused on the task and felt confident and calm about his decision to avoid collision with Scot Isles.

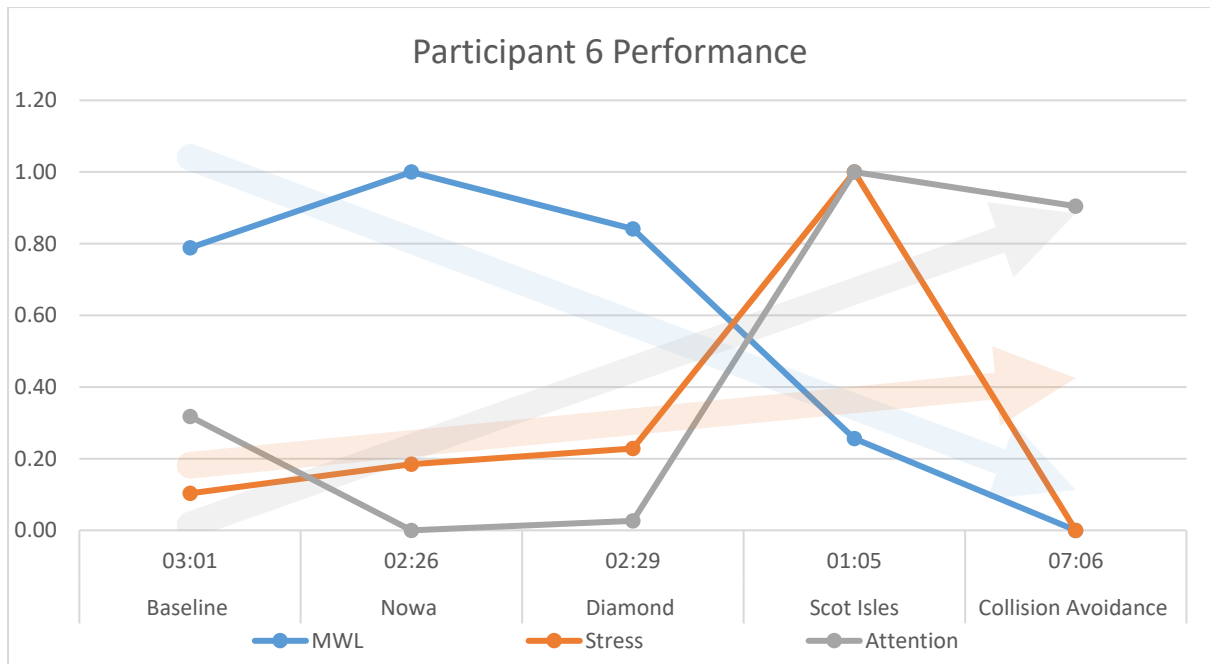


Figure 8.29: P6 EEG Data

In addition, pupil diameters for both eyes give a comprehensive view of Participant 6's performance through the events. Participant 6 began with low cognitive demand and increased until he reached the Scot Isles event when there was a slight decrease in pupil diameter. This indicates the varying MWL with the difficulties of the situation, Participant 6's eye pupil dilation and focus were changed in each event, as shown in Figure 8.36, and Table 8.8:

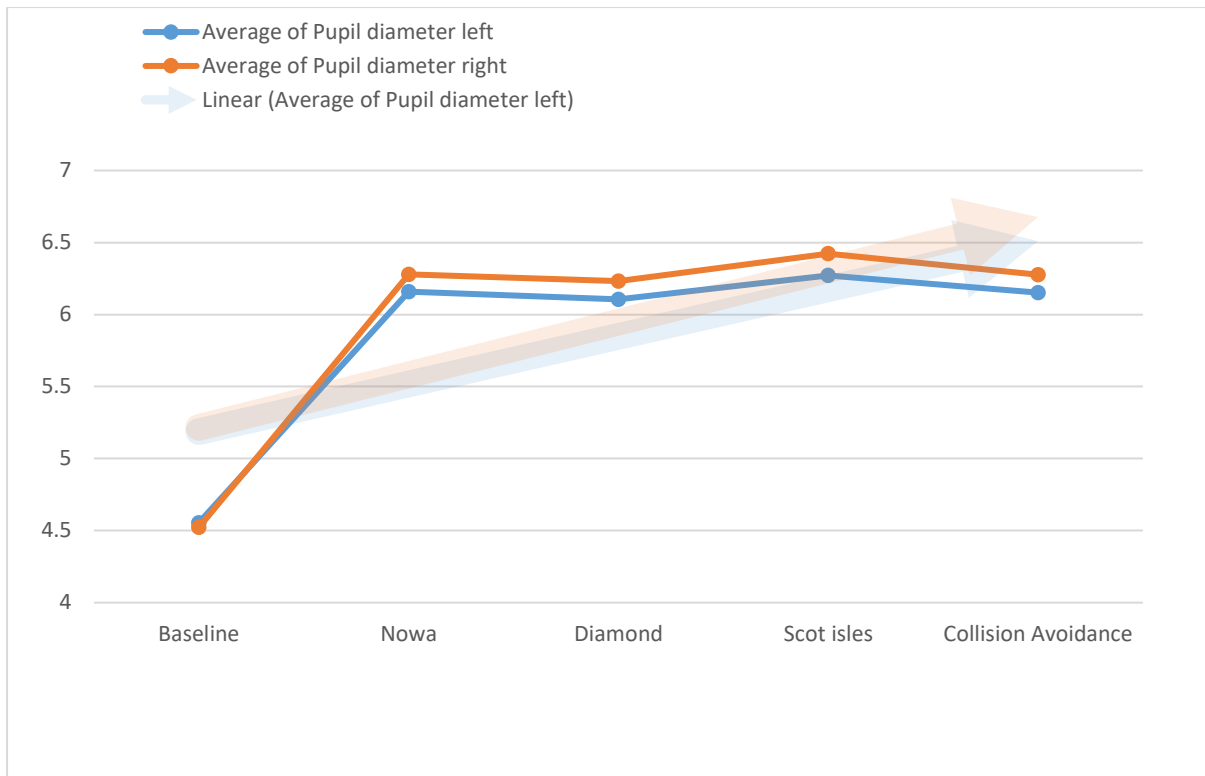


Figure 8.30 P6 Eye Pupil diameter

- **Event 1 Baseline:**

In the baseline, Participant 6 demonstrated a lower pupil diameter of (4.55 mm) on the left eye and (4.52) on the right eye. Participant 6 showed low cognitive load and a relaxed state in this event, as there were no targets around and no task engagement. This event lasts around (18%) of the total experiment time. During the event, Participant 6 focused on the radar for around (29%) of the event time and (13%) of the event time on the ECDIS, with around (56%) of the event time on scanning the screen for visualisation. This showed that the participant was familiarising herself with the navigation equipment and improving her situational awareness by scanning the external area. Figure 8.31 showed the participant's attention distribution during the baseline and the radar was the most focused equipment, suggesting that the participant was getting more familiar with the radar during a clear surrounding area.



Figure 8.31 P6 Heat map for baseline

- **Event 2 MV Nowa:**

With the appearance of the MV Nowa, the eye pupil diameters increased significantly to (6.16mm) on the left and (6.28mm) on the right, increasing the cognitive workload in this event. Participant 6 in this event spent approximately (14%) of the experiment time monitoring the MV Nowa. The engagement with the radar increased and took around (89%) of the event time, while the engagement with the visual check took around (4%) of the event time. The increased focus on the radar when detecting the MV Nowa suggests that the participant relied on the navigation equipment to monitor the situation, which increased his cognitive load. Figure 8.32 P6 shows that Participant 5 was focused on the radar in addition to checking the information from the top display unit and the display unit with a slight observation on the screens.



Figure 8.32 P6 Heat map for MV Nowa

- **Event 3 MV Diamond:**

Pupil diameter remained high (6.11 mm) on the left and (6.23 mm) on the right, showing a sustained cognitive load. Participant 6 spent around (15%) of the experiment time with the MV Diamond event. While monitoring MV Diamond, (for 94%) of the event time, Participant 6 concentrated on the radar and (5%) of the event time on the visualisation. This indicated that the participant increased his awareness through the radar rather than the external observation Figure 8.33.



Figure 8.33 P6 Heat map for MV Diamond

- **Event 4 MV Scot Isles:**

During this event, Participant 6's pupil diameter was still large, with a slight increase to (6.27mm) for the left side and (6.42mm) for the right side. This suggests that Participant 6 remained with a high cognitive load and possibly some stress because of the failure of communication with the Scot Isles. In addition, monitoring multiple ships and trying to manage situational awareness could be a reason for the increase in the cognitive load. Participant 6 spent around (6%) of the time of the experiment on the Scot Isles event, which indicates that the participant noticed the risk of collision and took action immediately after the communication failure. Most of the time in this event, participant 6 was focused on the radar for (93%) of the event time and (3%) of the event time on the visualisation with (3%) of the event time on the display unit, indicating that Participant 6 checked the information on the display unit preparing for taking action. Because of the short time event during the Scot Isles, Participant 6 spent more time in collision avoidance. It shows in the heat map that Participant 6 was focused on the radar and monitored the ship information on the radar more than visual observation and other equipment, Figure 8.34.



Figure 8.34 P6 Heat map for MV Scot Isles

- **Event 5 Collision Avoidance**

The final event showed consistent pupil dilation with a slight decrease to (6.15mm) for the left side and (6.28mm) for the right side. Participant 6 spent most of the experiment time focusing on avoiding collision (47%) of the experiment time. It shows in this event that Participant 6 distributed his observation around the bridge to gain his awareness of wider activities. Therefore, the focus on the radar was reduced to (71%) of the event time, while there was an increase in the visual observation (6%) of the event time, and the display unit to (23%) of the time event. Figure 8.35 shows that Participant 6, in addition to the radar concentration, had a moderate focus on the display unit, and that occurred when Participant 6 took over hand steering and was focusing on the course direction and the rudder information, Figure 8.35.



Figure 8.35 P6 Heat map for collision avoidance

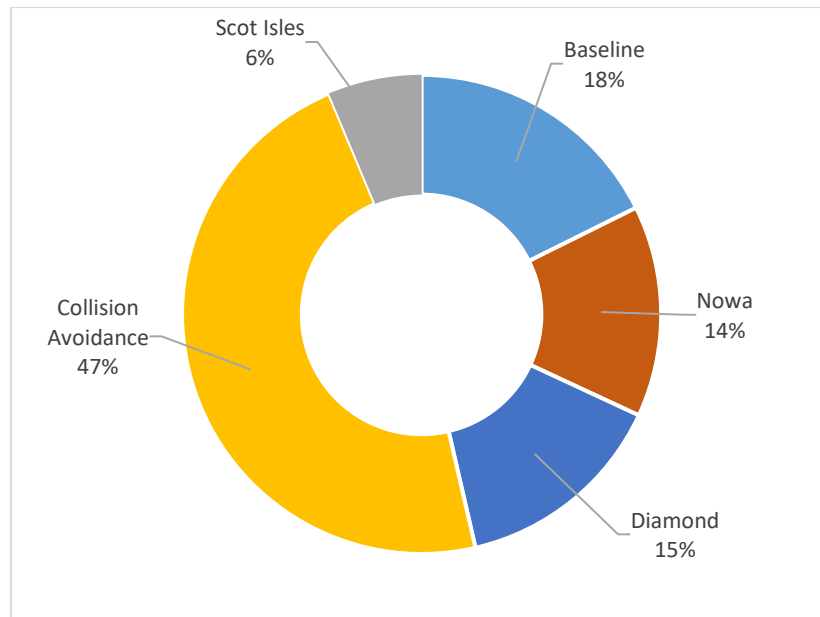


Figure 8.36 P6 Duration time for each event

Table 8.8: P6 point of focus at different scenario events

Row Labels	Display Unit	ECDIS	Engine	VHF	RADAR	Visualisation	Top Display Unit
Baseline	0%	13%	0%	1%	29%	56%	2%
Nowa	2%	0%	2%	1%	89%	4%	2%
Diamond	0%	0%	0%	0%	94%	5%	1%
Scot isles	3%	0%	0%	0%	93%	3%	1%
Collision Avoidance	23%	0%	0%	0%	71%	6%	0%

The Figure 8.37 presents Participant 6's performance through the EEG and Eye-tracking signals which clearly illustrate the cognitive demand throughout the scenario.

The EEG shows that Participant 6, during the baseline, was stable with low cognitive demand. However, some activities with (F4-Pz) and (F3-Pz) channels are related more to decision-making and solving problems. In the MV Nowa event, around (09m:10s), some activity appeared, indicating that the participant's cognitive load increased while communicating. In addition, the MV Diamond and MV Scot Isles events show some cognitive activity around (11m:40s) and (13m:20s), and this occurred during the communication with the other targets and might be related to some stress. In the collision

avoidance event, there is a significant spike (16m:40s) around this time when the participant took action to avoid collision and tried to solve the problem.

Eye-tracking signals show that Participant 6 during the baseline was trying to get familiar with the bridge environment. Small eye-pupil diameter compared to the other events indicates low cognitive load. With the appearance of the MV Nowa, the eye diameter increased and almost sustained the same size throughout all the events. However, there is a drop in the eye pupil diameter around (07m:37s) during the MV Diamond event and around (17m:51s) during the collision avoidance event, which suggests that the participant had some slight fatigue during these events.

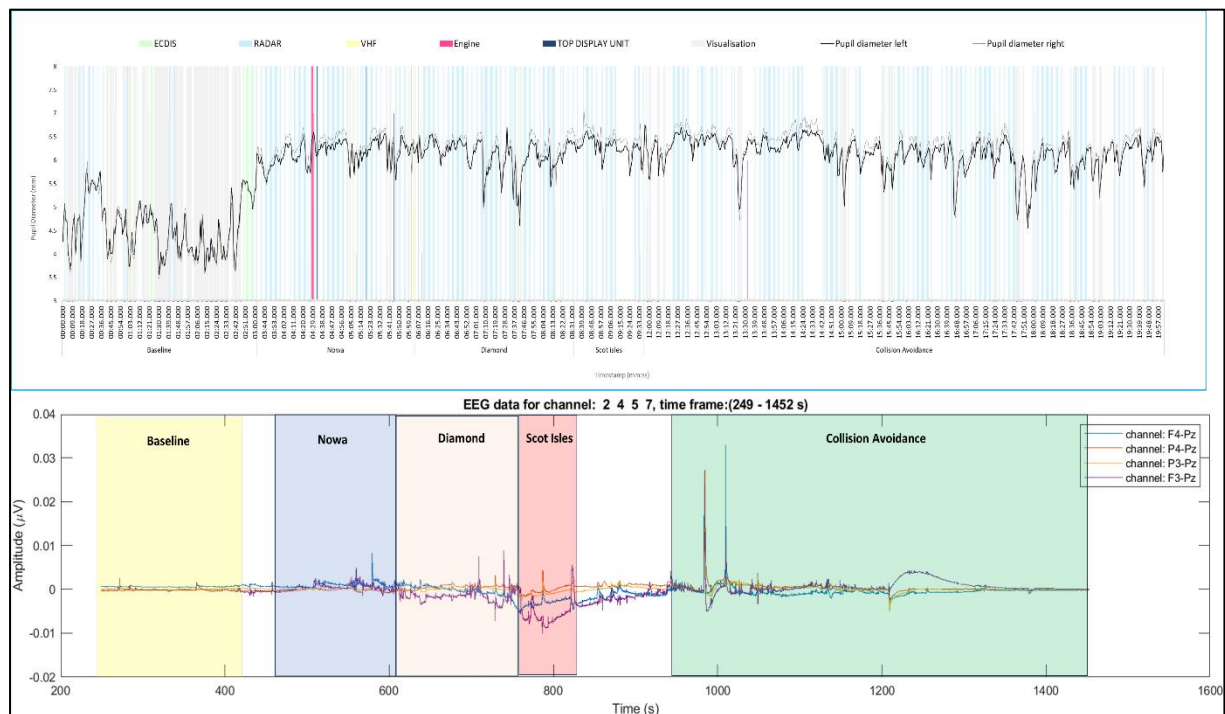


Figure 8.37 P6 EEG and Eye Track

Moreover, the EEG data showed a maintained cognitive process during the scenario. However, the delta band has the highest power, particularly in the frontal channel, which is consistent with deep cognitive processing or event-related brain activity. Especially around (16m:40s), the participant showed a significant spike, and this might be due to the increase in the MWL and the need to make the decision to avoid a collision. In addition, theta band showed an involvement, which suggests that the participant was required to pay attention and used memory to retrieve information to take the action, Figure 8.38.

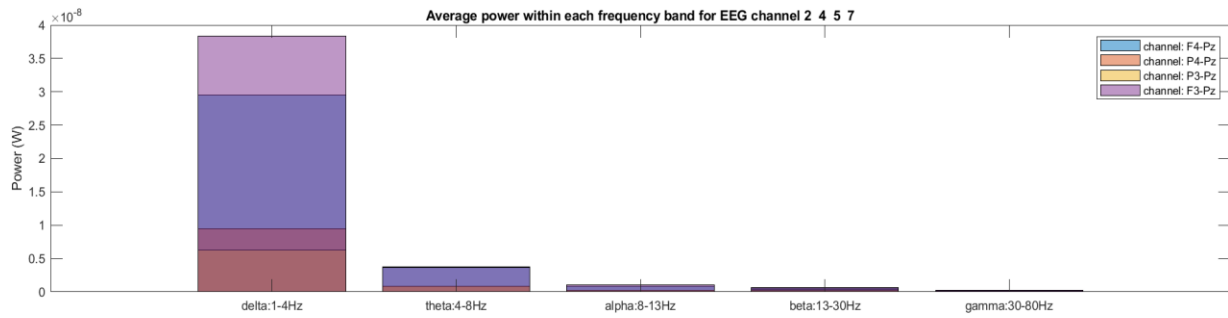


Figure 8.38 P6 Power band

8.3 Second Experiment Campaign

Thirteen different participants, who did not participate in the first experiment campaign, participated in the second experiment campaign, which used exactly the same scenario used in the first experiment. Each participant was accompanied by an assistant as a “lookout” during sailing this time. The objective was to see if the lookout impacted the participants’ performance compared to the participants sailing Solo assigned with the code (P No.-L) L= Lookout

8.3.1 Participant 6 Performance (P6-L)

During the simulator experiments, Participant 6 navigated on the port side of the ideal course, which is the green line and started to alter the course to the side to avoid a collision. The participant passes clear without any risk of collision with the ship Scot Isles. The participant's good navigational performance in this experiment was with a lookout who was assigned as an assistant on the bridge, Figure 8.39. Participant 6’s excellent performance was classed as a clear-pass performance with actions during the following five events:

- **Event 1 Baseline:**

In the baseline, there was a clear environment with no targets around. Participant 6 asked one question about the radar to make himself clear. During this event, the participant did not touch any equipment. Participant 6 moved around and observed the area. Then, the participant looked at the visualisation most of the time until the target ships appeared.

- **Event 2 MV Nowa:**

After the appearance of target ships, Participant 6 detected the MV Nowa a few seconds later. Participant 6 tried to acquire the target on the radar to get the information. In the beginning, Participant 6 struggled to get the information quickly and did not listen to the lookout for the first time. However, after acquiring the target and getting the information, Participant 6 received a call from the MV Nowa, which required him to keep course and speed. During the communication, Participant 6 started engaging with the lookout and instructed the lookout for hand steering and then confirmed with MV Nowa.

- **Event 3 MV Diamond:**

Participant 6 kept monitoring the MV Nowa on the radar. The lookout informed the participant about the MV Diamond, so the participant acquired the MV Diamond on the radar to get the ship information. In the meantime, the lookout informed Participant 6 about a ship on portside, which is MV Scot Isles. Participant 6 looked at the port side, went back to monitor the MV Diamond on the radar, and instructed the lookout to steer 10 degrees to the port side. Then, Participant 6 received a call from the Diamond to keep his course and speed. At the same time, Participant 6 ordered the lookout to steer as it is and informed the MV Diamond that his ship altered course to portside to avoid traffic.

- **Event 4 MV Scot Isles:**

After finishing the communication with the MV Diamond, Participant 6 used the radar to acquire other targets. However, the radar arrows stuck and did not move. Then, Participant 6 called the engine room, instructed them to keep on standby to reduce speed, and moved to use the ECDIS. The participant checked the ECDIS a few times and returned to the radar and called the engine room requesting help to fix the radar.

- **Event 5 Collision Avoidance:**

After requesting support, Participant 6 instructed the lookout to alter the course to the port side to avoid the traffic. The support team fixed the issue with the radar, and then Participant 6 went back to monitor the targets on the radar. In addition, Participant 6 used the visualisation panel to check the surroundings and ordered the lookout to keep steering until pass clear.

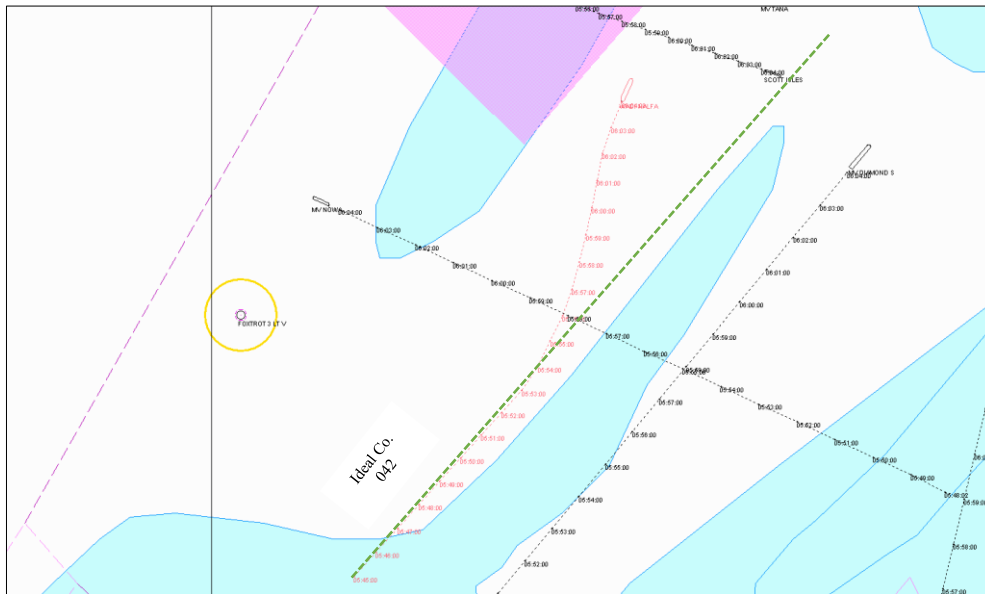


Figure 8.39: P6-L navigation chart

The heat map provides the distribution of Participant 6's visual attention during the ship bridge simulator experiment. The heat map offers a clear visual focus throughout the events. The red zones indicate the area with high focus, suggesting that the participant concentrated heavily on the radar. Also, the central navigation display shows that Participant 6 was focusing on the Scot Isles approaching ahead.



Figure 8.40 P6-L Heat map

Table 8.9: P6-L EEG Data

Time		Event	Time Period	MWL	Stress	Attention
00:00.0	03:04.2	Baseline	03:04.2	0.15	0.00	0.78
03:48.5	06:06.9	Nowa	02:18.5	0.00	0.02	0.22
06:32.9	07:01.8	Diamond	00:28.9	0.02	1.00	0.20
09:08.7	10:41.1	Scot Isles	01:32.4	1.00	0.00	0.44
12:36.4	17:00.9	Collision Avoidance	04:24.5	0.10	0.00	1.00

Based on the EEG results, Participant 6's performance metrics are illustrated in Table 8.9 and Figure 8.41 . We can observe how the cognitive demand (MWL, Stress and attention) differs across the different events in the simulator experiments as follows:

- **Event 1 Baseline:**

During the baseline, Participant 6 showed a low mental workload, no stress level, and his attention was high. This suggests that Participant 6 was calm and engaged with high attention because there were no targets and no immediate risk existed.

- **Event 2 MV Nowa:**

Moving to event 2 MV Nowa, there was no MWL and low stress with low attention. When the scenario started, and targets appeared, Participant 6 began to monitor the radar, which shows that cognitive demand started to increase.

- **Event 3 MV Diamond:**

In the next event, MV Diamond, Participant 6 showed significantly high stress with low MWL and low attention, indicating that the sudden detection of the MV Diamond and the communication commenced may have created stress on Participant 6, despite no risk of collision.

- **Event 4 MV Scot Isles:**

In the Scot Isles event, the MWL increased significantly, which might be due to the failure of the radar. However, the stress decreased, and a moderate attention level suggests the participant is still alert but without a high stress level.

- **Event 5 Collision Avoidance:**

In the last event, collision avoidance, after taking the action, there was a low MWL while the stress level dropped, and attention levels increased significantly, which reflects that Participant 6 still had a high focus when he cleared from the risk of collision situation.

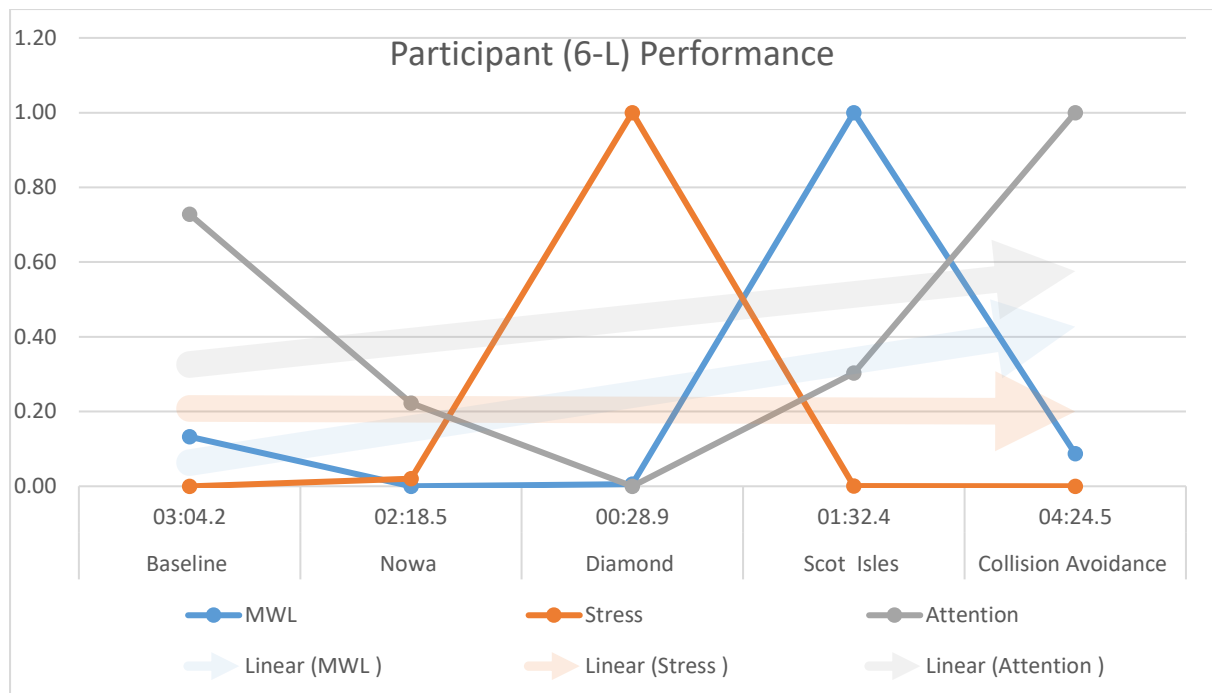


Figure 8.41 P6-L EEG Data

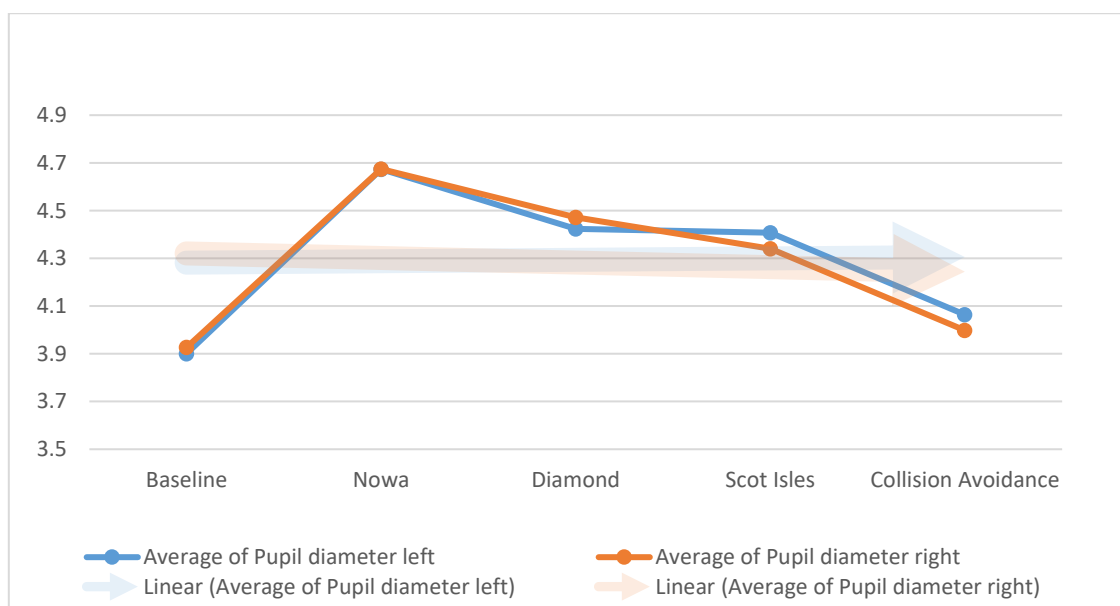


Figure 8.42 P6-L Average of the eye pupil

In addition, the pupil diameter for both eyes gives a comprehensive view of Participant 6's performance throughout the different events. Participant 6 began with low cognitive demand, increased, and peaked when MV Nowa appeared. During the scenario, there is a gradual decrease in the pupil diameter, which

indicates that the participant faces low cognitive demand within tasks. Participant 6's eye pupil size and focus have changed for different events as shown in Figure 8.42, Figure 8.48, and Table 8.10

- **Event 1 Baseline:**

In the baseline event, Participant 6 demonstrated a smaller pupil diameter of (3.90 mm) on the left eye and (3.92mm) on the right eye. The participant shows low cognitive load and a relaxed state in this event as no targets around and no task engagement. This event lasts around (22%) of the overall experiment time. During the event, the participant focused (44%) of the event time on the radar, around (18%) of the event time on the ECDIS, and around (12%) of the event time on scanning the visualisation. In addition, (12%) of the event time was spent on the display unit, and (11%) of the event time on the top display unit. This showed, Figure 8.43, that Participant 6 was familiarised with all navigation equipment and improved his situational awareness by scanning the external area.



Figure 8.43 P6-L Heat map for baseline

- **Event 2 MV Nowa:**

With the appearance of the MV Nowa, the eye pupil diameters increased significantly to the peak (4.67 mm) on the left and (4.67 mm) on the right. The participant in this event spent

approximately (17%) of the experiment time monitoring the MV Nowa. The engagement with the radar increased and took around (97%) of the event time while no engagement with the visual check was recorded in this event. The increase in focus on the radar when detecting the MV Nowa suggests that the participant relied on the navigation equipment for monitoring the situation which increased his cognitive load and relied on the lookout for external observation, Figure 8.44. This might be because of the presence of the lookout as Participant 6 kept his attention on the radar



Figure 8.44 P6-L Heat map for MV Nowa

- **Event 3 MV Diamond:**

Pupil diameter decreased in this event (4.42 mm) on the left and (4.47 mm) on the right, showing decreased cognitive load. Participant 6 monitored the MV Diamond around (3%) of the experiment time. Participant 6 detected MV Diamond on the radar and then detected the Scot Isles (30 seconds before receiving the call from MV Diamond; due to the short time of focusing on the Diamond, the result showed that Participant 6 spent (100%) of the event time focusing on the radar. Figure 8.45 showed some detection on the screens. This occurred when the lookout informed the participant about the ship ahead, which made the participant glance at the screens and go back to focus on the radar.



Figure 8.45 P6-L Heat map for the MV Diamond

- **Event 4 MV Scot Isles:**

During this event, Participant 6's pupil diameter slightly decreased further (4.40 mm) for the left side and (4.34 mm) for the right side. This suggests that Participant 6 remained with a low cognitive load. His actions at the beginning of the scenario led him to move away from the risk of the collision. The participant spent around (26%) of the experiment duration on the Scot Isles, indicating that the participant noticed the risk of collision very early. Most of the time in the event, the participant was focused on the radar for (93%) and (1%) of the event time on the screen for visualisation with (4%) of the event time on the top display unit, indicating that the participant checked the information on the top display unit preparing for taking action. Figure 8.46 showed that Participant 6 relied on the radar for monitoring Scot Isles.



Figure 8.46 P6-L Heat map for MV Scot Isles

- **Event 5 Collision Avoidance**

The final event showed a continuous decrease of the eye pupil to (4.06 mm) for the left side and (3.99 mm) for the right side. The participant spent most of the experiment time focusing on avoiding collision (32%). It shows in this event that the participant distributed his observation around the bridge to increase his overall awareness. Therefore, the focus on the radar was reduced to (80%) of the event duration, and there was an increase in the visual observation (10%) and on ECDIS (6%) of the event time while the participant spent (3%) of the event time on the top display unit. This indicates that Participant 6 distributed his attention to improve his awareness of the risk of the collision, and while focusing on the Radar, participant 6 slightly monitored the Scot Isles visually, as shown in Figure 8.47.



Figure 8.47 P6-L Heat map for collision avoidance

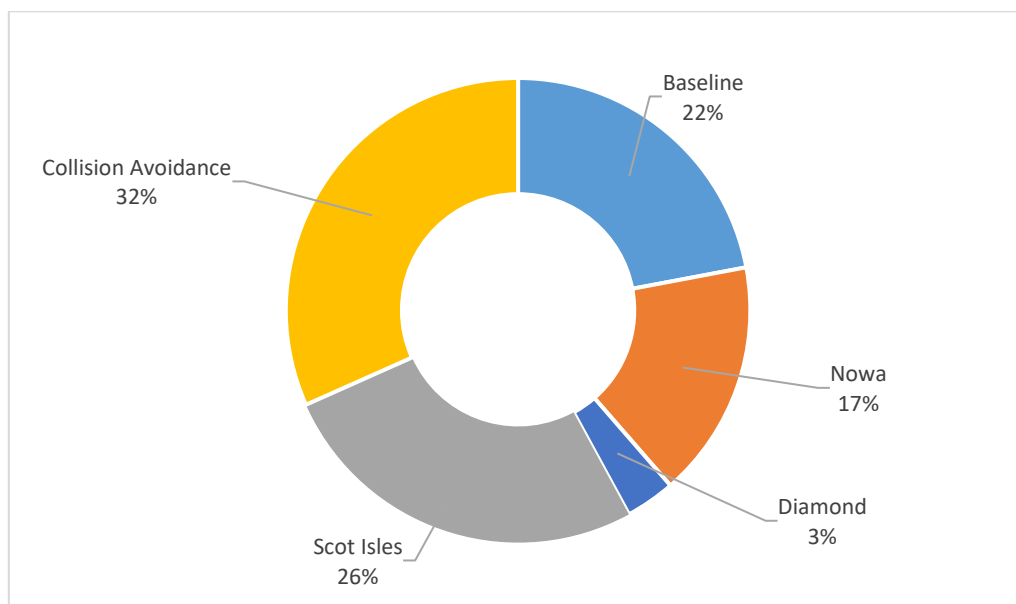


Figure 8.48 P6-L Duration time for each event

Table 8.10 P6-L point of focus at different scenario events

Row Labels	Display Unit	ECDIS	Engine	VHF	RADAR	Visualisation	Top Display Unit
Baseline	12%	18%	0%	3%	44%	12%	11%
Nowa	1%	0%	0%	2%	97%	0%	0%
Diamond	0%	0%	0%	0%	100%	0%	0%
Scot Isles	0%	0%	0%	1%	93%	1%	4%
Collision Avoidance	0%	6%	0%	1%	80%	10%	3%

The Figure 8.49 represents Participant 6's performance through EEG and Eye-tracking signals which clearly illustrate the cognitive demand throughout the scenario.

The EEG shows that Participant 6 was stable with low cognitive demand during the baseline event. However, there are some activities with (P4-Pz) and (P3-Pz) channels around (07m 30sec) which relate more to communication during the MV Nowa event. In addition, the MV Diamond with the sort of period illustrates some activity with a Parietal channel which is also related to communication and stress more than MWL. Moreover, the MV Scot Isles event showed a significant spike at the beginning of the event when the lookout informed Participant 6 about Scot Isles. However, Participant 6 was taking action and kept monitoring the target, and as signals show the participant's cognitive load decreased through the scenario until it became clear.

The eye-tracking shows that the participant, during the baseline event, was trying to get familiar with the bridge environment, as evidenced by the variation of the eye-pupil diameter.

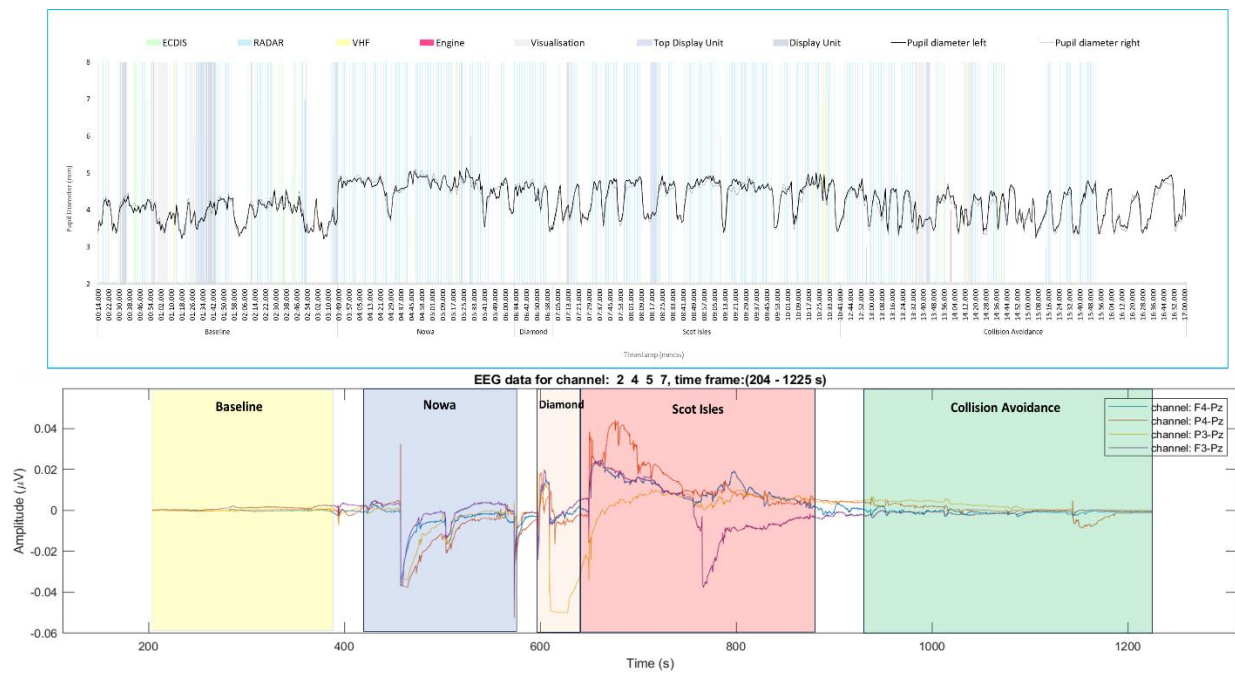


Figure 8.49 P6-L EEG and Eye track

Moreover, as shown in the EEG data, there is a fluctuation activity between (10m 00s) to (13m 20s) sec especially in the Parietal lobe (P4-Pz) and (P3-Pz). The delta power band also showed high power in the Parietal regions, indicating cognitive process and high workload or stress. This occurred during radar failure, indicating the participant's behaviour change. In addition, theta power also increased suggesting more attention retrieved from the participant, Figure 8.50

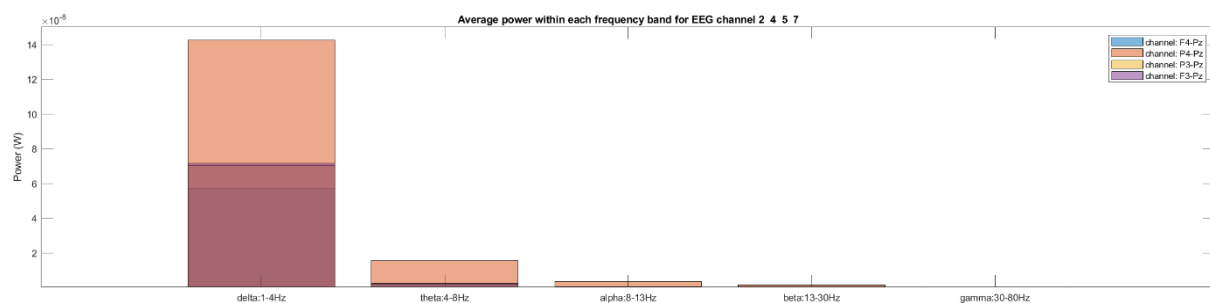


Figure 8.50 P6-L Power band

8.3.2 Participant 7 Performance (P7-L)

During the simulator training, Participant 7 followed the ideal course, which is the green line, and when the participant noticed the risk of collision, he altered the course to hard starboard to avoid collision, Figure 8.51. The participant passed clear with a near miss with the MV Scot Isles. Participant 7 in this experiment navigated with a lookout who was assigned as an assistant on the bridge. Participant 7's performance was classed as a near-miss performance with actions during the following five events:

- **Event 1 Baseline:**

During the baseline, the participant was only staying in one position behind the steering and was observing the ship's bridge environment visually.

- **Event 2 MV Nowa:**

Participant 7 detected the MV Nowa after one minute, while the lookout informed Participant 7 about the MV Nowa. During this event, Participant 7 was talking to himself (Loudly speaking) about the situation and what his action would be, which could be described as loud thinking. Furthermore, the participant received a call from MV Nowa informing him to keep course and speed, and when the participant 7 confirmed, the participant instructed the lookout to keep observing MV Nowa

- **Event 3 MV Diamond:**

Participant 7 detected the MV Diamond after the lookout informed him. Participant 7 then acquired the target to get the information. Participant 7 still kept talking to himself (Loudly speaking) about the situation and his actions. During the event, the lookout informed the participant about the ship on the port side, Scot Isles. Participant 7 said, "Okay," and continued monitoring the radar. Then, the participant received a call from the MV Diamond. Participant 7 answered and gave the order to the lookout to take the steer and steady. MV Diamond informed Participant 7 to keep course and speed, but Participant 7 replied with negative action and informed MV Diamond that he would reduce the speed, and that MV Diamond should keep clear.

- **Event 4 MV Scot Isles:**

Before detecting the MV Scot Isles, Participant 7 was concerned about MV Nowa, so Participant 7 called MV Nowa to confirm that she would pass from stern clear. After that, Participant 7 acquired the MV Scot Isles at (11m:42s) on the radar and started talking to himself about the information he observed on the radar. Participant 7 monitored the Scot Isles on the radar and visually moved between ECDIS and the radar during this event. In addition, the participant used the visualisation panel to check the surrounding area. At (18m:10sec), the participant got concerned and communicated with the Scot Isles and found no response. Therefore, Participant 7 instructed the lookout to ‘Starboard 20 degrees’.

- **Event 5 Collision Avoidance:**

After Participant 7 instructed the lookout to alter the course, Participant 7 monitored the Scot Isles on radar and visually and moved the ECDIS. Moreover, participant 7 used the sound signal to warn the Scot Isles but there was still no response, so Participant 7 kept altering the course until its own vessel was aligned parallel with the Scot Isles and passed with near misses, which was less than 0.2 nm.

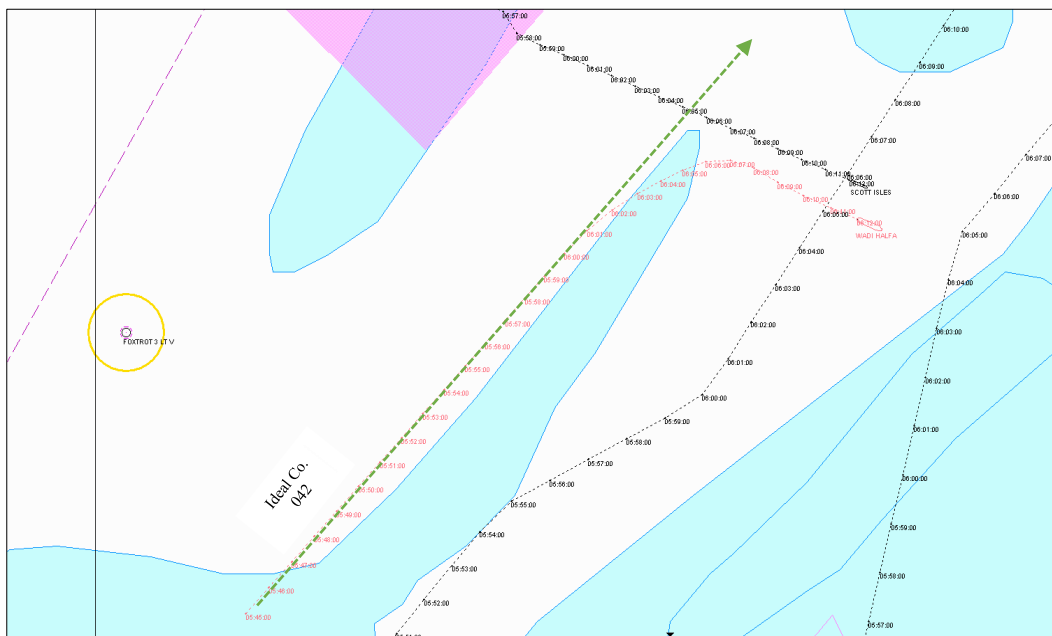


Figure 8.51 P7-L Navigation chart

The heat map provides Participant 7's visual attention during the experiment, Figure 8.52 . It offers a clear visual focus throughout the events. The red zones indicate the area with high focus, suggesting that Participant 7 concentrated heavily on the radar to get the target information, as shown by the red zone on the radar screen. Also, Participant 7 was looking at the top display unit to check ship information. The central navigation display shows that Participant 7 focused on the Scot Isles approaching ahead.



Figure 8.52 P7-L Heat map

Table 8.11 P7-L EEG Data

Time		Event	Duration	MWL	Stress	Attention
00:00.0	03:03.7	Baseline	03:03.7	0.41	0.00	1.00
04:03.7	06:41.3	Nowa	02:37.6	0.00	0.98	0.05
07:01.4	09:07.7	Diamond	02:06.3	0.01	1.00	0.05
11:43.0	18:16.4	Scot Isles	06:33.4	0.08	0.04	0.05
19:08.7	26:10.9	Collision Avoidance	07:02.2	1.00	0.01	0.00

Based on the EEG result and Participant 7's performance metrics illustrated in Table 8.11 and Figure 8.53, we can observe how the cognitive demand (MWL, Stress, and attention) differs across the different events in the simulator experiment as follows:

- **Event 1 Baseline:**

During the baseline, Participant 7 showed moderate mental workload while no stress level was observed, and attention was at its peak. This suggests that Participant 7 was calm and engaged with high attention because there were no targets and no immediate risk existed.

- **Event 2 MV Nowa:**

Moving to event 2 MV Nowa, there was no MWL, high stress, and low attention. When the scenario started, and targets appeared, Participant 7 started to monitor the radar, which showed that cognitive demand started to increase, and as a result, the stress increased because the participant was talking to himself and to the lookout most of the time, including the communication with the MV Nowa.

- **Event 3 MV Diamond:**

The next event, MV Diamond, shows significantly high stress with low MWL and low attention, indicating the sudden detection of the MV Diamond when the lookout informed the participant. Despite no risk of collision, Participant 7's attention dropped during communication.

- **Event 4 MV Scot Isles:**

In the Scot Isles event, Participant 7 tried to keep calm and focus on the navigation equipment. However, the participant also lost his attention while focusing and, when the participant noticed the risk of collision, started to give an order to the lookout to avoid collision.

- **Event 5 Collision Avoidance:**

In the last event, collision avoidance, after taking the action, there was a significant increase in the MWL while the stress and attention levels dropped. This indicates that when the participant noticed the risks after the failure of the attempted communication with Scot Isles, MWL increased, affecting his attention while his stress level was low. Fortunately, Participant 7 passed clear with a near miss.

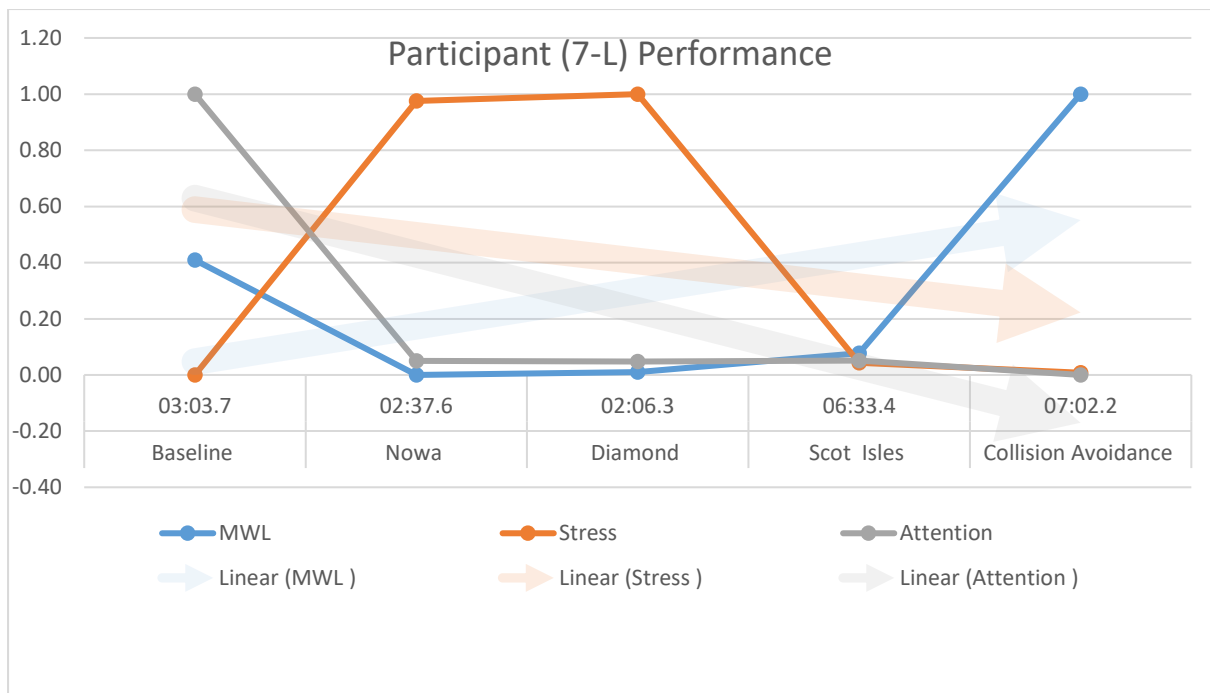


Figure 8.53 P7-L EEG Data

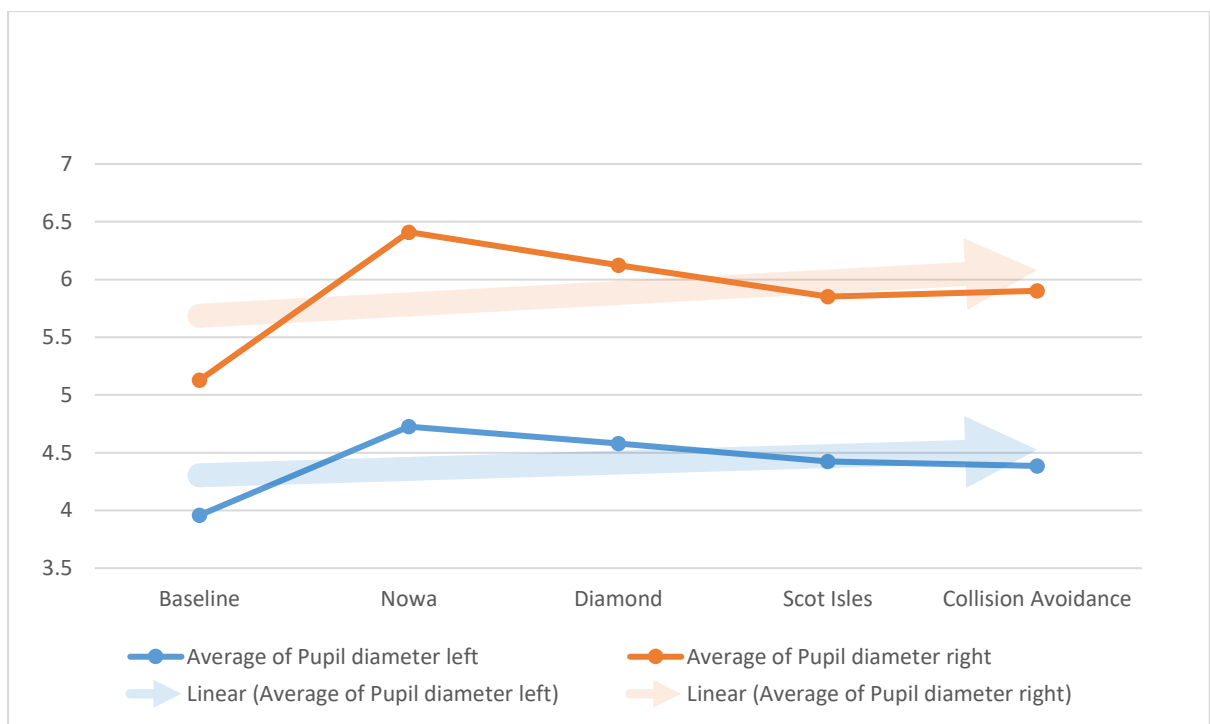


Figure 8.54 P7-L Eye pupil size

Furthermore, pupil diameters for both eyes give a comprehensive view of Participant 7's performance throughout the events. The participant began with low cognitive demand and increased with a peak in the MV Nowa appearance. During the scenario, there is a decrease in pupil diameter, which indicates that the participant faces low cognitive demand until the appearance of the Scot Isles which shows a slight increase until the participant passes clear with a near miss, Figure 8.54. Participant 7's eye pupil size and focus changed as shown in each event below, Table 8.12 and Figure 8.60:

- **Event 1 Baseline:**

In the baseline, Participant 7 demonstrated a lower pupil diameter of (3.95 mm) in the left eye and (5.12 mm) in the right eye. Participant 7 showed low cognitive load and a relaxed state in this event, as there were no targets around and no task engagement. This event lasts around (14%) of the experiment time. During the event, the participant focused on the radar for around (24%) of the event time and (30%) of the event time on the ECDIS, with around (23%) of the event time on the scanning screen for visualisation. In addition, (2%) of the event time was focused on the display unit, and (20%) of the event time on the top display unit. This showed that the participant was familiarising with all navigation equipment and improving his situational awareness with the scanning of the external area Figure 8.55.



Figure 8.55 P7-L Heat map for the baseline

- **Event 2 MV Nowa:**

With the appearance of the MV Nowa, the eye pupil diameters increased significantly to the peak (4.72 mm) on the left and (6.41 mm) on the right. Participant 7 in this event spent approximately (12%) of the experiment time monitoring the MV Nowa. The engagement with the radar increased and took around (97%) of the event time with a slight engagement with the visual check in this event, and (2%) of the event time on the VHF while communicating with (1%) of the event time on the top display unit. The increase in focus on the radar when detecting the MV Nowa suggests that the participant relied on the navigation equipment for monitoring the situation which increased his cognitive load, and relied on the lookout for external observation Figure 8.56.



Figure 8.56 P7-L Heat map for MV Nowa

- **Event 3 MV Diamond:**

Pupil diameter decreased in this event (4.58 mm) on the left and (6.12 mm) on the right, showing a decrease in the cognitive load. Participant 7 monitored the MV Diamond around (10%) of the experiment time. While monitoring MV Diamond (94%) of the event time, he spent (2%) of the event time on the VHF during communication and (3%) of the event on the top display unit. Moreover, Participant 7 relied on the lookout for external observation while he monitored the target on the radar equipment Figure 8.57.



Figure 8.57 P7-L Heat map for MV Diamond

- **Event 4 MV Scot Isles:**

During this event, there was a slight decrease in Participant 7's pupil diameter (4.42 mm) on the left side and (5.85 mm) on the right side. This indicates that Participant 7 remained with low cognitive demand while trying to monitor the Scot Isles. Participant 7 spent around (31%) of the experiment time on the Scot Isles, indicating that Participant 7 spent more time on the Scot Isles due to his concern. This event shows how the participant was moving between the bridge environments because it shows that the participant focused on the radar for (82%) of the event time, ECDIS for (14%) of the event time, and the top display unit (3%) of the event time with slight visual observation on the port side of the screen to ensure the appearance of the Scot Isles Figure 8.58. This suggests that the participant was moving around and checking the information.



Figure 8.58 P7-L Heat map for MV Scot Isles

- **Event 5 Collision Avoidance**

The final event showed a slight increase in the pupil size of the right eye which means that Participant 7 started to get MWL while monitoring and taking action to avoid the collision. The eye pupil size increased to (4.38 mm) for the left side and (5.90 mm) for the right side. Participant 7 spent (33%) of the time in the experiment focusing on collision avoidance. It shows in this event that the participant distributed his observation around the bridge to increase his overall awareness. Therefore, the focus on the radar was reduced to (65%) of the event time, and there was an increase in the visual observation (13%) and on ECDIS (19%) of the event time while the top display unit decreased to (1%) of the event time. At this time, the participant decided to steer hard to starboard and try to distribute his observation around the ship environment to avoid collision, Figure 8.59.



Figure 8.59 P7-L Heat map for collision avoidance

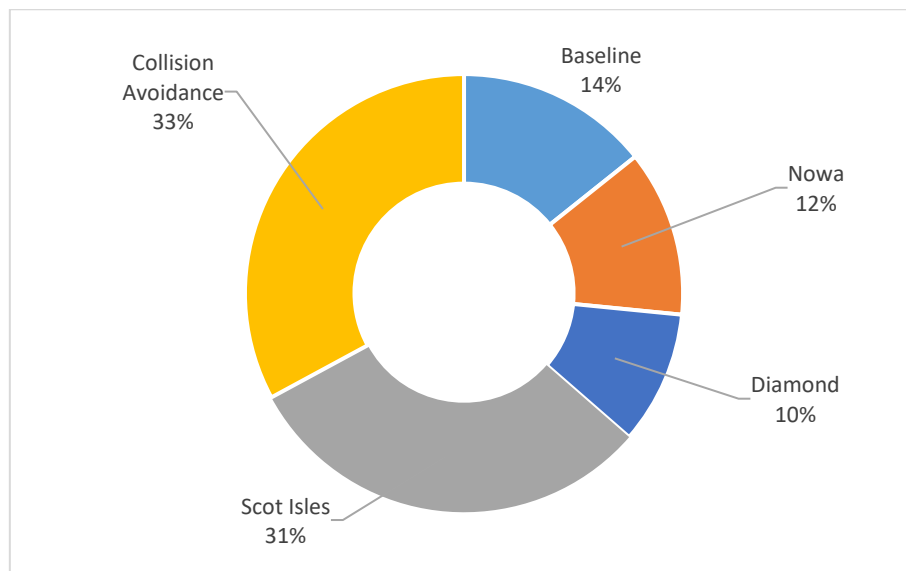


Figure 8.60 P7-L Duration for each event

Table 8.12: P7-L point of focus at different scenario events

Row Labels	Display Unit	ECDIS	Engine	VHF	RADAR	Visualisation	Top Display Unit
Baseline	2%	30%	1%	1%	24%	23%	20%
Nowa	0%	0%	0%	2%	97%	0%	1%
Diamond	2%	0%	0%	2%	94%	0%	3%
Scot Isles	0%	14%	0%	0%	82%	0%	3%
Collision Avoidance	1%	19%	0%	1%	65%	1%	13%

The Figure 8.61 represents Participant 7's performance through the EEG and Eye-tracking signals, clearly illustrating the cognitive demand throughout the scenario.

The EEG shows that Participant 7, during the baseline, was stable with low cognitive demand. However, when the targets started to appear, the channels (P4-Pz) and (P3-Pz) were active during the whole scenario. This indicates that Participant 7 was communicating most of the time during the task. The communication includes himself, the lookout, and the other target.

Furthermore, the eye-tracking shows that Participant 7, in the baseline event, was trying to get familiar with the bridge environment as the variation of the eye-pupil diameter was low and began to increase as the targets started to appear. The eye tracking shows that Participant 7 maintained his cognitive load throughout the scenario, and this was due to the presence of the lookout which made the participant rely on him for external observation.

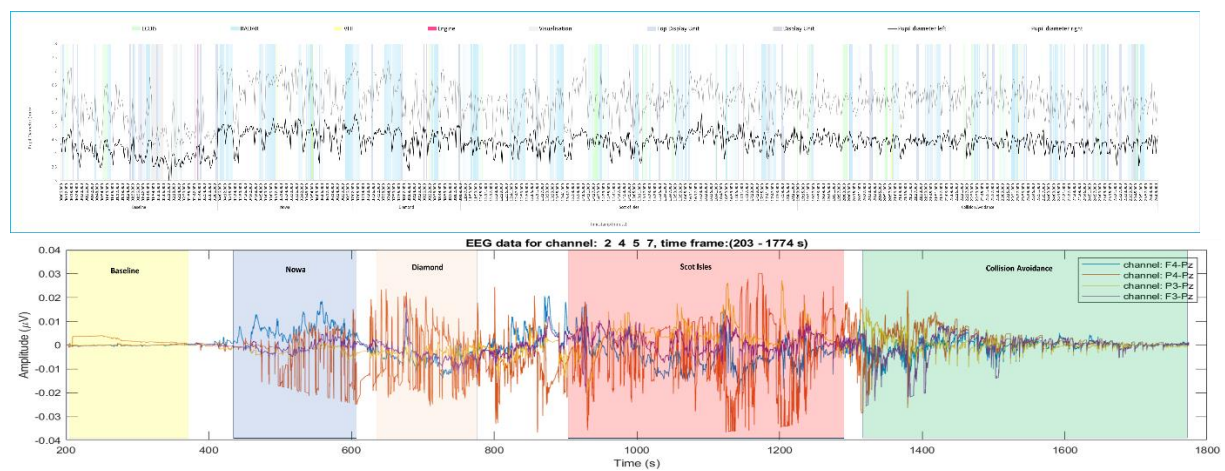


Figure 8.61 P7-L EEG and Eye Trak

In addition, the EEG data showed fluctuant signals in the parietal lobes; the delta band also shows a significant increase in the parietal lobes, which indicates the participant's deep engagement in the scenario. It also suggests an increase in spatial awareness as the participant was talking to himself and the lookout during the whole experiment. This suggests the participant was trying to make himself aware of the situation in the surroundings, Figure 8.62.

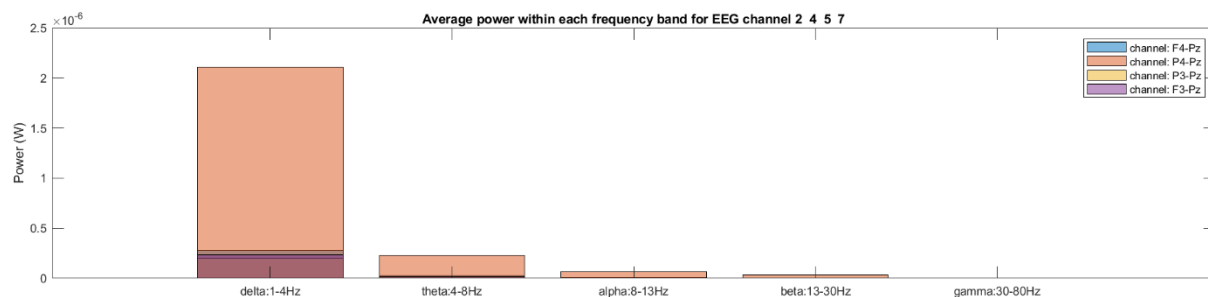


Figure 8.62 P7-L Power band

8.3.3 Participant 15 Performance (P15-L)

During the simulator training, Participant 15 navigated out of the ideal course, which was the green line. Participant 15 collided with the ship Scot Isles. Participant 15 in this training navigated with a lookout who was assigned as an assistant on the bridge, Figure 8.63. This collision performance was as a result of the interface with the following five events:

- **Event 1 Baseline:**

In the baseline, Participant 15 was moving around, checking the equipment and asking the lookout about the gyro in the conning display. Also, Participant 15 asked about the VHF and mentioned that only one VHF is used. Participant 15 did not stay calm during the baseline.

- **Event 2: MV Nowa:**

During the MV Nowa event, Participant 15 did not acquire the target on the radar. The lookout informed the participant about the MV Nowa, and Participant 15 answered that he knew about it. Furthermore, the participant was trying to use the autopilot and unexpectedly instructed the lookout to take the steering. Then, Participant 15 received a call from MV Nowa and instructed

him to keep course and speed. During the communication, Participant 15 demanded the lookout to alter to port and then mid-ship steady.

- **Event 3: MV Diamond:**

Between the MV Nowa event and MV Diamond Event, Participant 15 monitored the targets on the ECDIS and the screen for visualisation. Participant 15 moved to the radar for the first time. Usually the lookout inform the participant about the location of the MV diamond before receiving the communication, this time lookout did not inform Participant 15 about the location of the MV Diamond until receiving a call from the MV Diamond, then the lookout informed Participant 15 of the MV Diamond location. However, MV Diamond informed Participant 15 to keep course and speed passing from starboard. However, Participant 15 advised the MV Diamond to pass from the port because there was a ship passing from Starboard even when the lookout told him about the location after received the communication; the participant mentioned that ok just for advice to not pass from Starboard.

- **Event 4 MV Scot Isles:**

At (10m12sec), the lookout informed Participant 15 about Scot Isles on the port side. Participant 15 mentioned that he saw the ship, but Participant 15 described the ship wrongly as he said, “That is a fishing trawler”. After that, Participant 15 monitored the target on the ECDIS, and then Participant 15 communicated with MV Diamond to ensure that the MV Diamond would pass in which direction. Then, participant 15 told the MV Diamond, “Do not alter the ship from the starboard side because a Trawler is passing from the port of my stern”. After that, Participant 15 monitored the ship between the radar and ECDIS. During monitoring one of the screens for visualisation restarted but did not affect the scenario. However, Participant 15 kept instructing the lookout to alter the course as he ordered. Furthermore, Participant 15 noticed that Scot Isles came closer, so Participant 15 communicated with Scot Isles, but there was no response.

- **Event 5: Collision Avoidance:**

After trying to communicate with Scot Isles, Participant 15 did not get any response. Participant 15 communicated with the engine room to reduce the speed and, at the same time, instructed the lookout to go hard to starboard, but unfortunately, the Scot Isles were too close, and despite late action, the ship collided with Scot Isles.

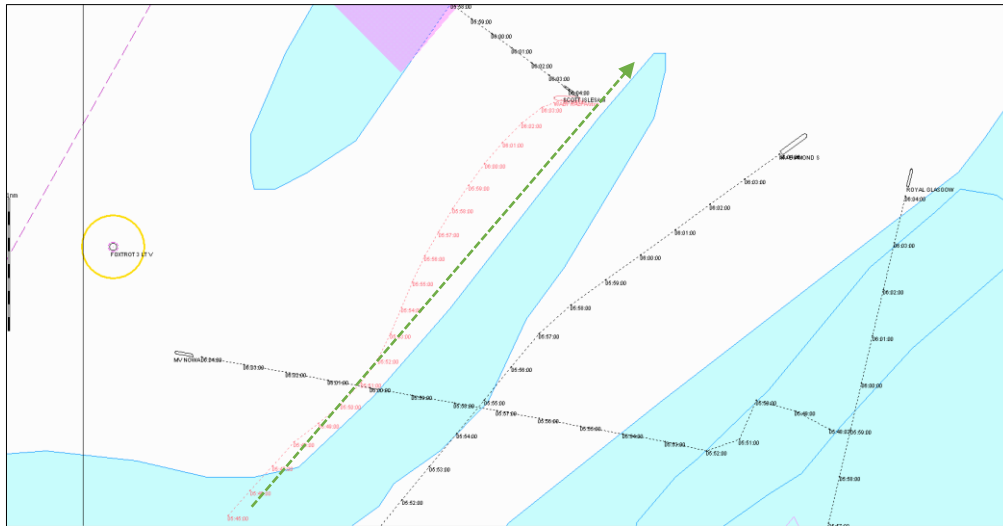


Figure 8.63: P15-L Navigation chart

The heat map from the Eye tracking provides the distribution of Participant 15's visual attention during the ship bridge simulation experiment, Figure 8.64. It provides a clear visual focus throughout the events. The red zones indicate the area with high focus. The heat map demonstrates that Participant 15 was not focusing on the navigation equipment most of the time. The participant relied on his visualisation. Even though Participant 15 has an assistant as a lookout, the participant did not utilise the lookout and did not concentrate on the navigation equipment. In addition, the red area indicates Participant 15 focused on Scot Isles while approaching but unfortunately got into a collision because of the late action.



Figure 8.64 P15-L Heat map

Table 8.13 : P15-L EEG Data

Time		Event	Duration	MWL	Stress	Attention
00:00.0	03:02.0	Baseline	03:02.0	0.20	0.04	0.00
03:54.7	06:32.1	Nowa	02:37.4	1.00	0.03	0.79
08:43.8	09:30.5	Diamond	00:46.7	0.00	1.00	0.22
10:03.0	13:51.1	Scot Isles	03:48.2	0.19	0.00	1.00
13:51.1	16:37.6	Collison Avoidance	02:46.4	0.54	0.03	0.36

Based on the EEG result and Participant 15's performance metrics illustrated in Table 8.13 and Figure 8.65, we can observe how the cognitive demand (MWL, Stress, and attention) differs across the different events in the simulator experiment as follows:

- **Event 1 Baseline:**

Participant 15 showed low mental workload and stress levels during the baseline, while no attention was shown. This suggests that Participant 15 was calm because there were no targets and no immediate risk existed. However, Participant 15 was looking at the conning display and communicating with the lookout with many questions, which indicates a loss of attention.

- **Event 2 MV Nowa:**

When the targets began to appear, Participant 15 detected the MV Nowa which increased Participant 15's attention to high. However, Participant 15 was trying to use autopilot but

suddenly asked the lookout to take the steering, and he received a call from the MV Nowa, which indicates the high MWL he has but no stress.

- **Event 3 MV Diamond:**

The next event, MV Diamond, shows significantly high stress with low attention and no MWL. In this event, Participant 15 was given the order to the lookout, which made the lookout not inform Participant 15 about the location of the MV diamond. They were aware of MV Diamond when receiving a call from the MV Diamond requiring Participant 15 to keep the course and speed and Participant 15 advised the MV Diamond to pass from the port side. This indicated that Participant 15 was stressed and lost his attention.

- **Event 4 MV Scot Isles:**

The lookout informed Participant 15 about Scot Isles. It shows that Participant 15 had low MWL and high attention with no stress. However, Participant 15 in this event thought that he was aware of and controlled the situation, especially when he described the ship as a “fishing trawler”, which indicates that there was missing information without noticing that he was wrong.

- **Event 5 Collision Avoidance:**

During the failure of communication with Scot Isles, the MWL of Participant 15 increased, and his attention decreased with low stress. This occurred when the participant noticed the risk and tried to take action but collided because of the late action.

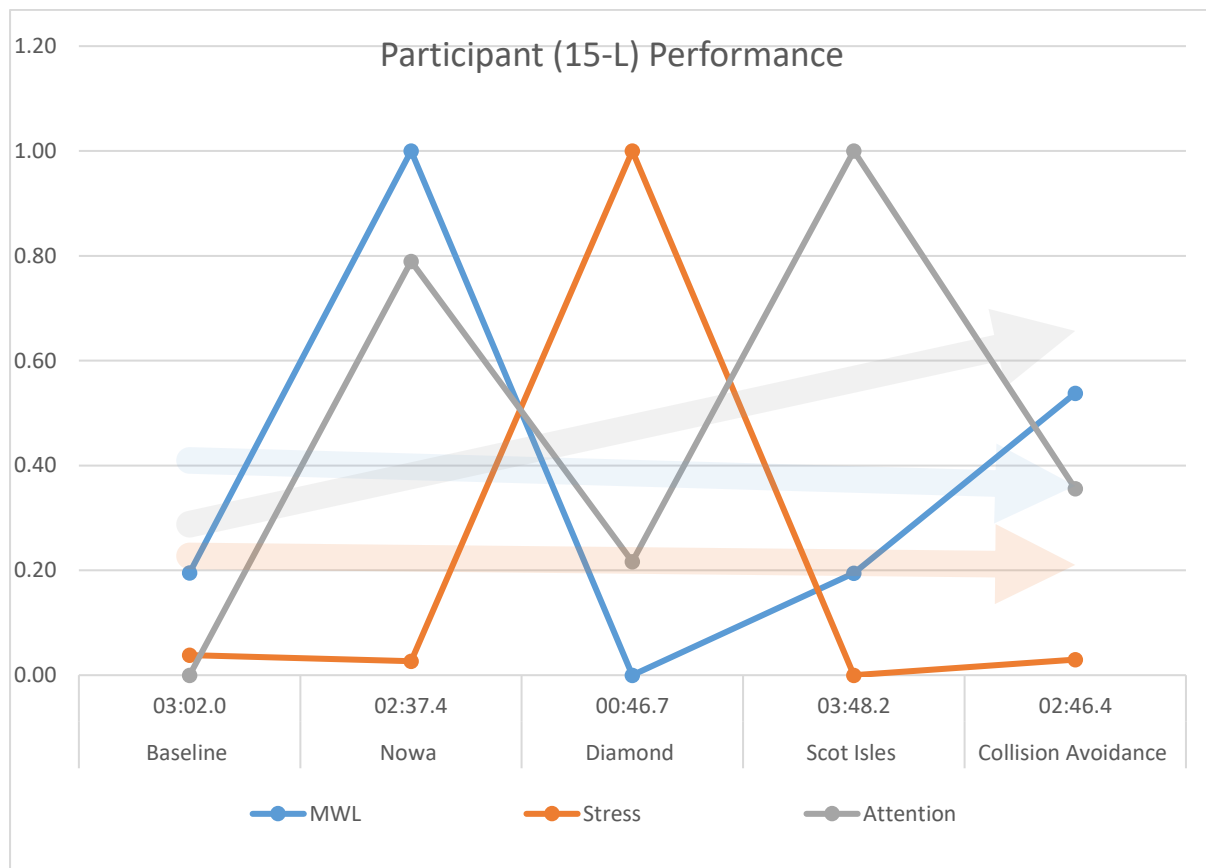


Figure 8.65 P15-L EEG Data

Furthermore, pupil diameters for both eyes give a comprehensive view of Participant 15's performance throughout the events. Participant 15 began with low cognitive demand and started to decrease slightly then, during the MV Diamond event, began to increase until reached the peak when the ship collided, Figure 8.66. Participant 15's eye pupil sizes and focus changed, as shown in Table 8.14 and Figure 8.72

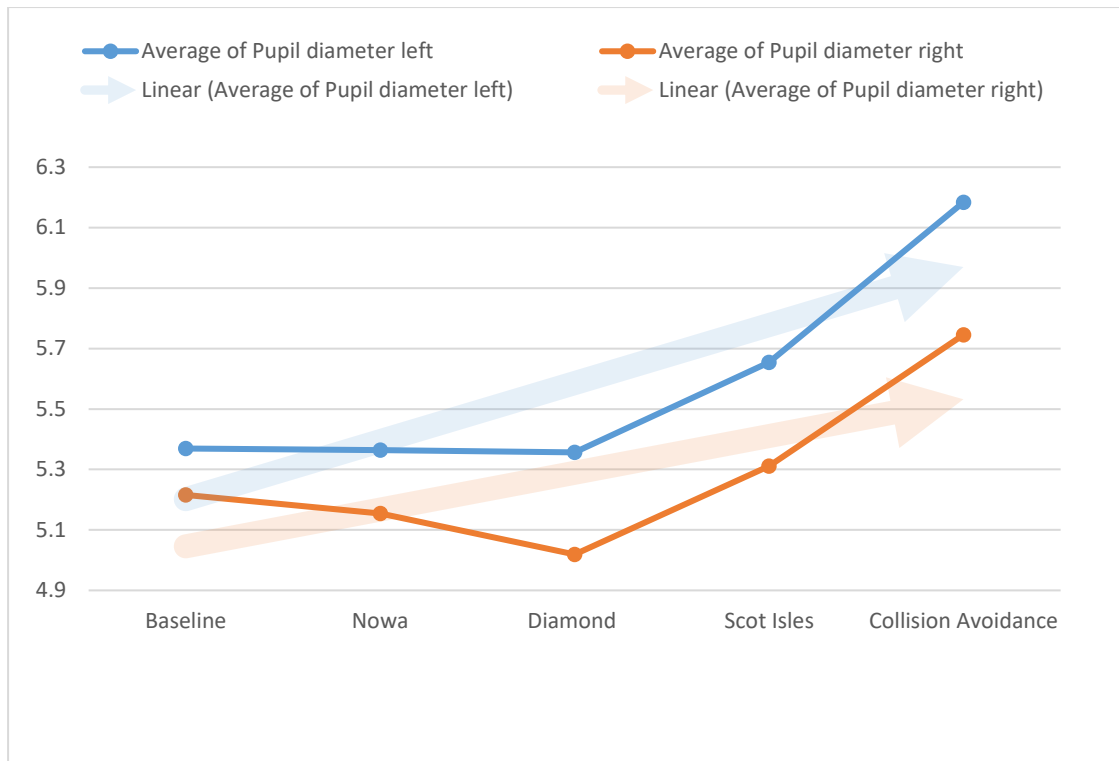


Figure 8.66 P15-L Eye Pupil Dimeter

- **Event 1 Baseline:**

In the baseline, Participant 15 demonstrated a lower pupil diameter of (5.36 mm) on the left side and (5.21 mm) on the right side. Participant 15 shows low cognitive load and a relaxed state in this event as no targets around and no task engagement. Participant 15 asked many questions during the event, but this did not affect his cognitive load. This event lasts around (22%) of the experiment time. During the event, the participant focused on the radar around (65%) and (13%) of the event time on the ECDIS, with around (5%) of event time on scanning the screen for visualisation. In addition, (9%) of the event time was focused on the display unit. This showed that Participant 15 was familiarising himself with all navigation equipment and improving his situational awareness more than visual observation as shown in Figure 8.67



Figure 8.67 P15-L Heat map for the baseline

- **Event 2 MV Nowa:**

With the appearance of the MV Nowa, the eye pupil diameters are almost the same, indicating that Participant 15 maintained his cognitive load with (5.36 mm) on the left and (5.15 mm) on the right. Participant 15 in this event spent approximately (18%) of the experiment time monitoring the MV Nowa. The engagement with the radar decreased and took around (43%) of the event time, and the engagement with the visual check in this event increased to (12%) of the event time, and (4%) of the event time on the VHF while communicating with (9%) of the event time on the display unit. The increase in focus on the screen visualisation when detecting the MV Nowa and in the display unit suggests that the participant relied on his observation and did not ask for support from the lookout, Figure 8.68.



Figure 8.68 P15-L Heat map for MV Nowa

- **Event 3 MV Diamond:**

Pupil diameter decreased slightly in this event (5.35 mm) on the left and (5.02 mm) on the right, showing that Participant 15 was calmer because the participant was just observing the screen for visualisation and not monitoring and engaging with the targets by the navigation equipment. In addition, Participant 15 was unaware of MV Diamond until receiving the call. Furthermore, Participant 15 monitors the MV Diamond around (5%) of the test time. While monitoring MV Diamond, the participant spent (85%) of the event time on screen for visualisation as shown in the heat map especially when the lookout informed the participant about the ship ahead, Figure 8.69. In addition, he spent (4%) of the event time on the VHF during communication. This suggests the participant was not using navigation equipment to avoid the collision.



Figure 8.69 P15-L Heat map for MV Diamond

- **Event 4 MV Scot Isles:**

During this event, there was a remarkable increase in Participant 15's pupil diameter (5.65 mm) on the left side and (5.31 mm) on the right side. This indicates a cognitive engagement while trying to monitor the Scot Isles. Participant 15 spent most of the time in this event, around (50%) of the experiment time, on the Scot Isles, which indicates that the participant was concerned with this target and kept focusing visually. This event shows how Participant 15 was moving between the bridge environments because it shows that the participant distributed his time on the radar for (46%) of the event time and (41%) of the event time on the ECDIS with (2%) on the top display unit and (10%) of event time scanning the screen for visualisation. This suggests that Participant 15 was moving and checking the information trying to avoid the risk of a collision and not relying on the navigation equipment as much as visual observation, Figure 8.70.



Figure 8.70 P15-L Heat map for MV Scot Isles

- **Event 5 Collision Avoidance**

The final event showed a greater increase in the eye pupil, which means that Participant 15 started to experience significantly higher MWL while monitoring and taking action to avoid collision as the eye pupil diameter increased to (6.18 mm) for the left side and (5.74 mm) for the right side. Participant 15 spent less time in the experiment focusing on avoiding collision as it took around (5%) of the experiment time. This suggests that the participant did not take early action which led him to the collision. It shows in this event that the participant was trying to distribute his observation around the bridge. The participant focused on the ECDIS (22%) of the time event, and there was an increase in the visual observation to (42%) of the event time and (8%) of the event time on the top display unit also (14%) of the time event in the engine while trying to reduce speed. However, the late action led Participant 15 to collide. It shows that Participant 15 was focusing on the Scot Isles visually when approaching rather than monitoring the navigation equipment to check the information as shown in Figure 8.71. This suggests that Participant 15 relied on his experience and perception, which gave him wrong anticipation to avoid the collision, Figure 8.71.



Figure 8.71 P15-L Heat Map for Collision Avoidance

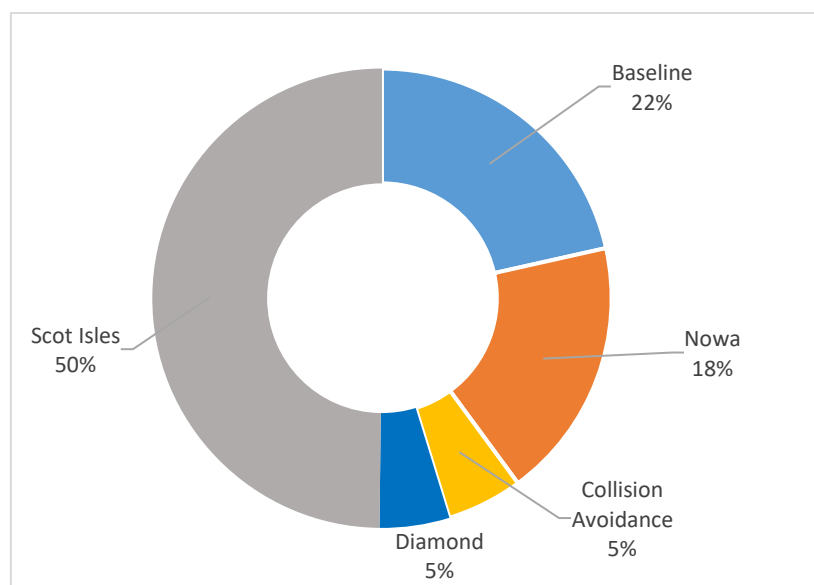


Figure 8.72 P15-L Event duration

Table 8.14 P15-L Point of focus at different scenario events

Row Labels	Display Unit	ECDIS	Engine	VHF	RADAR	Visualisation	Top Display Unit
Baseline	9%	13%	6%	1%	65%	5%	0%
Nowa	31%	10%	1%	4%	43%	12%	0%
Diamond	6%	0%	0%	4%	0%	85%	0%
Scot Isles	1%	41%	0%	0%	46%	10%	2%
Collision Avoidance	0%	22%	14%	14%	0%	42%	8%

The Figure 8.54 represents Participant 15's performance through the EEG and Eye-tracking signals which clearly illustrate the cognitive demand throughout the scenario. The EEG shows that Participant 15, during the baseline, was stable with low cognitive demand. However, when the targets began to appear, a spike appeared after the baseline event around (08m30s). Spikes from (F4-Pz) and (P3-Pz) indicate that Participant 15 engaged with the experiment mentally but stressfully. However, Participant 15 detects the MV Nowa after one minute. The Parietal channel ((P3-PZ) was active because Participant 15 was speaking with the lookout and showed a bit of stress when he instructed the lookout to steer. Between the MV Nowa and MV Diamond, Participant 15 was mentally highly overloaded. He was observing the targets only through visualisation, and after receiving the call from MV Diamond, he became aware of the situation. During the Scot Isles, it shows a spike around (16m:40s) and (20m:10s), indicating the engagement of Participant 15 with some action. Moreover, His engagement to avoid the collision increased as he was trying to take action, but Participant 15 eventually collided, and the scenario was terminated.

Furthermore, the eye-tracking shows that Participant 15 in the baseline had low cognitive demand and maintained his mentality with the task until he became aware of the Scot Isles, indicating a cognitive demand increase. In the middle of the Scot Isles event, a low eye pupil size appeared, and this could be because Participant 15 started to feel fatigued. However, Participant 15's cognitive demand increased again in the collision avoidance action when Participant 15 could not avoid the collision.

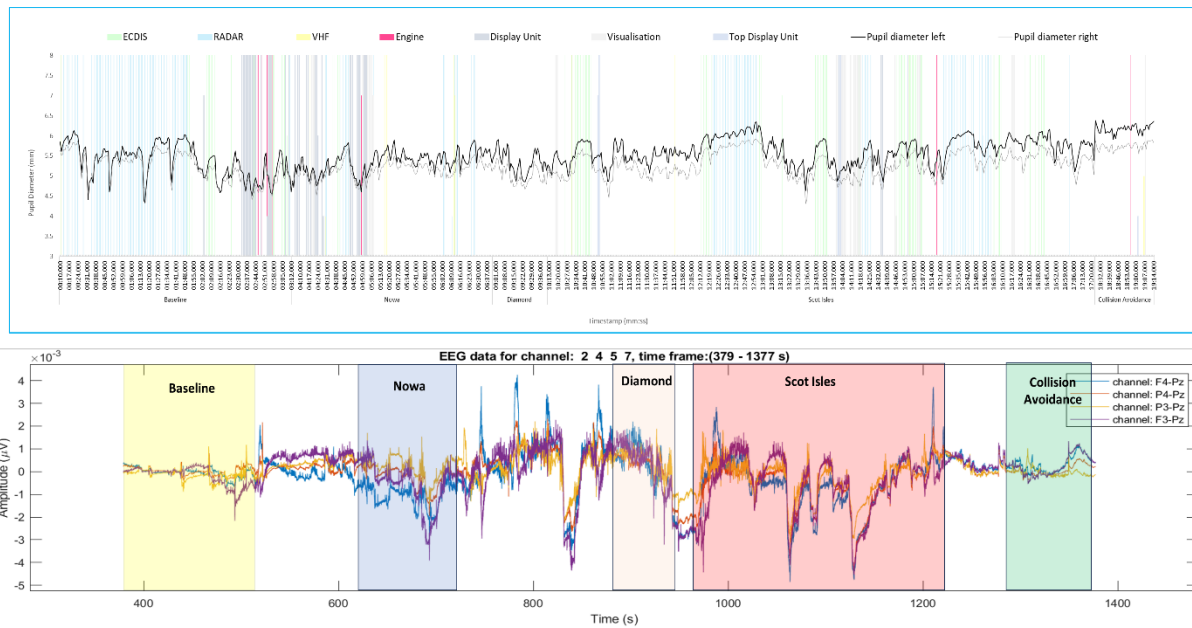


Figure 8.73 P15-L EEG and Eye track

Furthermore, the participant revealed cognitive engagement from the baseline event and across all channels. Especially between the MV Nowa and MV Diamond events, Participant 15 observed the external environment visually and did not monitor the navigation equipment. The increase in the delta band indicates a significant cognitive process that increases the MWL and need for decision-making. Moreover, Theta plays a role in the attentional process and working memory. Therefore, an increase in Theta suggests that Participant 15 try to solve the problems during the scenario, Figure 8.74.

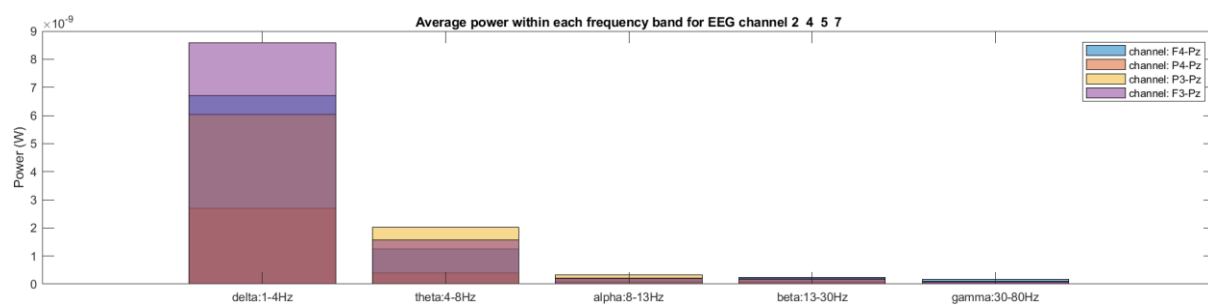


Figure 8.74 P15-L Power band

8.4 Conclusion of the Experiments

Results and analysis of the 6 participants' performance in both sets of experiments were presented in Sections 8.2 and 8.3, while the results of the remaining 20 participants will be illustrated in **Appendix D** and **Appendix E**. The EEG and eye-tracking data provide clear evidence that they can capture human performance and behaviour through a training scenario. Both elevated EEG activity and large pupil diameter evidence the changes in the signals. This combination of data provides a good understanding of the participant's performance. The convergence of high EEG amplitude and increased pupil diameter during the most challenging events underline the close relationship between cognitive load and behavioural focus, offering insight into the participant's decision-making process and their ability to manage complex tasks under stress. This integrated analysis highlights the importance of understanding both mental workload and behavioural adaptation for effective performance assessments in high-risk environments. Such insight will help the trainers to develop tailored simulator-based training to enhance individual Deck Officers' performance in safety-critical conditions and design a better task distribution. Furthermore, the data shows that there are differences between the pupil sizes of the left and the right eyes. According to the surgical study, (Menekse Dalveren and Cagiltay, 2019) mentioned that the increase in the eye pupil size results from an increase in the cognitive load. The study explores whether differences exist between the left and right eye pupil size in surgical resident computer-based simulation tasks using different hand conditions. The result shows that the right eye pupil size was generally larger during performing a task. This finding gives reasons for the differences in the pupil size between both eyes in our study. Moreover, the recordings show how each participant acted and reacted during the experiment, which could be linked to the differences in personality, experience and the training that they had received.

In the first set of experiments, where the participants navigated solo, more high cognitive demand was observed during certain events. The absence of support assistance during the critical situation made the participants not move freely around the ship bridge. When the participants decided on manual steering, participants were often stationed at the conning display, relying heavily on visual observation and limited devices for information. This lack of mobility and situational flexibility contributed to reduced

situational awareness. For example, one of the participants collided with MV Diamond, a ship that was not the main target, indicating that solo navigation may lead to a narrowed focus on one area or specific tasks lead him/her lose overall awareness and increase the errors.

On the other hand, the second set of the experiments, which is combined with an assistant “Lookout”, showed variability in cognitive demand. The presence of a lookout allowed the participants more flexibility in movement around the ship bridge, allowing them to engage more with navigation instruments such as, radar and ECDIS. During critical situations, participants usually delegated manual steering to the lookout, allowing them to focus more on monitoring targets and managing navigation instruments. This enables the participants to maintain wider situational awareness and respond more effectively to challenges. This underscores the advantage of collaborative navigation, especially in high-demand scenarios, where the presence of a lookout can reduce the cognitive load and enhance operational performance.

8.5 The Result

8.5.1 Subjective result

The demographic data of the study participants is presented in Table 8.15. Of the individuals who participated in the study, 73.1% were male and 26.9% were female. Examination of the age range reveals that most participants (46.2%) were between 35 and 49. Regarding education, 34.6% of the participants have an HND degree, 23.1% of the participants have a bachelor's degree, and 30.8% have an MSc degree. Of the participants, 57.7% held the Oceangoing Master certificate, while 42.3% held the Oceangoing Chief Officer certificate. Most participants (73.1%) had more than 10 years of experience, and 42.3% had held their position for 1-3 years. Regarding the type of ship used by the participants, 3.8% were container ships, 15.4% were Dry Cargo Ships, 15.4% were oil tankers, 11.5% were passenger ships, and 23.1% were RO-RO ships.

Regarding the current simulator experiments in which they participated, 84.6% of the participants responded with a "very positive" rating. Additionally, 96.2% of the participants had previously participated in a simulator study. Half of the participants (50%) completed the simulation without

assistance (lookout), while the remaining 50% completed the simulation with assistance (Lookout). As a result of the study, 23.1% of the participants experienced a collision in the first set of experiments where 13 participants were operating the vessel solo, while 7.7% of the participants in the second set of experiments where 13 participant navigated with the lookout had a collision.

Table 8.15 Demographic data of the participants

		N	%
Gender	Female	7	26,9
	Male	19	73,1
Age	26-34	9	34,6
	35-49	12	46,2
	50-65	5	19,2
Education	High/Secondary School	1	3,8
	HND	9	34,6
	MSc	8	30,8
	Others	2	7,7
	University	6	23,1
Certificate	Oceangoing Chief Officer	11	42,3
	Oceangoing Master	15	57,7
Onboard	6-10 years	7	26,9
Experience	More than 10 years	19	73,1
Years Current	1-3 year	1	3,8
Position	1-3 years	11	42,3
	4-5 years	4	15,4
	6-10 years	5	19,2
	More than 10 years	5	19,2
Ship Type	Container	1	3,8
	Dry Cargo Ships	4	15,4
	Oil Tankers	4	15,4
	Others	8	30,8
	Passenger	3	11,5
	RO-RO	6	23,1
What is your opinion about the current simulator experiments you have just participated in?	Positive	4	15,4
	Very Positive	22	84,6
Have you ever participated in	No	1	3,8
	Yes	25	96,2

full mission simulator training, if Yes, how many times?			
Lookout	Without Lookout	13	50,0
	With Lookout	13	50,0
Collision	Yes	Without Lookout	3 23,1
		With Lookout	1 7,7

Furthermore, NASA-TLX is a widely recognised and extensively used measurement tool that evaluates the subjective workload experienced by individuals performing complex tasks, especially in high-pressure environments. It provides valuable insight into the mental and physical demands placed on individuals during task execution, allowing for the identification of potential areas of improvement and optimisation in task design, workload distribution, and resource allocation. The Human Performance Group created it at NASA's Ames Research Centre through an extensive three-year process involving 40 laboratory simulations. It has since been applied across diverse fields, such as aviation, healthcare, and other complex socio-technical domains (So and Gore, 2020). This assessment evaluates workload across six core dimensions: Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, and frustration. Participants rate each dimension based on their perceived workload, typically using a scale that ranges from low to high or from 0 to 100, depending on the version of the NASA-TLX used. By capturing these multiple facets of workload, the tool provides a comprehensive overview of task demands from the participant's perspective. However, as a subjective, self-reported measure, NASA-TLX does not objectively quantify workload. In this experiment, we used a scale from 0 to 100 to measure the workload of the participants.

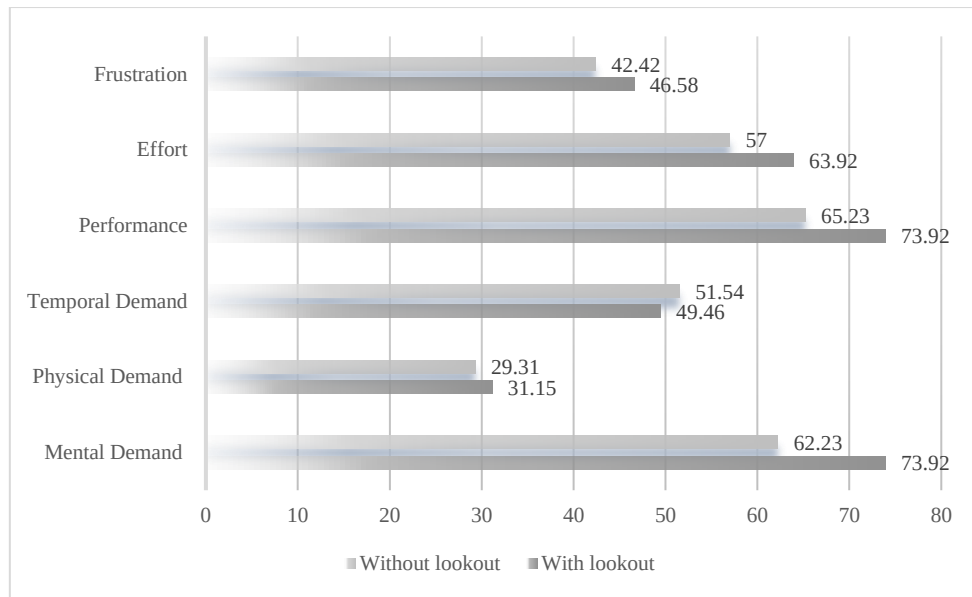


Figure 8.75 Statistical analysis of the NASA-TLX scores among the 1st experiment and 2nd experiment

Table 8.16 Statistical analysis of the NASA-TLX scores among the 1st experiment and 2nd experiment

		Mental	Physical	Temporal				
With/ without Lookout		Demand	Demand	Demand	Performance	Effort	Frustration	Total
Without Lookout	Mean	62.23	29.31	51.54	65.23	57.00	42.42	304.46
	Std. Deviation	20.49	16.56	18.89	26.56	25.28	22.30	90.55
	Median	60.00	30.00	50.00	73.00	60.00	44.00	274.00
	Min - Max	32-92	2-64	25-90	24-100	10-95	4-80	176-480
With Lookout	Mean	73.92	31.75	49.46	73.92	63.92	46.58	333.53
	Std. Deviation	19.37	26.52	30.79	19.87	21.55	33.20	104.91
	Median	81.00	31.00	50.00	81.00	71.00	45.00	324.00
	Min - Max	40-100	4-82	9-100	30-100	29-91	8-95	199-519
	p value	0.139	0.810	0.724	0.479	0.579	0.799	0.457

According to the results presented in Figure 8.75 and Table 8.16 Statistical analysis of the NASA-TLX scores among the 1st experiment and 2nd experiment, the NASA Task Load Index (TLX) data did not reveal any statistically significant differences between the presence and absence of a lookout as a P-value more than (0.05). The results indicate that mental demand (73.92) was higher during the experiment with the lookout, physical demand (31.15) was higher with the lookout, and performance (73.92) was also higher during the experiment with the lookout. In contrast, temporal demand (51.54) was higher during the experiment without a lookout, effort (63.92) was higher with the lookout, and frustration (46.58) was higher in situations with the presence of the lookout.

These findings suggest that the presence or absence of a lookout does not significantly impact the overall task load during the scenario. However, it is important to consider that specific task demands may vary between conditions, as evidenced by differences in mental, physical, and temporal demands. The results also suggest that the presence of a lookout may increase feelings of frustration among crew members. However, the result is related to the participant's perspectives and subjective opinions.

Table 8.17 Ship bridge simulator training questionnaires.

Question	Explanation
Q1	Was EEG and eye tracker comfortable?
Q2	Was the simulator easy to use?
Q3	The scenario is well-designed.
Q4	Simulators are useful for analysing past accidents and learning lessons.
Q5	The scenario was stressful
Q6	Bridge simulator training helps with bridge familiarisation.
Q7	Improves my performance of simulator work
Q8	Simulator work affects my practical skills positively
Q9	Having difficulty using the devices in the simulator
Q10	The scenario was realistic
Q11	The stress experienced was the same as in real life

Q12	Simulator training is useful to improve the performance of OOW in safety critical-Emergency/rare situations.
Q13	Ship maneuvering in the simulator was difficult

Table 8.18 Participants' responses to ship bridge simulator training questionnaires

		N	%
Q1	2-Somewhat disagree	3	11,5
	3-Neither agree nor disagree	3	11,5
	4-Somewhat agree	10	38,5
	5-Strongly agree	10	38,5
Q2	2-Somewhat disagree	1	3,8
	3-Neither agree nor disagree	2	7,7
	4-Somewhat agree	14	53,8
	5-Strongly agree	9	34,6
Q3	3-Neither agree nor disagree	1	3,8
	4-Somewhat agree	4	15,4
	5-Strongly agree	21	80,8
Q4	3-Neither agree nor disagree	1	3,8
	4-Somewhat agree	1	3,8
	5-Strongly agree	24	92,3
Q5	1-Strongly disagree	2	7,7
	2-Somewhat disagree	3	11,5
	3-Neither agree nor disagree	3	11,5
	4-Somewhat agree	13	50,0
	5-Strongly agree	5	19,2
Q6	4-Somewhat agree	8	30,8
	5-Strongly agree	18	69,2
Q7	2-Somewhat disagree	1	3,8
	3-Neither agree nor disagree	1	3,8
	4-Somewhat agree	4	15,4

	5-Strongly agree	20	76,9
Q8	4-Somewhat agree	7	26,9
	5-Strongly agree	19	73,1
Q9	1-Strongly disagree	6	23,1
	2-Somewhat disagree	5	19,2
	3-Neither agree nor disagree	4	15,4
	4-Somewhat agree	8	30,8
	5-Strongly agree	3	11,5
Q10	2-Somewhat disagree	1	3,8
	3-Neither agree nor disagree	1	3,8
	4-Somewhat agree	7	26,9
	5-Strongly agree	17	65,4
Q11	2-Somewhat disagree	2	7,7
	3-Neither agree nor disagree	3	11,5
	4-Somewhat agree	12	46,2
	5-Strongly agree	9	34,6
Q12	4-Somewhat agree	5	19,2
	5-Strongly agree	21	80,8
Q13	1-Strongly disagree	6	23,1
	2-Somewhat disagree	7	26,9
	3-Neither agree nor disagree	6	23,1
	4-Somewhat agree	6	23,1
	5-Strongly agree	1	3,8

According to Table 8.18, a majority of participants found the EEG and eye tracking comfortable (77% agreeing or strongly agreeing), with a small minority expressing slight discomfort (11.5% somewhat disagree, and 11.5% Neither agree nor disagree). This suggests that the devices did not cause significant discomfort, which is crucial for ensuring participants remain focused on the task without distraction. For the question of whether the simulator was easy to use, (55.8%) somewhat agreed, and (34.6%) strongly agreed. This indicates that the simulator's design and interface were approachable, allowing participants to engage effectively without technical difficulties. Moreover, (92.3%) strongly believed

that simulators are useful for analysing past accidents and learning lessons, underscoring the perceived educational value of simulation-based training in a maritime context. In addition, Half of the participants found the scenario somewhat stressful, and (19.2%) rated it as strongly stressful, reflecting that the simulation managed to induce a moderate level of stress, which may enhance the realism of the emergency training scenarios. Furthermore, the preparation and familiarisation of the simulation were rated highly, with (69.2%) strongly agreeing that the introduction was sufficient. This indicated that participants felt adequately prepared to engage in the simulation activities. Additionally, a significant majority (76%) felt that simulator work improved their performance, while (73%) agreed that it positively affected their practical skills. For the difficulty of using simulator devices, the response was mixed with (23.1%) strongly disagreeing, somewhat disagreeing (19.2%), neither agreeing nor disagreeing (15.4%), Somewhat agreeing (30.8%), and strongly agreeing (11.5%). This variation could indicate that while most participants did not find the devices difficult, some encountered challenges, possibly due to unfamiliarity or technical complexity. Moreover, (92.3%) of the participants agreed with the scenario's realism.

Despite most of the participants agreeing that the scenario was stressful, a small proportion (34.6%) felt that the stress experienced was comparable to real-life stress, suggesting that while the simulator did create some stress, it did not fully replicate real-world intensity which is a common limitation in a simulated environment. In addition, (80.8%) revealed that simulators improve OOW performance in safety -Emergency/rare situations, indicating a high confidence level in the simulator's value for enhancing operational skills and emergency readiness. With regard to the difficulty of the ship's manoeuvrability, (50%) almost disagreed, (23.1%) neither agreed nor disagreed and (26.9%) almost agreed. This response variation might reflect different participant experience levels or adaptability to the simulation controls.

In summary, the subjective result highlights that simulation-based training is highly useful and effective for maritime operations. While the simulation had some challenges, such as not fully replicating real-life stress and some difficulty with controls, most participants found it realistic, easy to use, and valuable for improving skills. The training was especially helpful for developing emergency response skills,

situational awareness, and learning from past accidents. Overall, participants agreed that the simulation improved their performance and decision-making. These findings support using simulation-based training as an important part of preparing OOW for real-world maritime challenges.

8.5.2 Objective Result

8.5.3 EEG and eye tracking Data Analysis

The following section presents a detailed interpretation of the data gathered from EEG and Eye-tracking analyses across a sequence of simulated navigational events in a ship bridge environment. These events were designed to reflect critical scenarios that the OOW may face, each with a unique demand on cognitive workload, situational awareness, and decision-making. By examining physiological and visual data within the specific situational context, this analysis aims to uncover how different navigational tasks affect the mental workload, stress, attention, and visual engagement of the OOW, and how these factors are influenced by the presence of a lookout.

The section is structured around five key events simulated during the experiment as explained in the section 8.1 : Baseline, MV Nowa, MV Diamond, MV Scot Isles, and collision Avoidance. Each event provides a distinct operational scenario, offering insight into the OOW's cognitive and visual response to the complex situation that was faced during the experiment. Through these events, we explore the interaction between the OOW mental state and the visual focus during the navigation solo and with lookout. Therefore, some questions are designed in this experiment;

Q1: where does the OOW focus more during the experiment?

Q2: How did the presence of the lookout influence the behaviour of the OOW during the experiment?

For each event, the data interpretation focuses on how the OOW's EEG and eye-tracking metrics reflect cognitive and behavioural responses, with attention given to variations in mental workload, stress, and attention levels. Eye-tracking metrics highlight visual focus areas, revealing information gathering and monitoring patterns that may correlate with cognitive load and situational demands. This event-based interpretation provides a detailed understanding of how specific challenges in maritime navigation

impact cognitive and visual resources, which is critical for identifying potential areas for training and operational improvement.

By analysing these events individually, we can explore how the mental state and visual attention change and appreciate the complex interaction between environmental demands and human factors, which is essential for developing training protocols that prioritise cognitive resilience, situational awareness, and stress management in high-risks maritime operations.

8.5.3.1 EEG data event-based

- **MWL**

The mental workload analysis provides a crucial understanding of the cognitive demands placed on the OOW throughout the ship bridge experiment. MWL was assessed through EEG across the different navigational events, reflecting the cognitive strain associated with each scenario's complexity and urgency. This section examines the MWL levels recorded during each phase, from the baseline condition where no targets appear to the increasingly complex condition involving different targets. By comparing these levels between the two experiments, the result highlights the influence of the lookout support on participants' mental states.

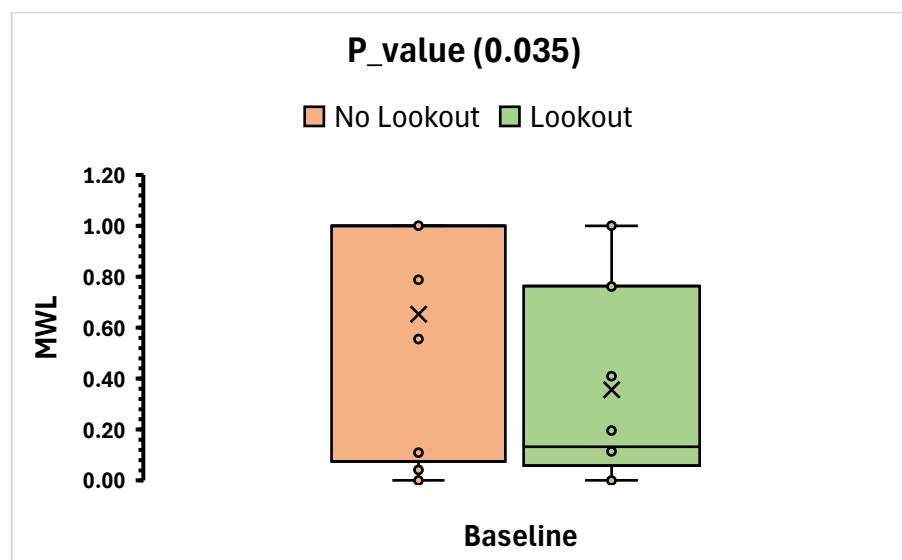


Figure 8.76 MWL baseline event

The MWL regarding the baseline event was statistically significant with the (P-value =0.035), as shown in Figure 8.76. This indicates that the presence of the lookout reduced the participant's mental state

during the baseline event, though no targets appeared. This is possibly due to the reassurance provided by an additional observer, or to participants' perception of reduced task demands when support is present.

Table 8.19 Descriptive MWL for baseline event

	Experiment	n	Mean	Median	Standard deviation	Min	Max
Baseline	No Lookout	13	0.654	1	0.447	0	1
	Lookout	13	0.355	0.13	0.387	0	1

The MV Nowa event also showed a significant result (P-value = 0.008), as shown in Figure 8.77. The mental demand for participants with the lookout is higher than those without the lookout, Table 8.20. The Author believes that the increase is due to the appearance of the targets and the need for communication with MV Nowa, combined with the additional information from the lookout, which could increase the mental workload in complex scenarios.

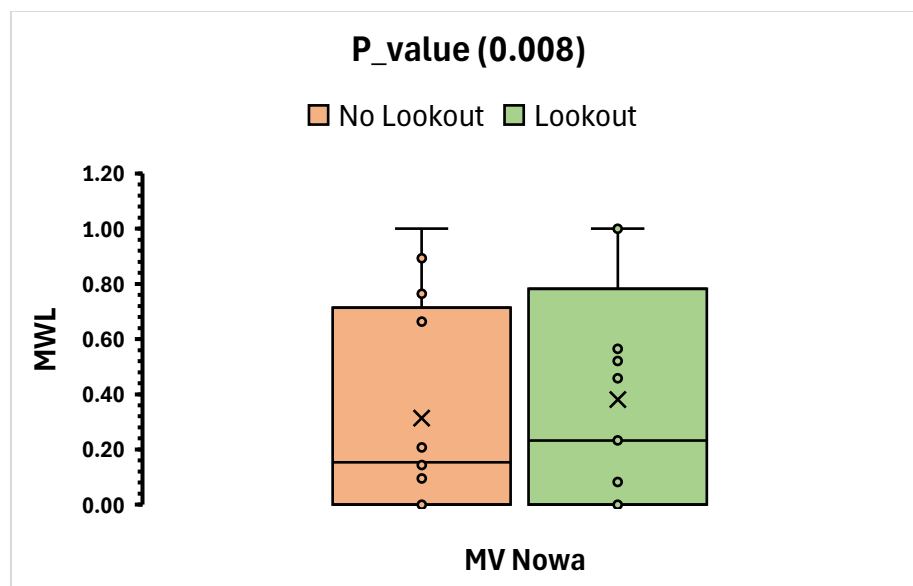


Figure 8.77 MWL MV Nowa event

Table 8.20 Descriptive MWL for MV Nowa Event

	Experiment	n	Mean	Median	Standard deviation	Min	Max
MV Nowa	No Lookout	13	0.312	0.15	0.372	0	1
	Lookout	13	0.38	0.23	0.407	0	1

However, in the MV Diamond event, despite the results were not statistically significant (P-value =0.305), Figure 8.78, the MWL was lower for the participants with the lookout Table 8.21. This suggests that information sharing by the lookout might help with reducing mental demand during a complex situation

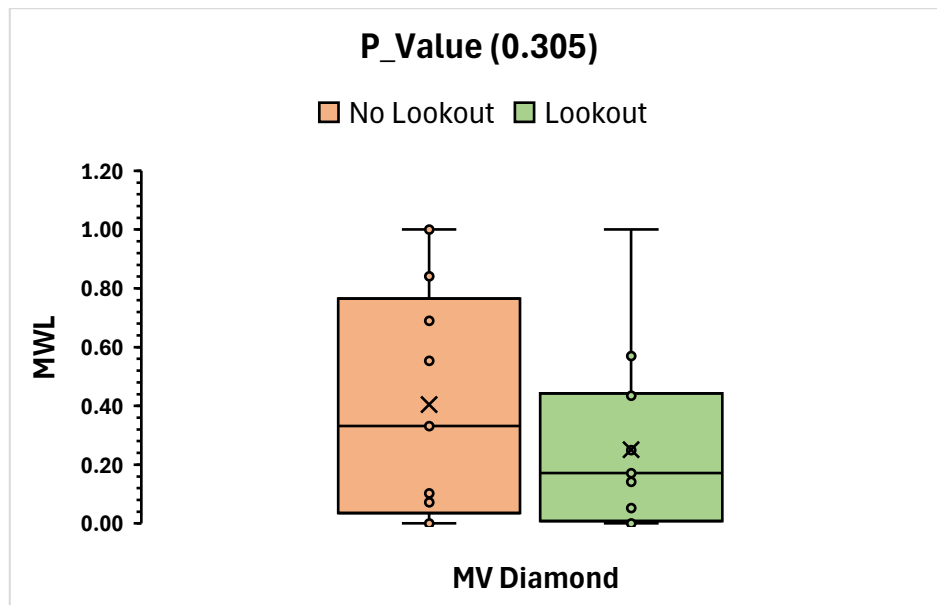


Figure 8.78 MWL MV Diamond event

Table 8.21 Descriptive MWL for MV Diamond event

MV Diamond	Experiment	n	Mean	Median	Standard deviation	Min	Max
	No Lookout	13	0.404	0.33	0.388	0	1
	Lookout	13	0.25	0.17	0.295	0	1

Furthermore, as the complexity increased in the MV Scot Isles event, the MWL was close to the significant with (P-value = 0.056), Figure 8.79, as the participant with the lookout illustrated higher MWL Table 8.22. This increase occurred due to the failure of communication with the MV Scot Isles, in addition to the information received from the lookout and the participant instructed the lookout during steering. All these reasons may increase the mental demands of the participants.

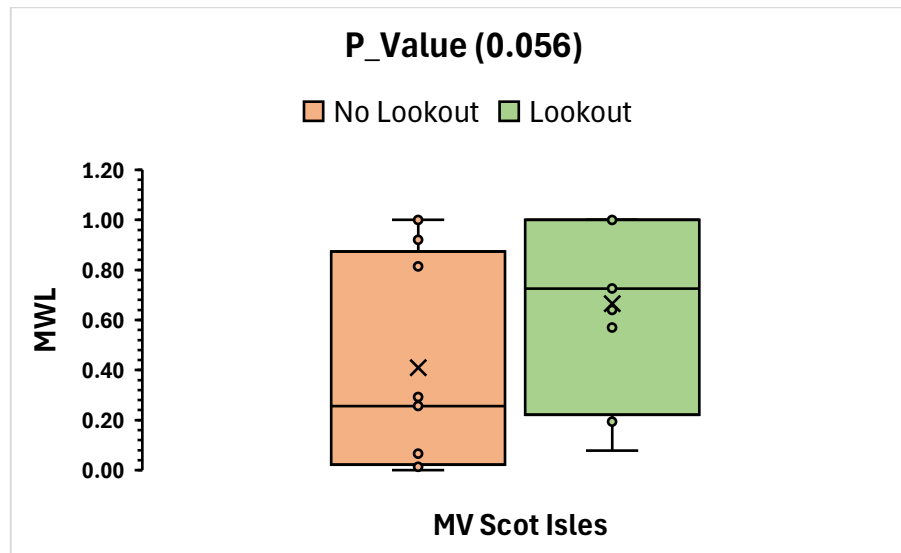


Figure 8.79 MWL MV Scot Isles event

Table 8.22 Descriptive MWL for MV Scot Isles event

MV Scot Isles	Experiment	n	Mean	Median	Standard deviation	Min	Max
	No Lookout	13	0.408	0.26	0.0.427	0	1
	Lookout	13	0.665	0.73	0.371	0.8	1

In the final event, which is collision avoidance, the participant revealed lower MWL Table 8.23, even though not significant (P-value= 0.213), Figure 8.80. This outcome indicates that the presence of the lookout could manage the mental demand and contribute to reducing the mental workload in high-demand scenarios.

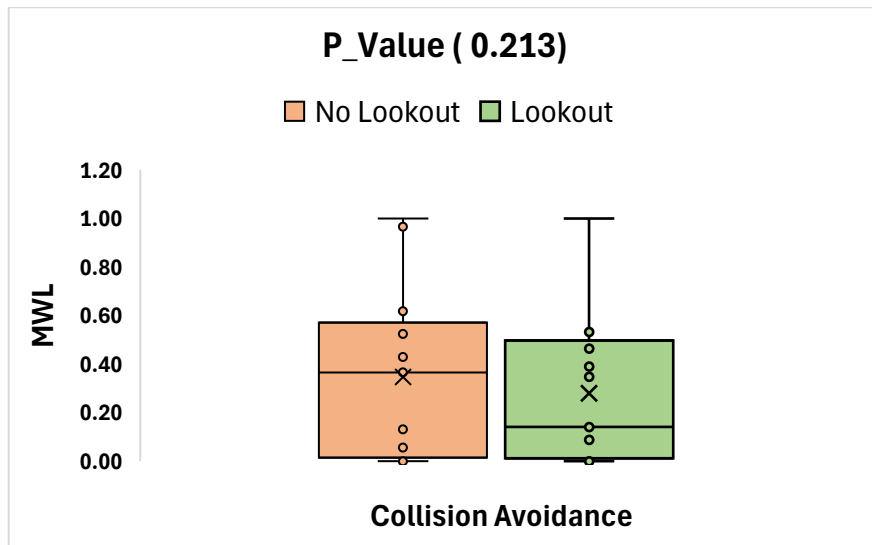


Figure 8.80 MWL collision avoidance event

Table 8.23 Descriptive MWL for collision avoidance event

Collision Avoidance	Experiment	n	Mean	Median	Standard deviation	Min	Max
	No Lookout	13	0.348	0.37	0.356	0	1
	Lookout	13	0.28	0.14	0.3	0	1

Overall, while MWL increased in certain events for participants with a lookout, this does not imply a lack of support. Instead, the lookout's information could increase MWL in complex scenarios without necessarily harming the performance, on the contrary, it possibly increases the performance due to the additional situational awareness provided by the lookout. the lower MWL observed in the final event suggests that lookout support can help participants manage their mental workload effectively as demands increase.

- Stress

The analysis of stress levels throughout the ship bridge simulation offers valuable insight into how different navigational scenarios impact the OOW. Stress levels were measured through five events, as explained before. This section details the observed variation in stress and looks into how the presence of the lookout with the complexity of the scenario influences the OOW stress level.

In the baseline event, there was no significant difference in stress level (P-value= 0.941), Figure 8.81.

This is likely because no targets were present, and there was no risk of collision.

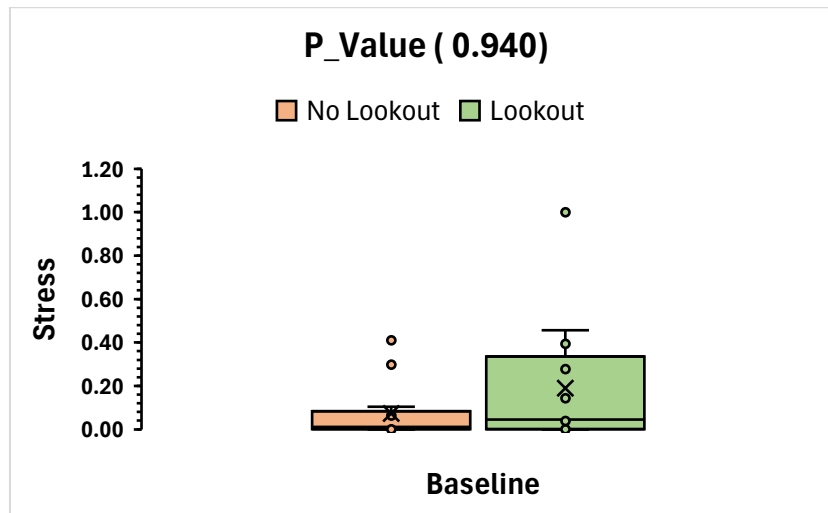


Figure 8.81 Stress baseline

Table 8.24 Descriptive stress for baseline event

	Experiment	n	Mean	Median	Standard deviation	Min	Max
Baseline	No Lookout	13	0.072	0.01	0.131	0	0.41
	Lookout	13	0.188	0.04	0.29	0	1

However, a significant difference in stress was observed during the MV Nowa event, with participants assisted by a lookout showing higher stress levels (P-value = 0.017), Figure 8.82. Table 8.25 shows an increase in the mean stress level, which may result from the added communication demands and the pressure to coordinate effectively with the lookout.

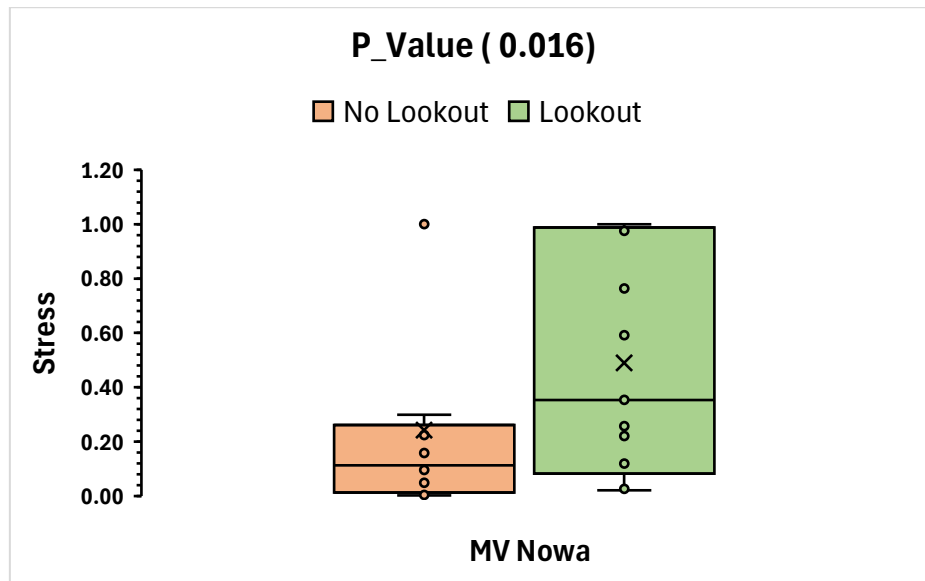


Figure 8.82 Stress MV Nowa

Table 8.25 Descriptive Stress for MV Nowa event

MV Nowa	Experiment	n	Mean	Median	Standard deviation	Min	Max
	No Lookout	13	0.242	0.11	0.349	0	1
	Lookout	13	0.491	0.35	0.409	0.02	1

No significant stress levels were observed for the remaining events MV Diamond, MV Scot Isles, and collision avoidance (Figure 8.83, Figure 8.84, and Figure 8.85). Remarkably, Table 8.27 shows that the mean stress levels without outlook are higher during the MV Scot Isles event. This is indicated by the presence of the lookout, and I think also that when the lookout informed the participants about the appearance of the ship in the early stage they could manage their stress. Moreover, the final collision avoidance event was low, suggesting that stress decreased once participants began taking corrective action to avoid a collision Table 8.28.

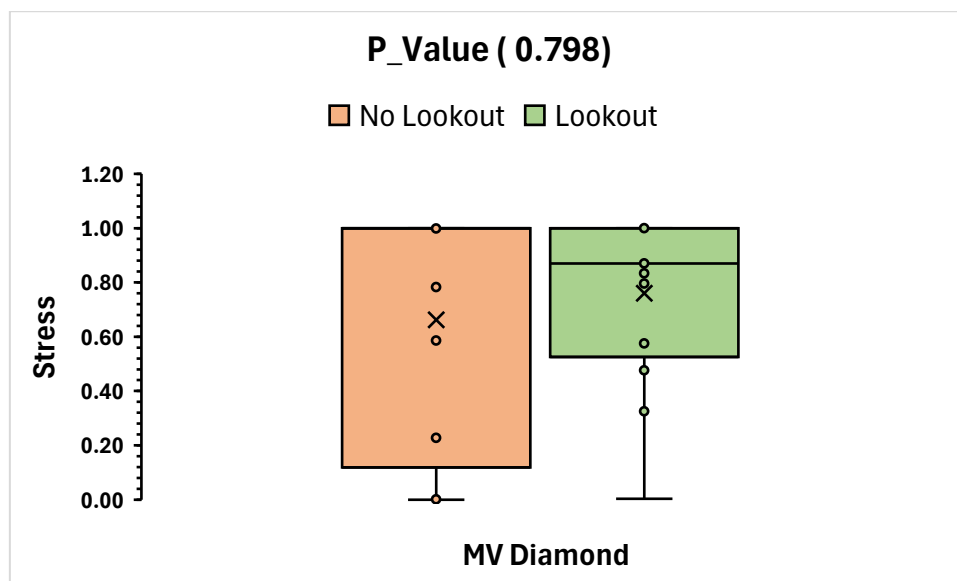


Figure 8.83 Stress MV Diamond

Table 8.26 Descriptive Stress for MV Diamond event

MV Diamond	Experiment	n	Mean	Median	Standard deviation	Min	Max
	No Lookout	13	0.662	1	0.438	0	1
	Lookout	13	0.761	0.87	0.321	0	1

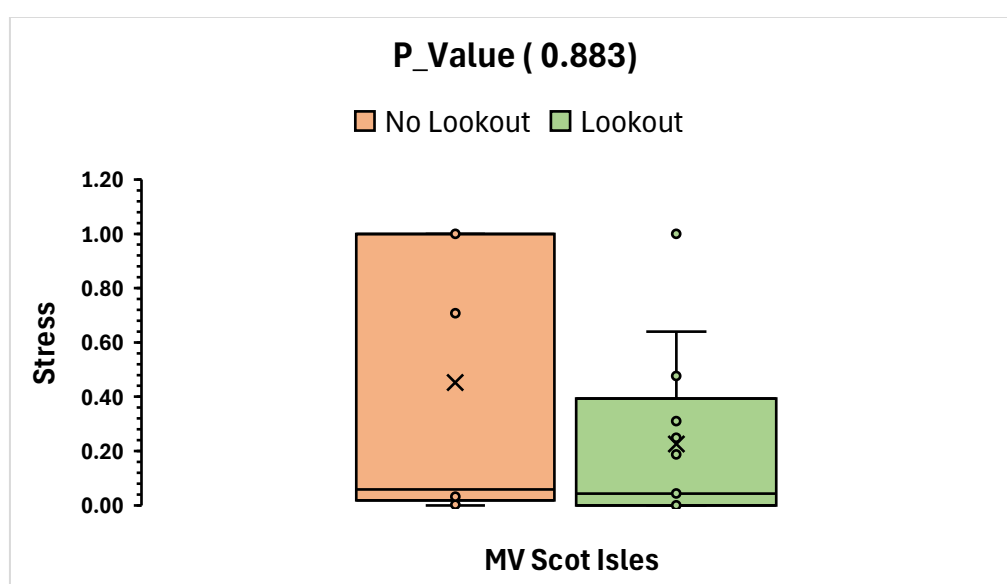


Figure 8.84 Stress MV Scot Isles

Table 8.27 Descriptive Stress for MV Scot Isles event

MV Scot Isles	Experiment	n	Mean	Median	Standard deviation	Min	Max
	No Lookout	13	0.452	0.06	0.487	0	1
	Lookout	13	0.226	0.04	0.313	0	1

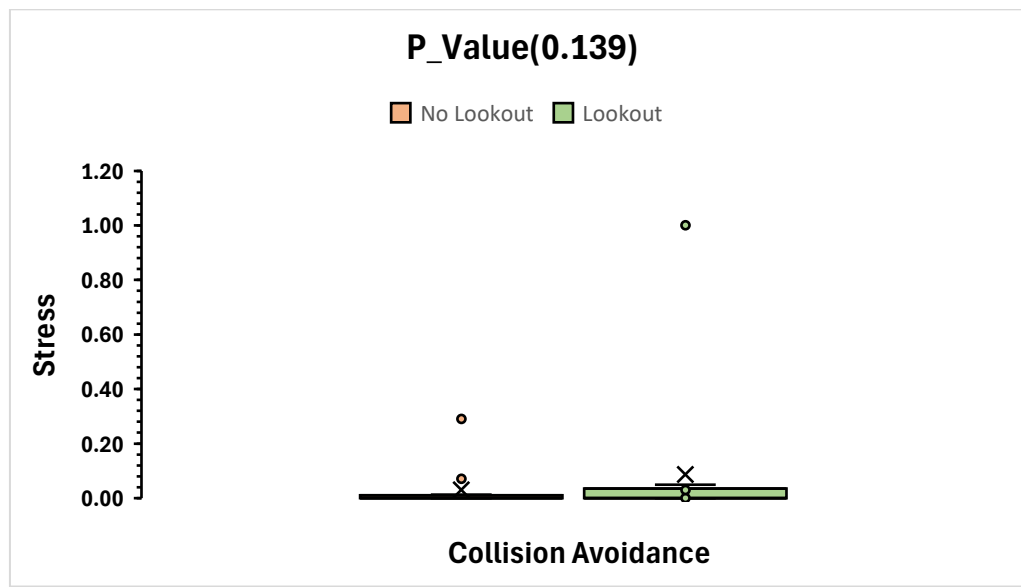


Figure 8.85 Stress collision avoidance

Table 8.28 Descriptive stress for collision avoidance event

Collision Avoidance	Experiment	n	Mean	Median	Standard deviation	Min	Max
	No Lookout	13	0.03	0	0.08	0	0.29
	Lookout	13	0.087	0	0.275	0	1

Overall, the presence of the lookout may increase the stress in certain events because of the communication and coordination required from the participant with the lookout. However, when the participants are able to control and act with the situation, particularly in the collision avoidance event, the stress level tends to be reduced and managed better with the presence of a lookout.

- **Attention**

The assessment of the attention levels will provide a comprehensive view of how the OOW allocated his attention in response to different operational demands. This section will explore how the lookout influenced the OOW's focus and situational awareness during the complex condition.

In the baseline, there was no significant difference in attention levels between the two experiments (P-value = 0.658), Figure 8.86. This suggests that the presence of the lookout does not impact attention in low-demand situations, likely because the minimal cognitive demand does not require high focus.

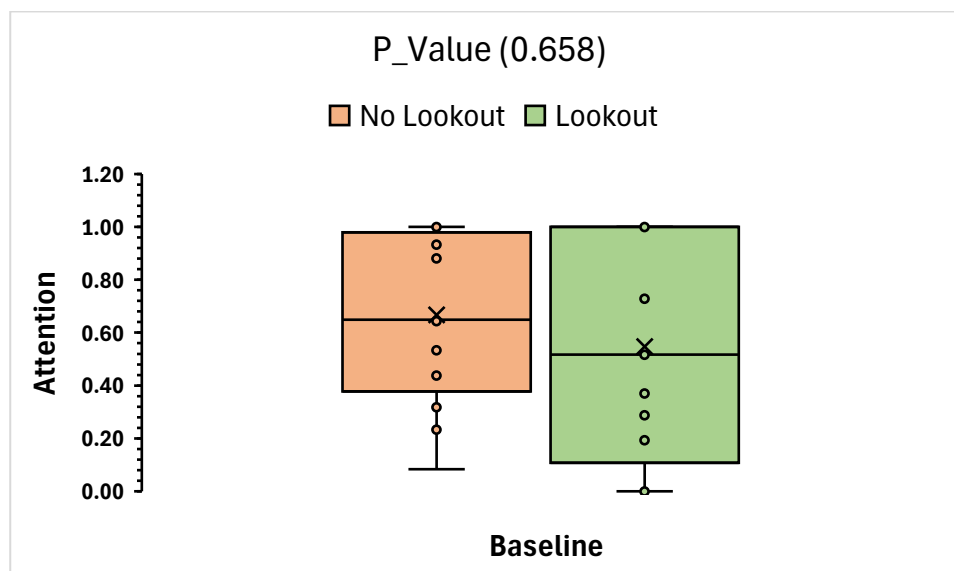


Figure 8.86 Attention baseline

Table 8.29 Descriptive attention for baseline event

Baseline	Experiment	n	Mean	Median	Standard deviation	Min	Max
	No Lookout	13	0.666	0.65	0.324	0.08	1
	Lookout	13	0.548	0.52	0.424	0	1

In addition, during the MV Nowa and MV Diamond vents, there were no significant differences in attention levels between the two groups (P-value =0.863) for MV Nowa and (P-value = 0.181) for MV Diamond), Figure 8.87 and Figure 8.88 respectively.

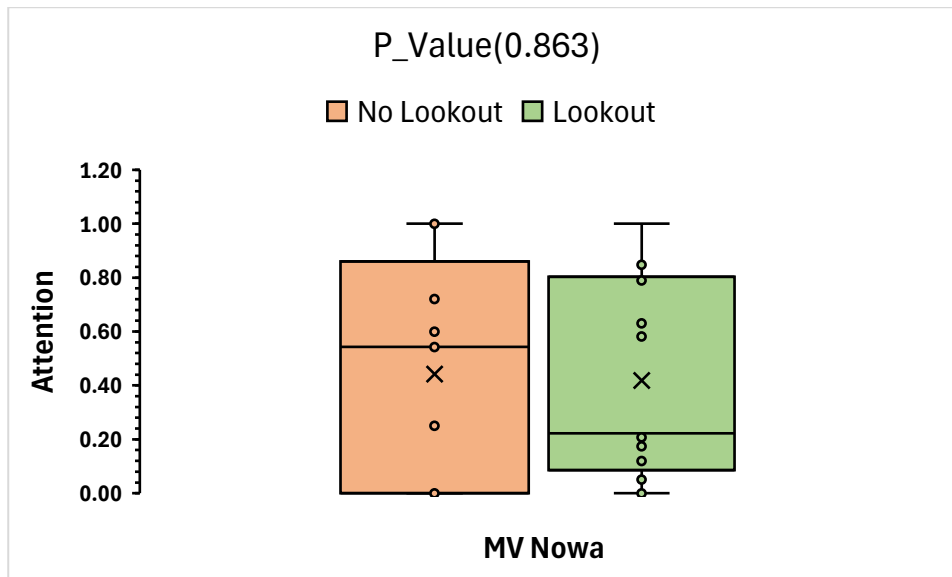


Figure 8.87 Attention MV Nowa

Table 8.30 Descriptive Attention for MV Nowa event

MV Nowa	Experiment	n	Mean	Median	Standard deviation	Min	Max
	No Lookout	13	0.442	0.54	0.418	0	1
	Lookout	13	0.418	0.22	0.367	0	1

These results indicate that participants were able to manage their attention effectively, with or without lookout support, suggesting that the OOW maintained focus independently in these scenarios. However, Table 8.30 illustrated lower attention levels in the participants with the lookout in the MV Nowa event; this reduction might be because the presence of the lookout allows the participant to distribute their focus more around, reducing the individual cognitive demand of monitoring visually and focusing on the navigation equipment more. However, the Table 8.31 showed a remarkable increase in the mean, suggesting that the lookout's presence shifted the participant's attention to increase, especially since MV Diamond was approaching from a stern and the lookout informed the participant of the location and then received communication from MV Diamond, which needed more attention.

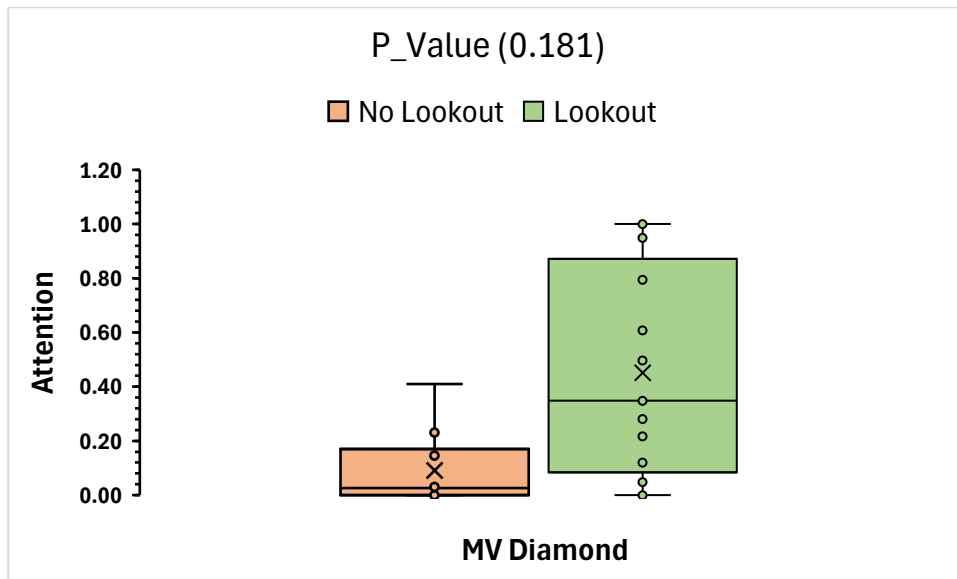


Figure 8.88 Attention Mv Diamond

Table 8.31 Descriptive attention for MV Diamond event

MV Diamond	Experiment	n	Mean	Median	Standard deviation	Min	Max
	No Lookout	13	0.092	0.03	0.127	0	0.41
	Lookout	13	0.452	0.35	0.383	0	1

However, the MV Scot Isles event revealed significant differences in attention (P-value = 0.026), Figure 8.89, with the lookout-assisted group showing a lower mean attention level Table 8.32. This suggests that the presence of a lookout may reduce the need for the OOW to maintain high attention levels, possibly due to a distribution of attentional demand between the OOW and the lookout. Thus, lookout support may ease attentional requirements, enabling the OOW to manage cognitive resources more effectively, which might be one of the reasons that increased the MWL in this event.

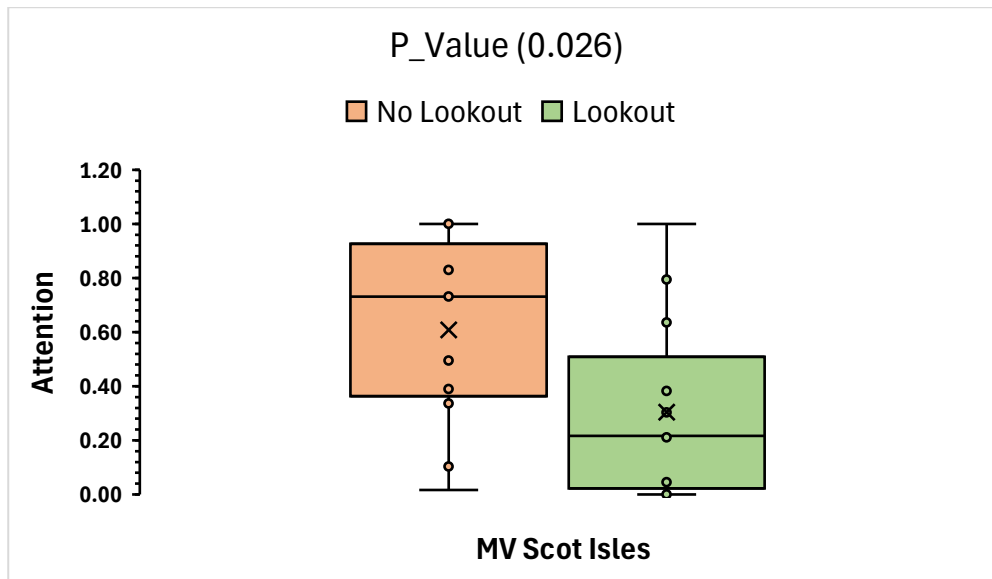


Figure 8.89 Attention MV Scot Isles

Table 8.32 Descriptive attention for MV Scot Isles event

MV Scot Isles	Experiment	n	Mean	Median	Standard deviation	Min	Max
	No Lookout	13	0.608	0.73	0.339	0.02	1
	Lookout	13	0.304	0.22	0.324	0	1

In the collision avoidance event, no significant differences in attention were observed between the two groups (P-value = 0.388), Figure 8.90. However, Table 8.33 showed a lower mean in the group with the lookout, which means less attention. This reduction suggests that the lookout presence may help reduce the need for sustained focus and make the OOW rely on shared situational awareness to manage the high cognitive load, especially when the participants find support to take action. In addition, in this event, participants made the lookout steering manual and gave him orders for steering, which could also help distribute the attention.

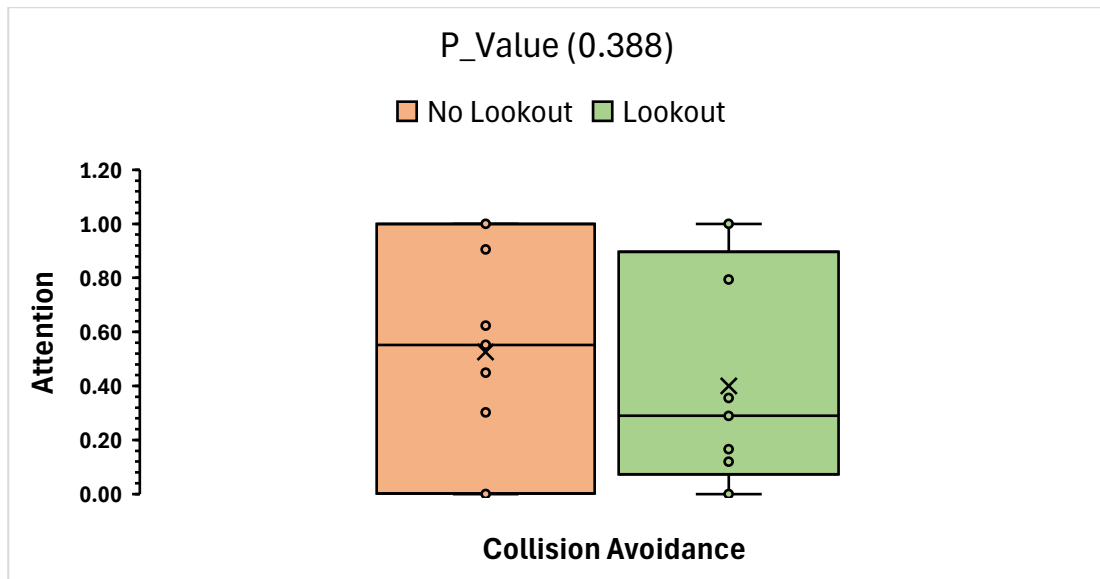


Figure 8.90 Attention collision avoidance

Table 8.33 Descriptive attention for collision avoidance event

Collision Avoidance	Experiment	n	Mean	Median	Standard deviation	Min	Max
	No Lookout	13	0.525	0.55	0.43	0	1
	Lookout	13	0.402	0.29	0.398	0	1

Although there were no significant differences in attention events, participants with the lookout support group generally showed lower attention levels. This may suggest that having a lookout enables the OOW to share attentional tasks, allowing them to focus more effectively on navigating with the bridge equipment.

8.5.3.2 Conclusion

These findings highlight the important role of the lookout in supporting the cognitive demands of the OOW, especially in complex scenarios. While lookout support may increase the cognitive factors in certain events, it eventually reduces the demands when the lookout assists with collision avoidance. This support is particularly valuable when the OOW allocates manual steering to the lookout, allowing the OOW to focus more closely on navigational equipment and maintain visual attention. Therefore, enhancing decision-making efficiency during critical moments. This suggests that the presence of a

lookout in high-demand navigational situations improves OOW's performance by facilitating a more balanced distribution of cognitive tasks across the bridge team and increasing situational awareness.

In the next section, we will illustrate the Eye tracking result and the heat maps for each event to exhibit the visual distribution of the participants during the experiment.

8.5.3.3 Eye Tracking Event-Based

In the context of maritime navigation, understanding where and how the OOW allocates visual attention is crucial for evaluating situational awareness, decision-making, and overall performance. Eye-tracking technology provides a precise method for capturing eye fixation area and visual scanning behaviour, offering insights into the cognitive process underlying navigational tasks. This research utilises eye-tracking data collected from participants across five simulated navigational events, designed to replicate real-world challenges in a ship bridge simulator. This result assesses how visual attention shifts in response to different task demands and environmental factors. This analysis forms a critical component of understanding the impact of the cognitive load and attention on maritime performance, contributing to the development of more effective training protocols for OOW.

- **Baseline Event**

Table 8.34 Eye-Tracking result for baseline event.

Baseline			
	P-value	P-value > 0.05	Result
Eye Left	0.572684	Yes	Not Significant
Eye Right	0.758316	Yes	Not Significant
Display Unit	0.074207	Yes	Not Significant
ECDIS	0.04581	No	Significant
Engine	0.694241	Yes	Not Significant
VHF	0.10545	Yes	Not Significant
RADAR	0.007568	No	Significant
Visualisation	0.796884	Yes	Not Significant
Top Display Unit	0.156896	Yes	Not Significant

In the baseline, Table 8.34, significant differences between solo and lookout assistance experiments were observed regarding ECDIS and Radar usage. Figure 8.91 and Figure 8.92 showed no significant difference in the eye left and eye right metrics, suggesting that the lookout presence did not influence the MWL and the attention during the baseline. However, Table 8.35 and Table 8.36 showed a slight increase in the mean eye pupil size for the participants without a lookout, suggesting that having an assistant might reduce MWL, possibly by providing a sense of support.

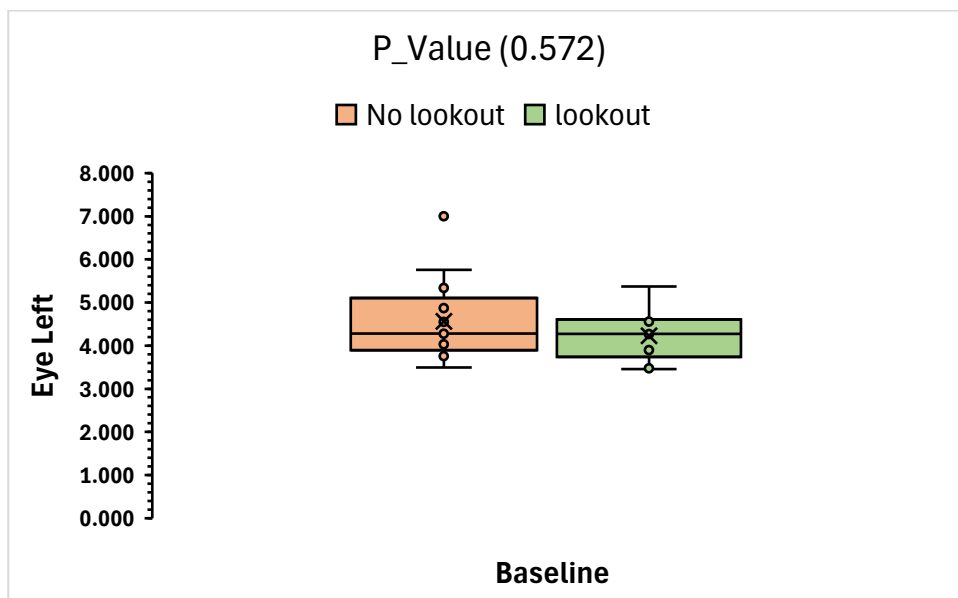


Figure 8.91 Eye left for baseline event

Table 8.35 Eye left descriptive result for baseline

Eye Left	Experiment	n	Mean	Median	Standard deviation	Min	Max
	No Lookout	13	4.563	4.278	0.974	3.494	6.999
	Lookout	13	4.231	4.277	0.553	3.4590	5.369

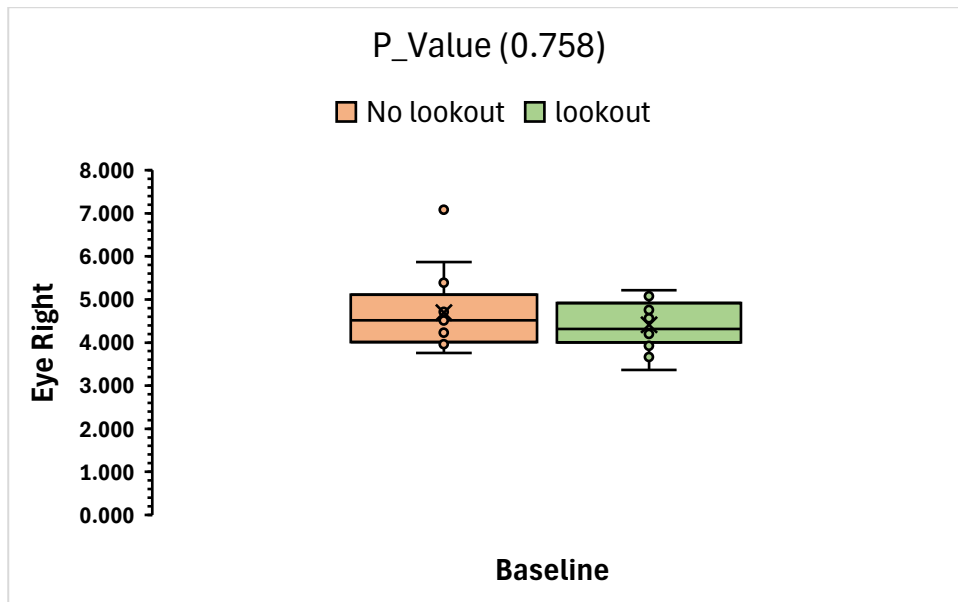


Figure 8.92 Eye right for baseline event

Table 8.36 Eye right descriptive result for baseline

Eye right	Experiment	n	Mean	Median	Standard deviation	Min	Max
	No Lookout	13	4.692	4.515	0.94	3.761	7.089
	Lookout	13	4.41	4.316	0.571	3.362	5.215

There was a significant difference in the usage of the ECDIS and RADAR during the baseline event between the two groups. It shows that participants without lookout paid more attention to the usage of ECDIS and RADAR than the participants with the lookout, as illustrated in Figure 8.93 and Figure 8.94. Table 8.37 showed that the mean is increase in the group without lookout but is close between the two group , indicating that the level of engagement with the ECDIS is similar to each other across this event; this might be due to the need to gather more information independently and maintain situational awareness while participants with a lookout felt less need to focus as they had the lookout support that would help them. However, the mean increase in eye pupil size value in the RADAR, Table 8.38, showed a higher mean value in the group with the lookout, suggesting that the presence of the lookout allowed the participants to engage more with the RADAR monitoring, which could improve the situation awareness and get more familiar with the RADAR.

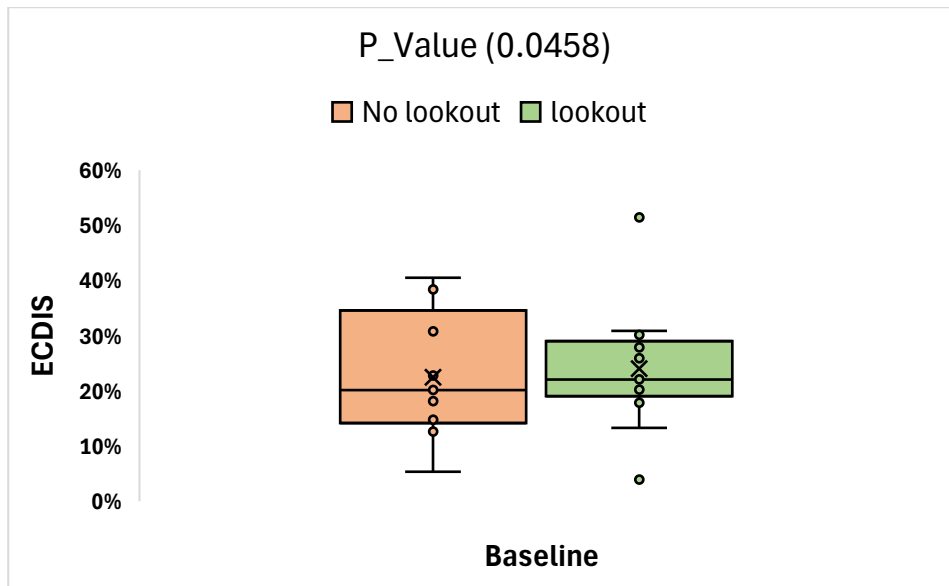


Figure 8.93 ECDIS result for baseline

Table 8.37 ECDIS descriptive result for baseline event

ECDIS	Experiment	n	Mean	Median	Standard deviation	Min	Max
	No Lookout	13	0.225	0.202	0.113	0.053	0.405
	Lookout	13	0.241	0.221	0.11	0.039	0.515

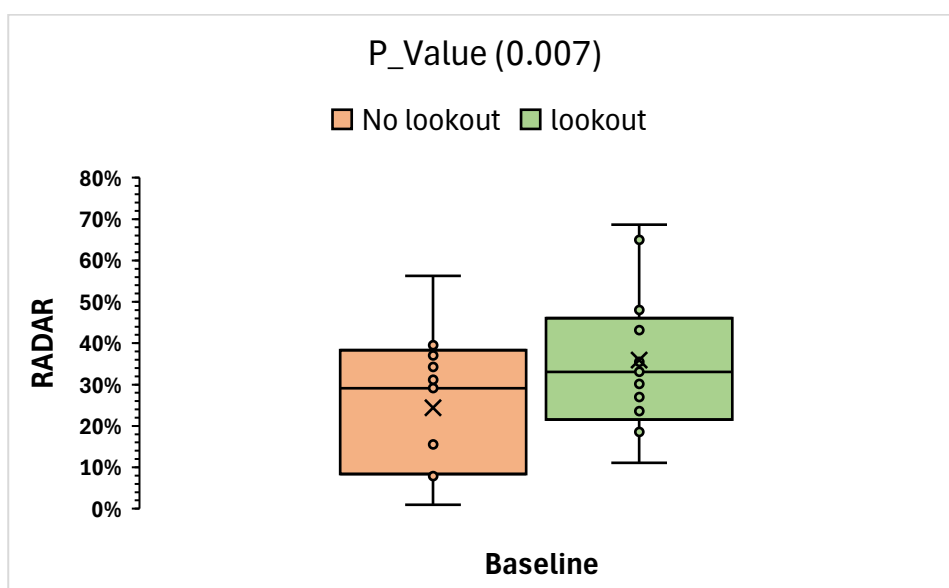


Figure 8.94 RADAR result for baseline

Table 8.38 RADAR descriptive result for baseline event

RADAR	Experiment	n	Mean	Median	Standard deviation	Min	Max
	No Lookout	13	0.244	0.291	0.171	0.009	0.563
	Lookout	13	0.359	0.331	0.174	0.111	0.687

This result is aligned with the baseline purpose of familiarisation and low cognitive demand due to no targets and any risk of collision, where the impact of the lookout on participants' performance is minimal overall. Furthermore, the heat map for both experiments showed that heavily focused on the ECDIS and the RADAR. In the visual distribution, the second experiment with the lookout demonstrated a border distribution across the surrounding area, which suggests that the presence of the lookout influences their visual attention Figure 8.95 and Figure 8.96.



Figure 8.95 Baseline heat map for the first experiment



Figure 8.96 Baseline heat map for the second experiment

- **MV Nowa Event**

Table 8.39 Eye-Tracking result for MV Nowa

MV Nowa			
	P-value	P-value > 0.05	Result
Eye Left	0.182422	Yes	Not Significant
Eye Right	0.166098	Yes	Not Significant
Display Unit	0.32251	Yes	Not Significant
ECDIS	0.557477	Yes	Not Significant
Engine	0.650507	Yes	Not Significant
VHF	0.177878	Yes	Not Significant
RADAR	0.111641	Yes	Not Significant
Visualisation	0.00033	No	Significant
Top Display Unit	0.346753	Yes	Not Significant

During the MV Nowa event, there were no significant results except with the visualisation, which is the screens to check the surroundings observed significant results, Table 8.39. However, the left and right eyes did not reveal a significant difference; the mean value in the participants without a lookout was higher than in the participants with a lookout, Table 8.40 and Table 8.41. This indicates that the participants without a lookout received more MWL and attention when the targets began to appear. In addition, the slight increase in the mean value suggests that solo OOWs may need to expand their

scanning range to ensure comprehensive environmental monitoring, possibly because of the absence of additional support.

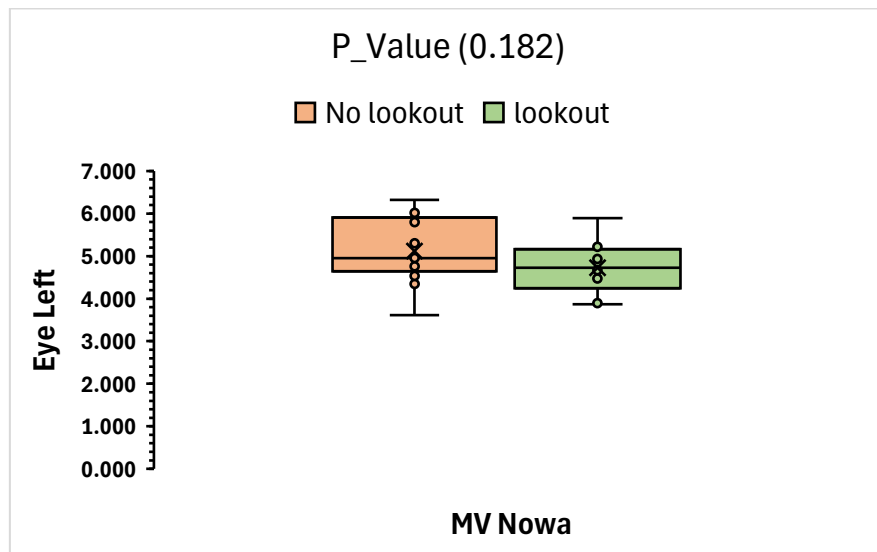


Figure 8.97 Eye left result in MV Nowa event

Table 8.40 Eye left descriptive result for MV Nowa event

Eye Left	Experiment	n	Mean	Median	Standard deviation	Min	Max
	No Lookout	13	5.116	4.954	0.782	3.617	6.319
	Lookout	13	4.727	4.726	0.594	3.87	5.894

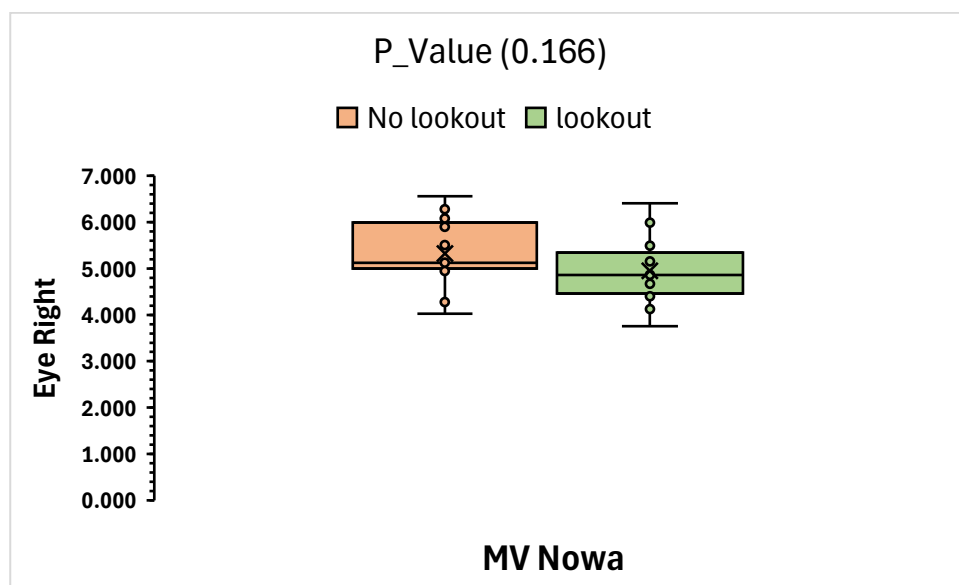


Figure 8.98 Eye right result in MV Nowa event

Table 8.41 Eye right descriptive result for MV Nowa event

Eye Right	Experiment	n	Mean	Median	Standard deviation	Min	Max
Eye Right	No Lookout	13	5.324	5.125	0.738	4.024	6.559
	Lookout	13	4.951	4.864	0.725	3.758	6.411

A notable difference is observed in the visualisation with the (P-value= 0.00033), Figure 8.99, where the participants without lookout have a mean increase in eye pupil size of (0.202). This is significantly higher than the participant with the lookout with the mean value of (0.023), Table 8.42, indicating that participants did not look at the visualisation display when a lookout was present. This suggests that OOWs rely more on visualisation displays to gather more information about the surroundings, which is associated with the need for more comprehensive monitoring without assistance. On the other hand, OOWs with lookout rely less on the visualisation display, possibly due to the support provided by the lookout in maintaining awareness of the surrounding environment.

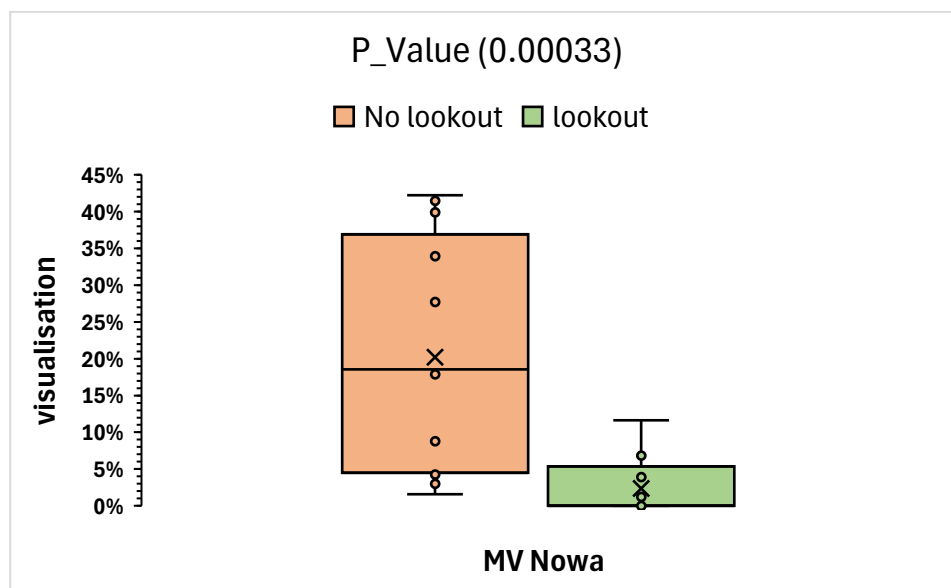


Figure 8.99 Visualisation for the MV Nowa event

Table 8.42 Visualisation descriptive result for MV Nowa event

Visualisation	Experiment	n	Mean	Median	Standard deviation	Min	Max
Visualisation	No Lookout	13	0.202	0.186	0.154	0.016	0.422
	Lookout	13	0.023	0	0.038	0	0.116

The heatmap also shows that OOWs who navigate solo show a tendency to rely more on the navigational display and visual aids, while the participant with lookout distribute their visuals differently, Figure 8.100 and Figure 8.101. Overall, the MV Nowa event supports the view that the lookout's presence can reduce the OOW's visual and cognitive load, allowing for a more focused and less extensive scanning pattern.



Figure 8.100 MV Nowa heat map for the first experiment



Figure 8.101 MV Nowa heat map for the second experiment

- **MV Diamond Event**

Table 8.43 Eye-Tracking result for MV Diamond event

MV Dimond			
	P-value	P-value > 0.05	Result
Eye Left	0.021711	No	Significant
Eye Right	0.016733	No	Significant
Display Unit	0.97846	Yes	Not Significant
ECDIS	0.850094	Yes	Not Significant
Engine	1	Yes	Not Significant
VHF	0.775525	Yes	Not Significant
RADAR	0.010659	No	Significant
Visualisation	0.00027	No	Significant
Top Display Unit	0.509422	Yes	Not Significant

Multiple significant differences were observed during the MV Diamond event as the scenario got complex. MV Diamond event observed in both eyes, RADAR, and the visualisation were significant. This suggests that the lookout influences the eyes' size and focus on the navigation equipment, which impacts the participants' cognitive demand and behaviour.

Both eyes show significant differences between the solo participants and the participants with a lookout. The (P-value= 0.217) for the left eye and (P-value=0.0167) for the right eye, Figure 8.102 and Figure 8.103. The mean value in the groups without a lookout was higher than the mean value of the group with a lookout, Table 8.44 and Table 8.45. This indicates that the participants who navigated solo experienced more MWL and paid more attention than those who navigated with the assistant "lookout". This consistency in both eyes suggests that solo OOWs adopted more visual scanning to ensure safe surroundings and maintain situational awareness without a lookout. On the other hand, the participants with the lookout focused more on the navigation equipment because they had an assistant who could observe visually and inform them in case any potential risk appeared, which reduced their MWL.

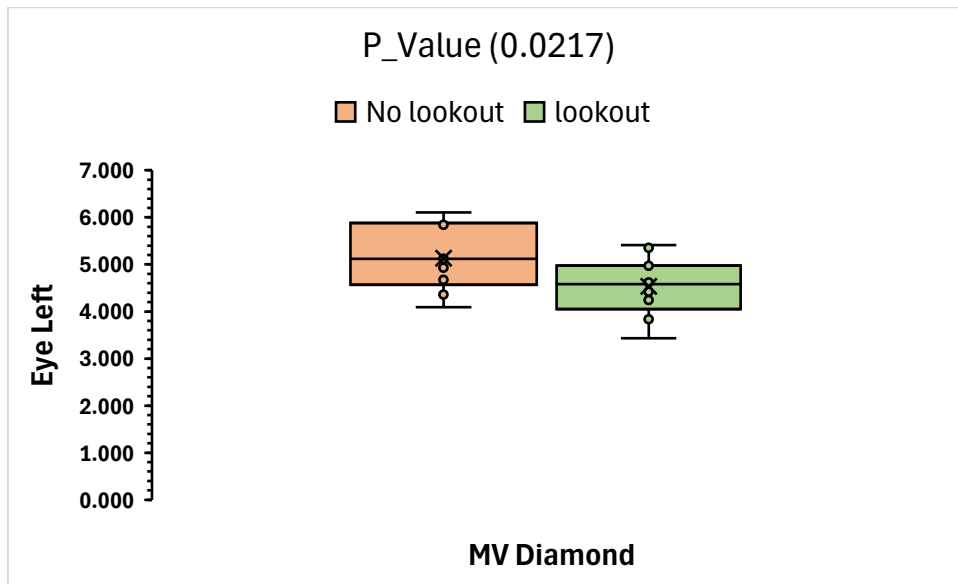


Figure 8.102 Eye left for the MV Diamond event

Table 8.44 Eye left descriptive result for MV Diamond event

Eye Left	Experiment	n	Mean	Median	Standard deviation	Min	Max
	No Lookout	13	5.132	5.122	0.652	4.095	6.106
	Lookout	13	4.534	4.58	0.587	3.432	5.409

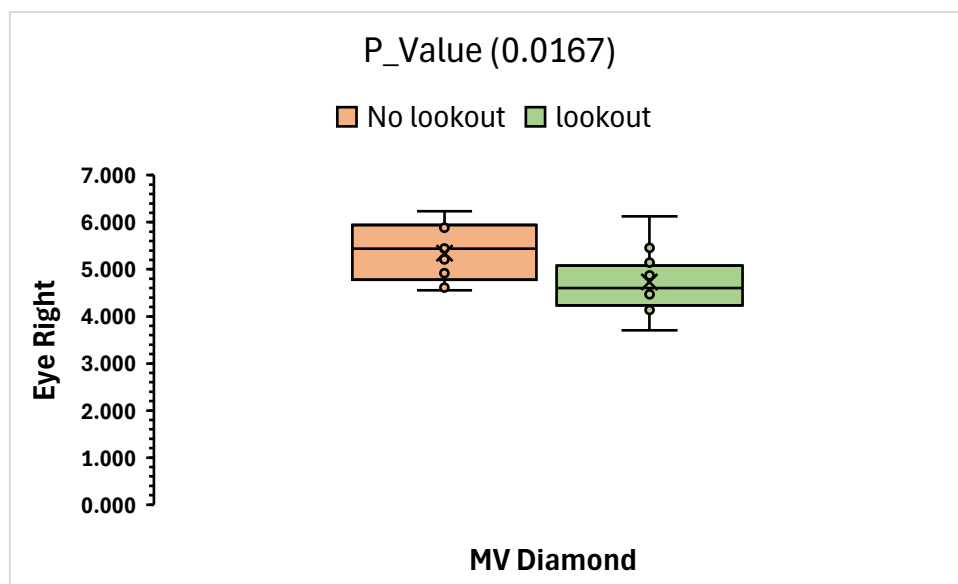


Figure 8.103 Eye right for the MV Diamond event

Table 8.45 Eye right descriptive result for MV Diamond event

Eye Right	Experiment	n	Mean	Median	Standard deviation	Min	Max
Eye Right	No Lookout	13	5.344	5.44	0.58	4.556	6.233
	Lookout	13	4.732	4.604	0.633	3.703	6.124

Moreover, the RADAR equipment usage also revealed a significant difference as the (P-Value=0.010659), Figure 8.104. The mean increase in the pupil size value of the participants without lookout showed a higher value than the participants with the lookout, Table 8.46. This indicates and aligns with what we mentioned: having a lookout enables the OOW to engage more with the RADAR, possibly because the lookout supports monitoring the surroundings, allowing the OOW to focus more attention on the radar for precise navigation and situational awareness.

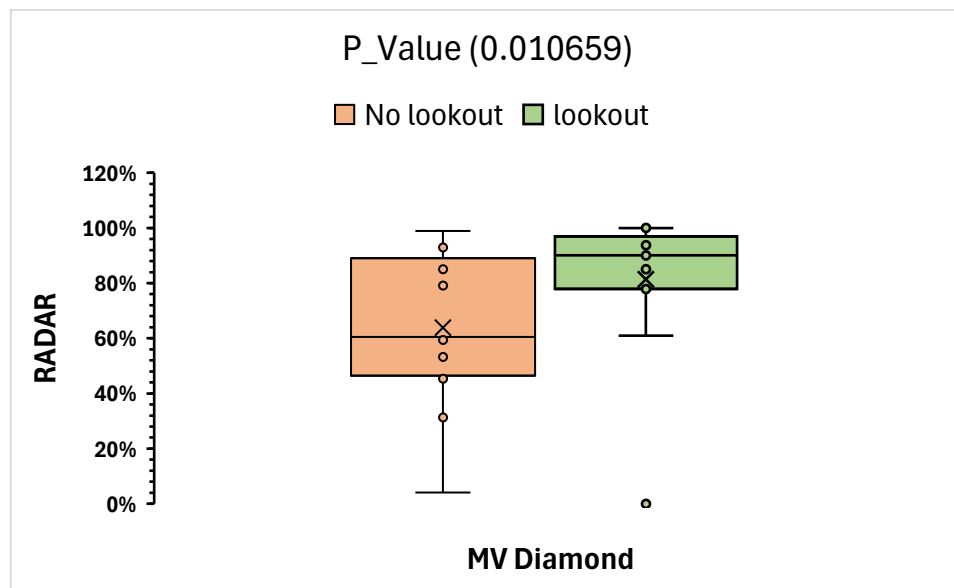


Figure 8.104 RADAR for the MV Diamond event

Table 8.46 RADAR descriptive result for MV Diamond

RADAR	Experiment	n	Mean	Median	Standard deviation	Min	Max
RADAR	No Lookout	13	0.639	0.605	0.278	0.041	0.989
	Lookout	13	0.815	0.901	0.269	0	1

Furthermore, the screen visualisation showed a significant difference with (P-value= 0.00027), Figure 8.105, with the group without the lookout having a higher means value than the group with the lookout, Table 8.47. This also indicates, as we mentioned, that the participants without the lookout engaged more in the visualisation to observe the surrounding environment. In contrast, the group with the lookout depended on the lookout for surrounding environment monitoring. Therefore, solo navigation gathers additional information independently, which impacts OOWs' MWL.

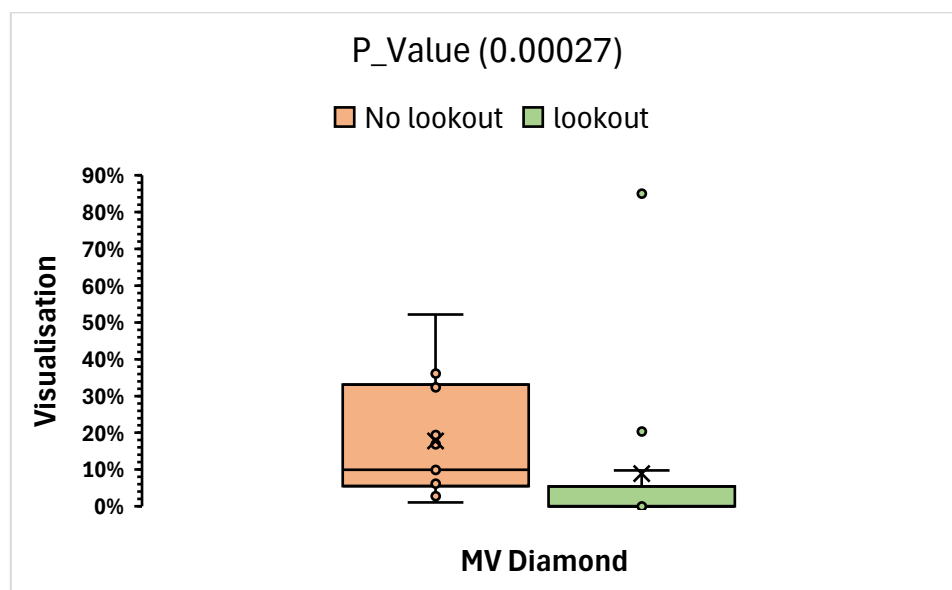


Figure 8.105 Visualisation for the MV Diamond event

Table 8.47 Visualisation descriptive result for MV Diamond event

Visualisation	Experiment	n	Mean	Median	Standard deviation	Min	Max
	No Lookout	13	0.178	0.099	0.16	0.011	0.521
	Lookout	13	0.089	0	0.236	0	0.85

These findings align with the observation that a lookout's presence helps distribute the visual and cognitive workload, enabling more focused attention on critical navigation tools. This event emphasises the importance of team-based situational awareness in maritime navigation. Also, the heat maps with the result shown in Figure 8.106 and Figure 8.107 that the second group with the lookout showed more distribution on the visualisation and more focus on the radar.



Figure 8.106 MV Diamond heat map for the first experiment



Figure 8.107 MV Diamond heat map for the second experiment

- **MV Scot Isles Event**

Table 8.48 Eye-Tracking result for MV Scot Isles

MV Scot Isles			
	P-value	P-value > 0.05	Result
Eye Left	0.057004	Yes	Not Significant
Eye Right	0.052425	Yes	Not Significant
Display Unit	0.096198	Yes	Not Significant
ECDIS	0.872897	Yes	Not Significant
Engine	1	Yes	Not Significant
VHF	0.677955	Yes	Not Significant
RADAR	0.0239	No	Significant
Visualisation	0.00092	No	Significant
Top Display Unit	0.209762	Yes	Not Significant

During the MV Scot Isles event, the p-value of the eye left is (0.0570), and for the eye right is (0.0584), indicating that there are no significant differences, Figure 8.108 and Figure 8.109. However, the p-value was too close to be significant. The author believes that if the size of the samples were bigger, more accurate results could be obtained. Even though there was no significant difference in the p-value, the mean value showed that the participants with the lookout were higher than the participants with the lookout, Table 8.49 and Table 8.50. This suggests that the solo navigation caused more MWL and attention during this event, especially when the participants did not receive a response when communicating with the MV Scot Isles and could not receive support from anybody. While communicating, this would not impact their eye size but could influence the cognitive demands and behaviour of the participants.

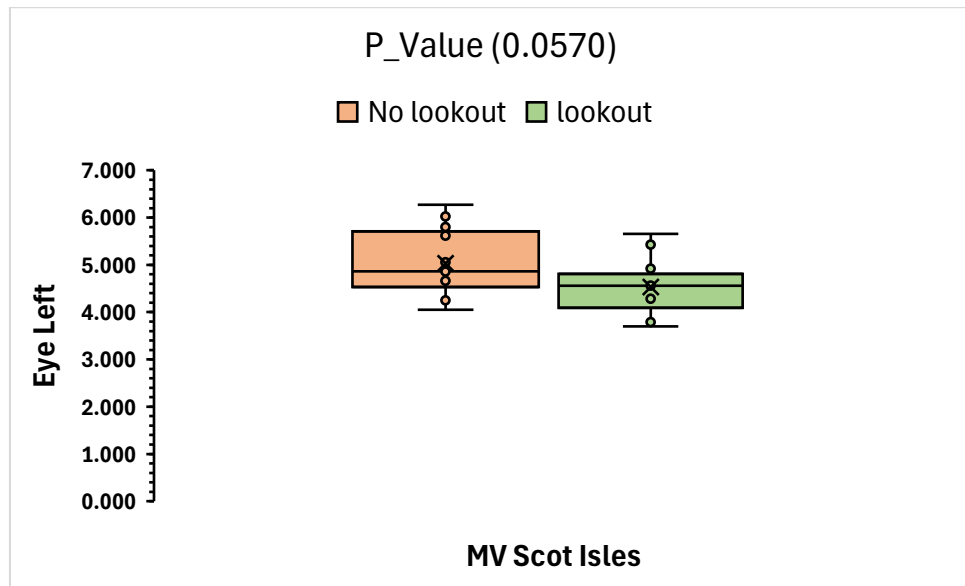


Figure 8.108 Eye left for MV Scot Isles event

Table 8.49 Eye left descriptive result for MV Scot Isles

Eye Left	Experiment	n	Mean	Median	Standard deviation	Min	Max
	No Lookout	13	5.033	4.861	0.692	4.053	6.271
	Lookout	13	4.533	4.559	0.576	3.695	5.655

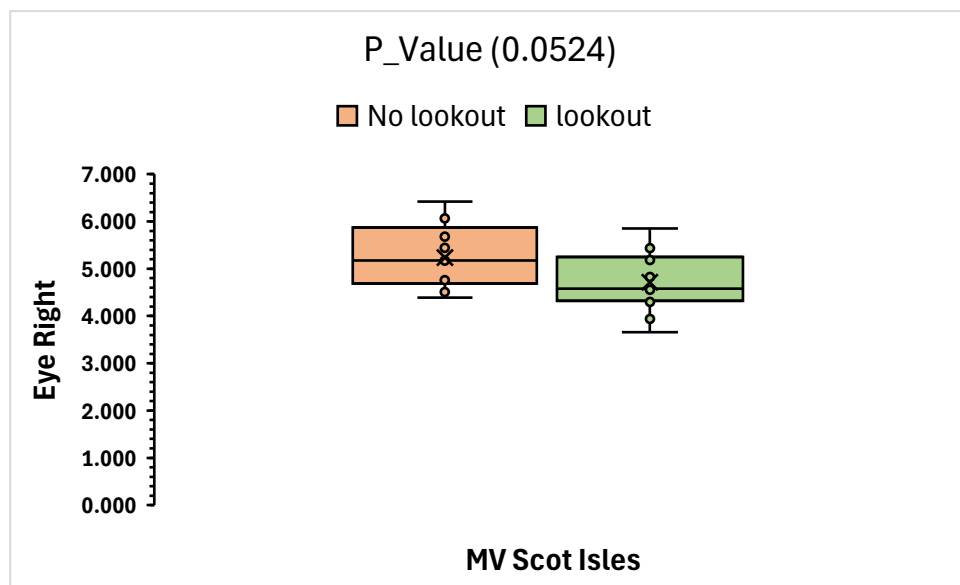


Figure 8.109 Eye right for MV Scot Isles event

Table 8.50 Eye right descriptive result for Mv Scot Isles event

Eye Right	Experiment	n	Mean	Median	Standard deviation	Min	Max
Eye Right	No Lookout	13	5.233	5.172	0.667	4.389	6.423
	Lookout	13	4.716	4.579	0.623	3.661	5.853

In addition, The RADAR utilisation in the MV Scot Isles event still shows a significant difference with the (P-value=0.0239), Figure 8.110. The mean value in the group with the lookout higher than the mean value in the group without a lookout, Table 8.51. This suggests that the presence of the lookout allows the OOW to allocate more attention to the RADAR display, possibly to focus more on gathering and monitoring precise data while relying on the lookout for surrounding environmental monitoring.

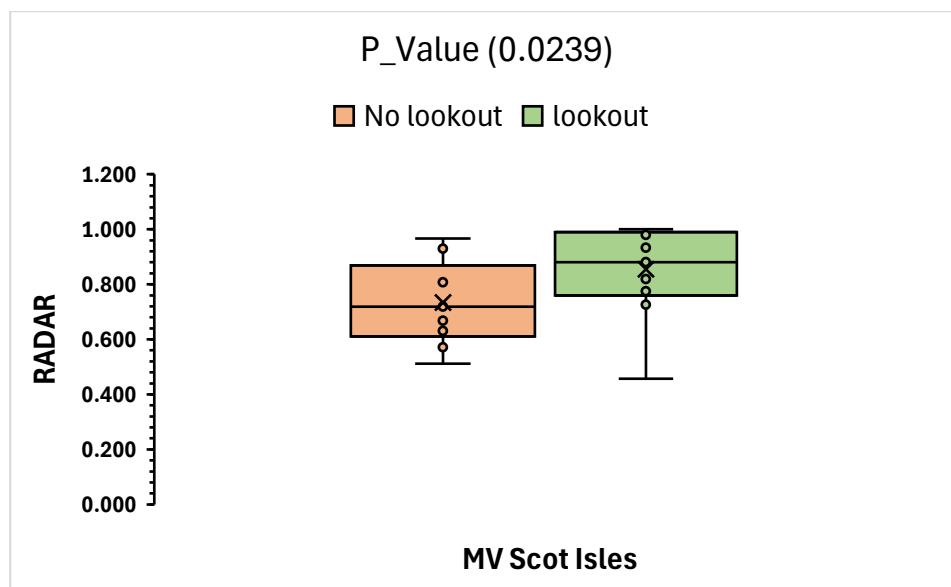


Figure 8.110 RADAR for MV Scot Isles event

Table 8.51 RADAR descriptive result for MV Scot Isles event

RADAR	Experiment	n	Mean	Median	Standard deviation	Min	Max
RADAR	No Lookout	13	0.734	0.719	0.148	0.512	0.966
	Lookout	13	0.855	0.881	0.156	0.457	1

Furthermore, the utilization of the screen visualization showed a notable contrast between the two groups with (p-value=0.00092). In addition, the mean value showed that the group without a lookout had a higher value than the group with a lookout, Table 8.52. This suggests that participants with a lookout focused more on the navigation equipment. In contrast, the participants without a lookout focused more on the visualisation with navigation equipment to maintain situational awareness as they did not have support to help them monitor the targets visually.

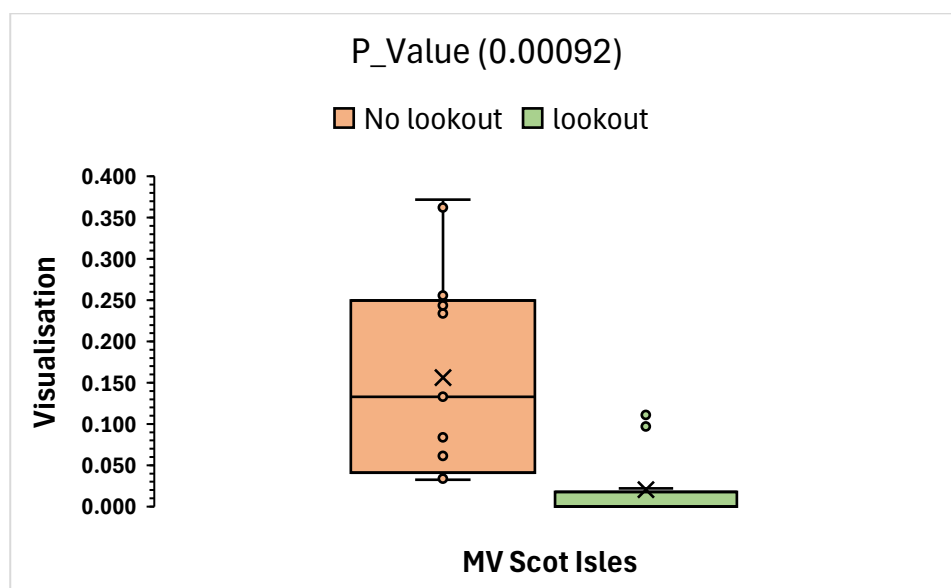


Figure 8.111 Visualisation for MV Scot Isles event

Table 8.52 Visualisation descriptive result for MV Scot Isles event

	Experiment	n	Mean	Median	Standard deviation	Min	Max
Visualisation	No Lookout	13	0.156	0.133	0.124	0.033	0.372
	Lookout	13	0.021	0	0.038	0	0.111

Also, the heat maps with the result shown in Figure 8.112 and Figure 8.113 that the second group with the lookout showed more distribution on the visualisation and more focus on the radar, while the group without a lookout showed that they were observed more in the ECDIS and the display unit (Conning display) as they did not have an assistant to support them.



Figure 8.112 MV Scot Isles heat map for first experiment



Figure 8.113 MV Scot Isles heat map for second experiment

- **Collision Avoidance Event**

Table 8.53 Eye-Tracking result for collision avoidance

Collision Avoidance			
	P-value	P-value > 0.05	Result
Eye Left	0.093924	Yes	Not Significant
Eye Right	0.094597	Yes	Not Significant
Display Unit	0.003733	No	Significant
ECDIS	0.238128	Yes	Not Significant
Engine	0.075544	Yes	Not Significant
VHF	0.415214	Yes	Not Significant
RADAR	0.008913	No	Significant
Visualisation	0.000264	No	Significant
Top Display Unit	0.0239	No	Significant

During collision avoidance events, there were more significant observations as the participants took action to avoid a collision, indicating that the lookout's presence influences their behaviour. However, both eyes did not observe a significant difference, but still, the participants without a lookout got higher MWL and attention as a mean value was higher than the participants with a lookout, Table 8.54 and Table 8.55. This suggests that solo navigation needs wider scanning and interaction with the ship bridge environment to maintain a comprehensive awareness of the environment. This is essential in high-demand scenarios where immediate situational awareness is crucial. On the other hand, the participants with the lookout can focus more on critical equipment as they have an assistant that supports them for observation.

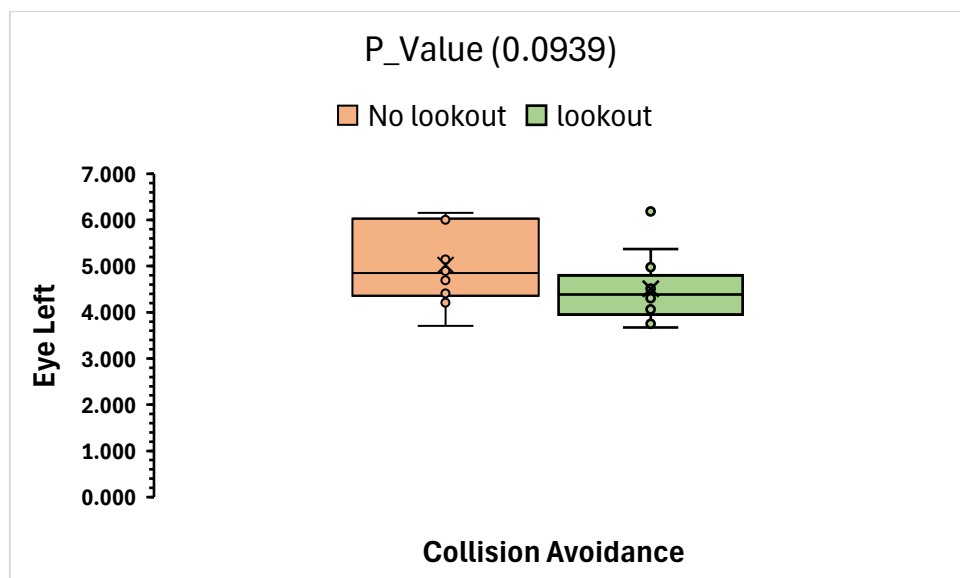


Figure 8.114 Eye left for collision avoidance event

Table 8.54 Eye left descriptive result for collision avoidance event

Eye Left	Experiment	n	Mean	Median	Standard deviation	Min	Max
	No Lookout	13	5.026	4.849	0.81	3.706	6.151
	Lookout	13	4.509	4.385	0.696	3.67	6.184

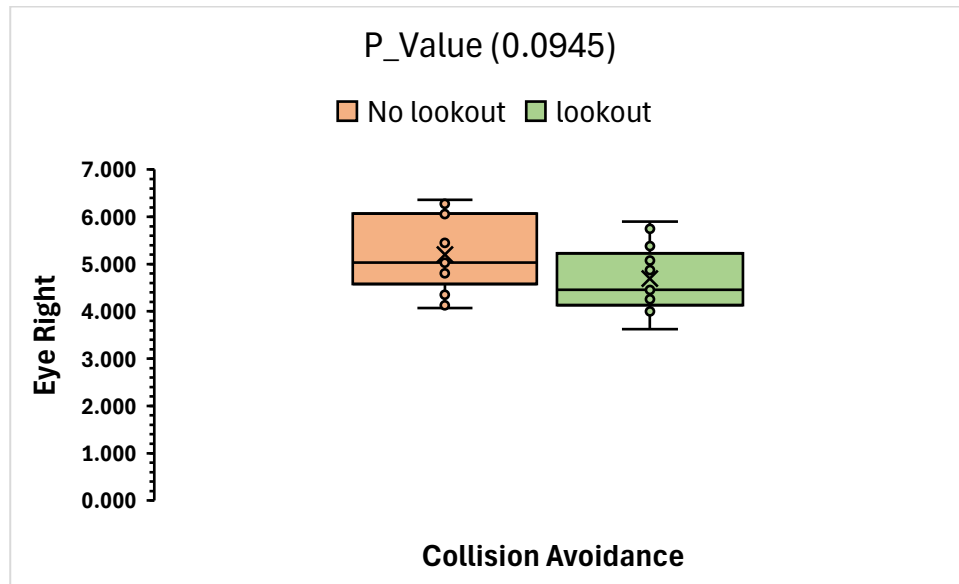


Figure 8.115 Eye right for collision avoidance event

Table 8.55 Eye right descriptive result for collision avoidance event

Eye Right	Experiment	n	Mean	Median	Standard deviation	Min	Max
	No Lookout	13	5.205	5.029	0.792	4.074	6.361
	Lookout	13	4.695	4.458	0.7	3.624	5.901

The display unit engagement in the collision avoidance event shows a substantial difference between the two experiments. The p-value was (0.0037), Figure 8.116, with the mean value in the group without lookout significantly higher than the group with the lookout, Table 8.56. This indicates that participants navigated solo, engaged, and relied more on the display unit. This occurred because participants without a lookout were usually required to steer manually in response to the risk of collision, which needed their direct monitoring and observation of ship information from the display unit. In contrast, participants with a lookout assigned the manual steering task to the lookout, who also provided critical information

from the display unite. This assignment allowed the participants to shift their attention to other navigational equipment, enabling them to focus on monitoring targets and making decision.

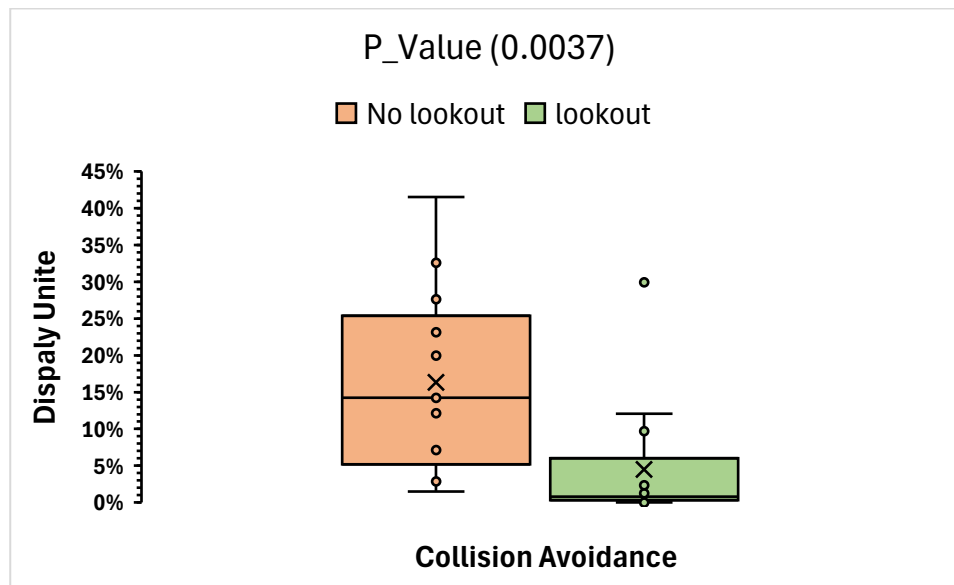


Figure 8.116 Display unit for collision avoidance event

Table 8.56 Display unit descriptive result for collision avoidance event

Display Unit	Experiment	n	Mean	Median	Standard deviation	Min	Max
	No Lookout	13	0.164	0.142	0.122	0.015	0.415
	Lookout	13	0.045	0.008	0.086	0	0.299

Moreover, the analysis of the RADAR utilisation revealed significant differences between the two groups, with the (p-value=0.008913) Figure 8.117. The mean value of the RADAR utilisation was greater in the group with the lookout compared to the group without a lookout, Table 8.57. This finding aligns with the result observed for the display unit, emphasising the critical role of the lookout present. The presence of the lookout allowed participants to focus more on the RADAR, as they could delegate tasks and rely on the lookout for additional monitoring and information sharing. On the other hand, participants without a lookout were unable to effectively monitor multiple pieces of equipment during critical situations, as their attention was focused on the manual steering and observing the targets visually.

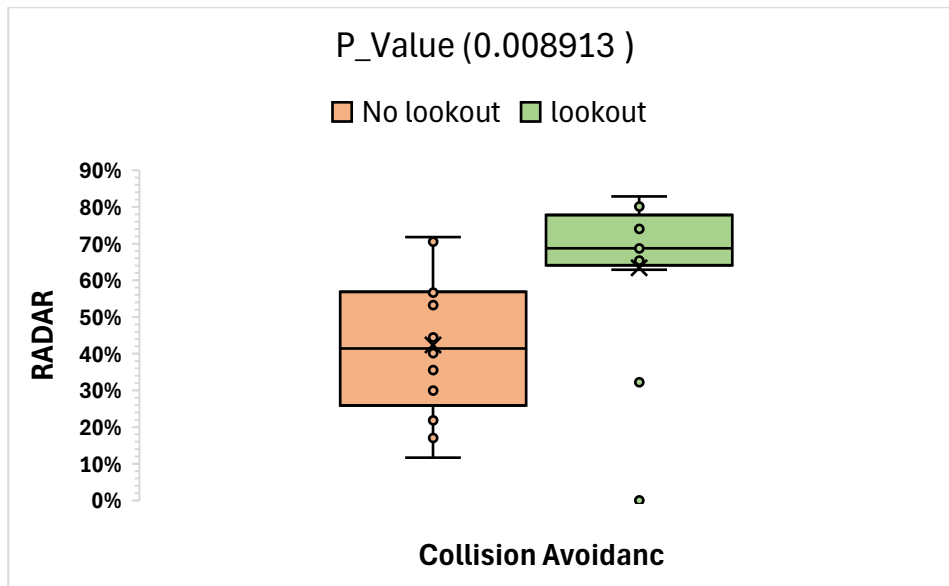


Figure 8.117 RADAR for collision avoidance event

Table 8.57 RADAR descriptive result for collision avoidance event

RADAR	Experiment	n	Mean	Median	Standard deviation	Min	Max
	No Lookout	13	0.424	0.414	0.192	0.117	0.718
	Lookout	13	0.634	0.687	0.229	0	0.829

Furthermore, the analysis of the visualisation engagement revealed significant differences between the two groups, with a (P-value=0.000264) Figure 8.118. The mean visualisation usage was higher in the group without a lookout compared to the group with a lookout, Table 8.58. This finding highlights that participants without lookout relied more on visualisation screens to gather additional visual information and maintain situational awareness, compensating for the absence of external observation support. On the contrary, in the presence of the lookout, the reduced engagement with visualisation screens suggests that OOW could rely on the lookout to provide critical visual information. This shift allowed the OOW to focus on other essential navigation equipment, optimising their attention allocation during the high-demand collision avoidance scenario.

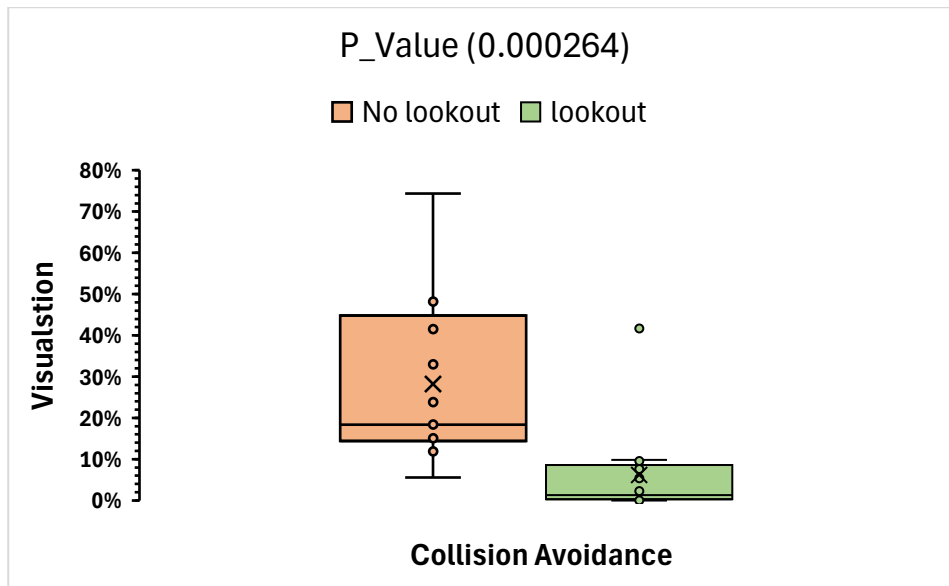


Figure 8.118 Visualisation for collision avoidance event

Table 8.58 Visualisation descriptive result for collision avoidance event

	Experiment	n	Mean	Median	Standard deviation	Min	Max
Visualisation	No Lookout	13	0.282	0.184	0.2	0.055	0.744
	Lookout	13	0.061	0.013	0.113	0	0.417

The analysis of the top display unit illustrates significant differences, with the (P-value= 0.0239) Figure 8.119. The mean value engagement with the top display unit was higher in the group with the lookout compared to the solo participants, Table 8.59. This increased engagement suggests that the presence of the lookout allowed participants to utilise additional resources to enhance their situational awareness. The lookout's contribution to core monitoring tasks likely enabled participants to access and integrate more information from top display units while they were monitoring other critical navigation equipment, such as radar, particularly during complex situations.

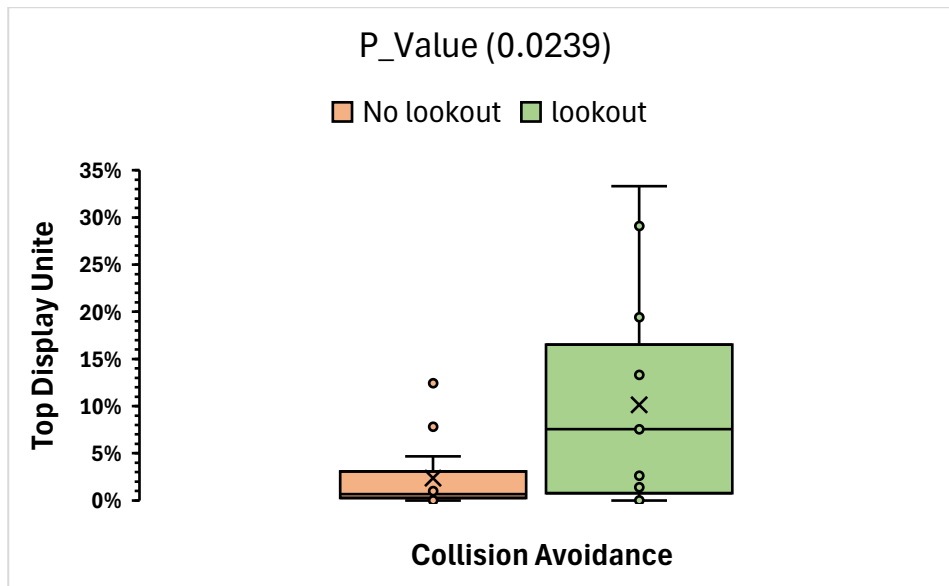


Figure 8.119 Top display unit for collision avoidance event

Table 8.59 Top display unit descriptive result for collision avoidance event

Top Display Unit	Experiment	n	Mean	Median	Standard deviation	Min	Max
	No Lookout	13	0.024	0.007	0.038	0	0.124
	Lookout	13	0.101	0.076	0.112	0	0.333

In addition, the heat map illustrates the distribution of attention and observation between the two groups during the collision avoidance event. In the group without a lookout, participants focused more intensively on the display unit after getting information from the radar. This increased attention can be attributed to their need to steer manually and then rely solely on the information provided by the display unit to navigate and manage the situation, Figure 8.120. On the other hand, participants in the group with the lookout showed a more distributed pattern of attention, Figure 8.121. They engaged more with the top display unit and extensively monitored the radar and ECDIS. This wider focus was facilitated by the presence of the lookout, who provided additional support by steering manually and sharing critical information. With the lookout's assistance, participants could allocate their attention across multiple equipment and displays while also moving around the ship bridge to monitor the surroundings effectively. This highlights that the presence of the lookout enables more comprehensive situational awareness during high-demand situations.



Figure 8.120 Collision avoidance heat map for the first experiment



Figure 8.121 Collision avoidance heat map for the second experiment

8.5.4 Discussion

The findings of this study provide valuable insights into the cognitive demands and behavioural response of the (OOW) during a simulated ship bridge scenario, particularly in a complex situation. The analysis highlights how the presence of a lookout influences the OOW's performance and behaviour across the five experimental events. The EEG results revealed notable variations in MWL, stress, and attention. MWL and stress levels were initially high in certain events despite the presence of the lookout. Still, they were eventually reduced at some points with the Scot Isles and collision avoidance events.

This reduction suggests that the lookout plays a critical role in managing situational awareness and improving cognitive demands during high-risk scenarios. However, attention levels were high in only one event, MV Diamond, which is also a complex situation, and different communication occurred with the lookout. However, it was generally low with the group with a lookout in the other events. Indicating a shift in the participants' focus. This shift, the author believes, likely reflects the OOW's reliance on the lookout to monitor the surroundings, allowing the participants to prioritise other critical areas, such as navigation and system management.

The eye-tracking result complements these findings by demonstrating how participants engaged with the ship bridge equipment and how MWL and attention were influenced by visual behaviour, including pupil dilation. While pupil size was not significant in most events, it showed significance during the MV Diamond event, which involved high complexity, and came close to significant during the MV Scot Isles event, where communication failure required immediate action. A larger sample size may have provided more precise results in these scenarios. Additionally, mean MWL values revealed that participants with lookout experienced lower cognitive demand, reinforcing the lookout's role in reducing mental strain and enhancing situational awareness in critical situations.

The analysis of eye-tracking data and heat maps for each event further highlighted differences in equipment utilisation between the two groups, especially with the last event, where the participants needed to take action to avoid a collision. Participants with the lookout spent more time engaging with the critical equipment, such as the RADAR and top display unit and utilised a wider range of resources on the ship bridge. The lookout support allowed these participants to move freely across the ship bridge, monitor multiple systems, and focus on essential navigational tasks. In contrast, solo participants were more restricted, particularly when steering manually. They had to remain stationary, focusing on visual observation and relying heavily on the display unit in front of them to gather information. This limitation underscores the cognitive and physical issues placed on solo participants, emphasising the crucial role of the lookout in enabling more efficient monitoring and task management.

8.5.4.1 Conclusions

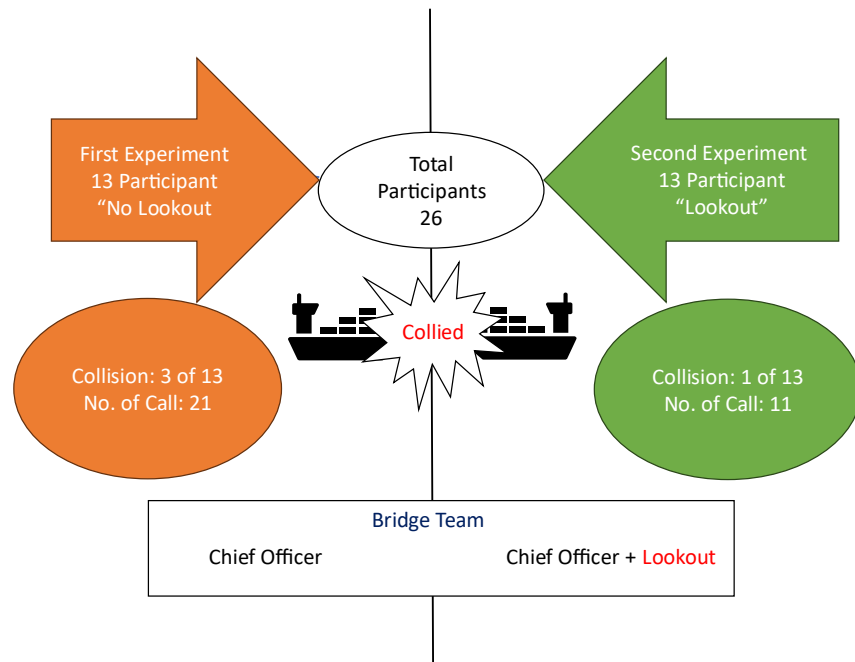


Figure 8.122 the result of the data experiments

After analysing all the participants and getting the result, collision rate, communication and near-miss frequency with the target ship were key indicators of participant performance during both experiments. A total of 26 participants were involved in the study, with comparisons made between scenarios where the OOW navigated solo and when assisted by the lookout. The results demonstrated a meaningful impact of lookout intervention and increased bridge manning, Figure 8.122. The collision rate decreased by 61% when a lookout was present, highlighting the effectiveness of a lookout in reducing collision risk. Furthermore, communication patterns were analysed by comparing the number of calls made in both scenarios. In the first experiment, 21 calls were recorded, while only 11 calls were recorded in the second experiment. This reflects a 56% reduction in call frequency when the lookout is present; this suggests that the presence of the lookout reduces the need for direct communication. This might be because the OOW can rely more on the lookout for observation and reports. This allows the OOW to dedicate more attention to navigation and operational tasks. Moreover, near misses were defined as situations where the ship passed clearly but at a distance of less than 0.2 nautical miles (nm). In the first experiment, while the participants navigated solo, they recorded 3 near misses and 3 collisions. The

total risk of collision faced during this set of experiments was 6, which is a 50% result in actual collision. On the other hand, the second set of experiments performed with the lookout recorded 4 near misses and 1 collision. The total risk of collision was 5 with only 20% resulting in a collision.

These findings demonstrate that the lookout not only enhances situational awareness and safety but also contributes to more efficient bridge operations by reducing the cognitive and communication workload of the OOW. However, the result showed a slight increase in near misses compared to the solo navigation scenario. Also, the result supports the importance of effective teamwork and the lookout's role in optimising overall bridge performance and reducing collision, especially in -high-demand scenarios.

Chapter 9 Discussion and Recommendation

This chapter provides the research outcomes, achievements, contributions, limitations, and future studies. The conclusion and recommendation will also be presented in this chapter.

9.1 Discussion

The research addresses critical gaps in maritime safety by focusing on human factors contributing to ship accidents, especially in congested water and with increasing ship size and restricted manoeuvring. The challenge here is that OOW has to navigate and monitor multiple navigation equipment across the ship bridge. This requires him/her to make frequent moves around the ship bridge, which could result in a loss of situation awareness, especially in the congested water where high attention is crucial. Additionally, the reduced manning on modern ships increases the mental work of the OOW because he needs to deal with all the devices alone, which increases the cognitive load on the OOW, requiring him/her to manage all equipment and decisions alone. This increased their mental workload, leading to a loss of awareness and making mistakes. To mitigate these issues, introducing an assistant to the OOW could significantly enhance attention and situational awareness, reducing cognitive strain and improving overall navigation safety. Although ColReg provides clear guidelines with regard to the utilisation of the lookout, in practice, such guidelines are ignored, and the lookout is doing anything else but lookout duties. Lookout duties should be enforced through stricter regulations to enhance safety, as clearly evidenced by the analysis of the accident investigation reports and the conducted experimental research.

While simulator training has proven valuable in enhancing performance, it remains limited by a lack of standardisation and reliance on subjective assessment methods. In addition, STCW mentioned that training needs to integrate new technologies to enhance the seafarer's performance. Traditional training scenarios often fail to replicate rare or safety-critical conditions informed by real-world accidents. To address these deficiencies, the research adopted multiple approaches, combining accident analysis using the novel SHIELD taxonomy, and advanced neuroscience tools like EEG and Eye-tracking. The SHIELD taxonomy categorised human factors into Acts, Preconditions, Operational Leadership, and

Organisational deficiencies, providing a structured framework to analyse 244 maritime accidents. These analyses highlight collision accident scenarios in congested water as a significant concern. This research first time captured the safety-critical conditions and events using SHIELD taxonomy and created a pool of events under the SHIELD's main headings 'ACT', 'PRECONDITION', 'OPERATIONAL LEADERSHIP' and 'ORGANISATIONAL FACTORS'. This event pool provides an excellent resource for developing solutions for rare events and building mission-specific training scenarios for the simulator environment.

This research recreated real-world scenarios to assess seafarers' performance by utilising a full-mission ship bridge simulator. Two sets of experiments were conducted, the first one where the OOW navigated solo, and the second was navigated with an assistant (Lookout). Findings showed that the presence of the lookout reduced cognitive load in some areas and improved decision-making and situation awareness by focusing more on critical equipment and timely actions. Integrating EEG and Eye-Tracking provides objective insight into cognitive demand and attention allocation, demonstrating their value in enhancing maritime training. Despite challenges, including signal accuracy, scenario complexity, and participant standardisation, the study successfully developed a realistic safety critical scenario, informed by the SHIELD taxonomy, that highlights areas for improvement in individual and team performance. These findings underscore the need to standardise simulator training and integrate advanced tools to evaluate cognitive load and situational awareness, contributing to the development of intelligent, evidence-based training programs.

9.2 Achievement of the research

The research aims to enhance the OOW's performance through maritime simulator training for safety-critical situations. This research provides valuable insight into the role of human factors in maritime accidents, particularly focusing on how non-technical skills such as situational awareness, communication, teamwork, and decision-making affect human performance and maritime safety. The study highlights how the cognitive demand and behaviour of the OOW changes during navigation in sole and with an assistant "Lookout", especially in complex and busy situations.

The study also aligns with the IMO review of the STCW convention (Fitzgerald, 2024; IMO, 2024). As mentioned in 2.6.7, the IMO's road map for future revision, the maritime industry increasingly recognises the importance of integrating new technologies into ship operation and training, enhancing seafarers' psychological well-being, and improving training flexibility. Furthermore, the research addresses some of the 22 key areas identified in the STCW review, such as integrating emerging technologies into maritime education and improving flexibility and quality in simulator-based training. Consequently, this research focuses on utilising the full mission simulator to replicate the real-world conditions with advanced technologies in the ship bridge, such as ECDIS, RADAR and AIS, and integrating advanced technologies such as EEG and eye-tracking to gain deeper insight into human performance. By emphasising seafarers' mental and behavioural aspects during ship operations, we aim to develop training methods that enhance cognitive performance and align with the IMO call for updated training that addresses technical and non-technical skills for enhancing safety.

Moreover, the importance of using real accident scenarios in simulator training is a major focus of this study. By analysing human mentality and behaviour in safety-critical rare events and understanding how seafarers interact with navigational equipment and with external and internal people, this research aims to improve training practice that addresses cognitive demand and behaviour. Also, considering the presence of the lookout and how an assistant (Lookout) influences the OOW's performance in a complex situation, the findings suggest that mistakes from past accidents can provide us with a valuable learning opportunity, allowing training to be refined to focus on preventing future incidents. Furthermore, such investigations will provide scientific evidence of the impact of unsafe practices observed in past accidents with the aim of improving the regulatory framework to prevent such unsafe practices.

This is in line with the current discussion at the Sub Committee on Human Elements, Training, and Watchkeeping (HTW). The study proposes that simulator-based training can be improved by focusing more on cognitive and behavioural aspects of ship operation rather than only focusing on technical or team-based exercises. By proposing a training framework that allows seafarers to earn credit hours through simulator training, we can offer a valuable solution to enhance cognitive skills and create a

more flexible and effective training program that prepares seafarers for everyday operations and emergencies.

After obtaining the result, although EEG and eye-tracking did not show significant results in mental workload for all events between solo and lookout-assisted navigation, The EEG results revealed notable variations in MWL, stress, and attention. MWL and stress levels were initially high in certain events despite the presence of the lookout but were eventually reduced during the Scot Isles and collision avoidance events. However, the differences in the equipment interaction suggest that the lookout allowed the OOW to focus more on the critical navigation equipment. That indicates that having a lookout helps manage workload and attention more effectively with the navigation equipment in the ship bridge. Additionally, the recording highlights how each participant behaved and reacted during the scenarios and critical situations. These differences in behaviour could be attributed to individual personality traits, which influence decision-making. For Example, in the first set of experiments, one of the participants collided with the MV Diamond, which was not the intended target ship for observation. This suggests that while navigating solo, the operator may become overly focused on specific tasks, causing him to lose awareness of his surroundings. This indicates that focusing on one aspect of the environment can lead to distraction, reducing overall situational awareness. However, the experiments demonstrated that adding a lookout significantly reduced the accident. The collision rate decreased by 61%, and communication frequency was reduced by 56%, allowing the OOW to concentrate more on navigation. These findings reinforce the importance of effective bridge resource management, where the support of additional crew members can enhance overall performance. In addition, these results clearly indicate the importance of utilising the crew members on the bridge for the intended tasks, as COLREG outlines.

9.3 Novelty and Contribution to the Research

The study introduces an innovative proposal for maritime ship bridge simulator training, emphasising the integration of credit-based simulator training with real-time cognitive and behavioural performance assessment by using past accident scenarios.

The novel approach leverages advanced bio-sensory technologies and AI-driven monitoring to create a flexible and structured framework that enhances both technical and non-technical competencies. The AI-driven training program introduces an advanced integration of AI to monitor, analyse, and enhance trainees' performance in real-time. This component emphasises physiological data and advanced algorithms to deliver an action plan and solution on screen in case of abnormal activity from the trainees during the training process. By integrating cognitive and behavioural insight into training, this approach seeks to foster mental resilience and prepare seafarers for the increasing complexities of modern ship bridge operations.

9.3.1 Proposed System Description

The Maritime Simulator Training – Artificial Intelligence (MST-AI) approach incorporates a sensors-based setup within the ship simulator, designed to objectively measure cognitive demand through bio-sensory tools worn by the operator. These tools monitor physiological parameters, such as the tools we used (EEG and Eye-tracker), body temperature, heart rate, and skin conductance, which serve as indicators of stress and workload. AI systems analyse this data in real-time, detecting variances that may indicate heightened stress or cognitive overload, as illustrated in Figure 9.1. The aim is to enhance the training framework, ensuring advanced monitoring and decision-making capabilities to improve the performance and SA and design the human-technology interaction, procedures and training methods.

In the training, the operator will be briefed about the training and then familiarised with the simulator before the training. After that, the operator will be prepared to calibrate the sensors to commence the training. During the training, the operator will go through four phases. The first phase starts with the baseline to adjust himself/herself to normal conditions; then, the scenario will commence. In the second face of the scenario, the operator will approach the traffic separation Scheme (TSS), which is a congested area with different ship crossings and some shallow water. In this case, the operator will take an overview of the area to improve the awareness of the situation. The third face is critical conditions, such as bad weather/tide, traffic, and collision or grounding situations. If abnormal activity impacts the operator's performance, such as a rapid increase in heart rate or sweating, the system generates real-time alerts for the operator. These alerts are designed not only to notify the operators of their

physiological state but also to guide them in regaining composure, such as by suggesting calming techniques or refocusing on critical tasks. This immediate feedback loop builds situational awareness and helps operators develop a deeper understanding of their physiological responses and behavioural patterns during high-pressure scenarios. In the last phase, after dealing with the critical situation, the operator will exit the TSS, and the scenario will end. After that, the debriefing session will take place to illustrate the performance that has been done.

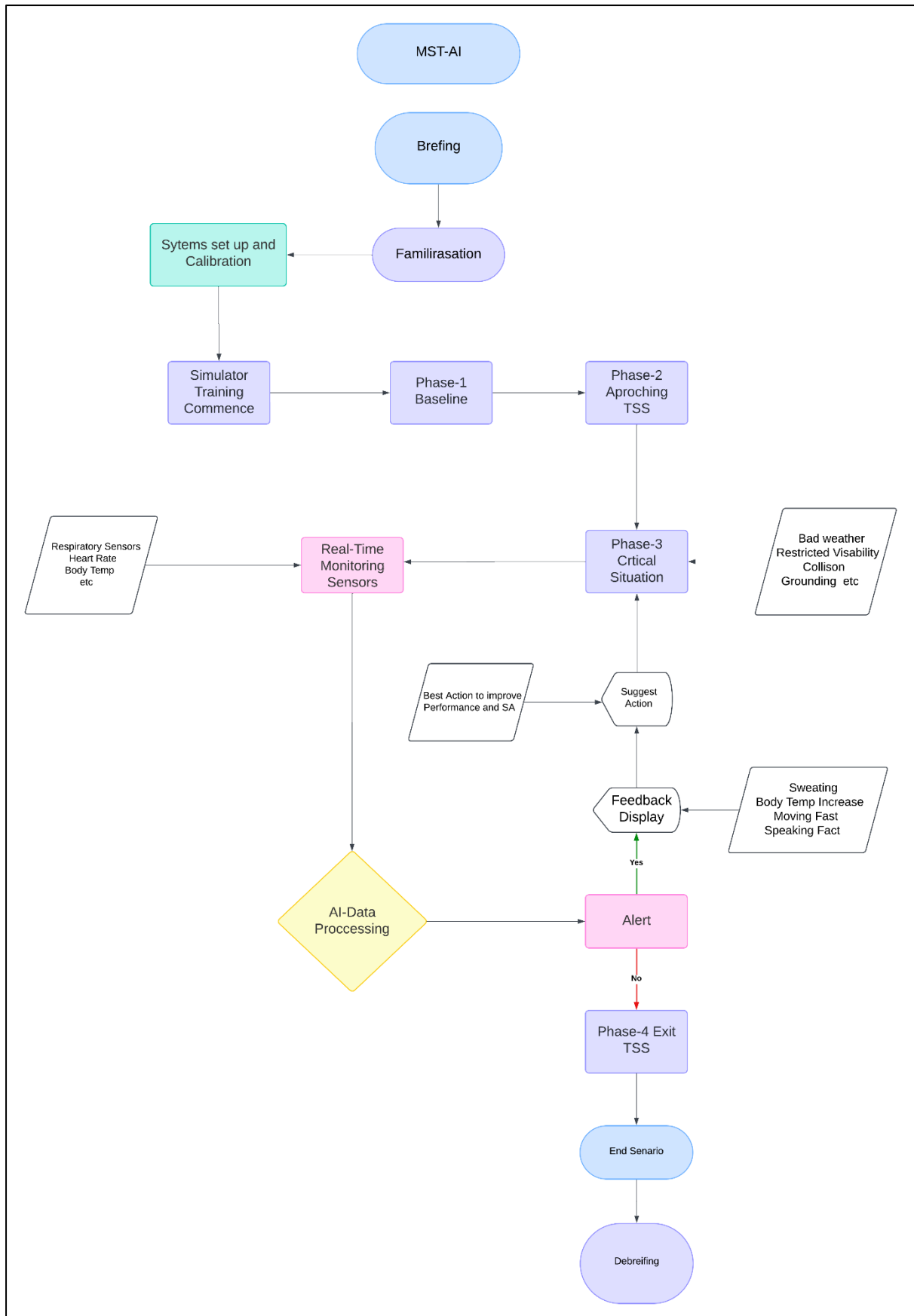


Figure 9.1 New Training Proposal

The proposed training framework introduced several new approaches and contributed to improving ship bridge simulator training by:

- **Introduction Objective Cognitive Monitoring Assessment Tools in Maritime training:**

Unlike conventional training, which often relies on subjective assessments, the proposed framework incorporates advanced bio-sensory and AI technologies to provide an evidence-based evaluation of cognitive and behavioural states during the training.

- **Integrating Real-Time Feedback:**

The real-time alert system empowers operators to recognise and manage stress or cognitive overload independently, fostering self-awareness and being proactive during critical operations.

- **Focus on Non-technical Skills and Cognitive and behavioural performance:**

By addressing the cognitive and behavioural dimensions of ship bridge operation, the framework emphasises skills such as situational awareness, stress management, and decision-making, which are usually neglected in traditional training that always focuses on technical aspects. This approach is associated with the evolving needs of the maritime industry.

- **Integration with the IMO and STCW review:**

The research supports the IMO's recent efforts to review and update the STCW convention, especially in areas such as integrating recent technologies into training and focusing on psychological safety. The study's emphasis on using advanced simulation technology and cognitive assessment tools offers a novel contribution to these discussions, providing a concrete method to enhance training programs based on real-world accident scenarios. Furthermore, full mission simulator assessment and training provide an ideal platform to assess the suitability of the minimum manning requirements in various scenarios, including safety-critical situations and proposal of updated minimum safe manning requirements, if needed.

- **AI-driven personalisation and optimisation:**

As we mentioned in 9.3.1, the integration of AI into the training framework enables operators to gain a deeper understanding of their behavioural and cognitive states during simulation exercises. Through real-time alerts generated by AI-driven systems, operators are informed of

physiological or cognitive irregularities. This immediate feedback allows operators to recognise their challenges and take corrective action to enhance performance.

By fostering self-awareness, the AI system empowers trainees to actively optimise their behaviour, adapt to situational demands, and implement more effective strategies. This continuous feedback loop helps operators refine their decision-making process, builds resilience, and improves their ability to maintain focus under pressure, ensuring a significant enhancement in overall performance and preparedness for a real-world scenario.

- **Enhancing training flexibility**

We can suggest a credit hour system from this training framework, allowing OOW to accumulate measurable progress through simulator-based training. By earning credit hours, operators demonstrate their development of technical and mental resilience in a structured and objective manner.

In aviation, the Federal Aviation Administration (FAA) permits up to 50 hours of flight simulator training for commercial pilots under part 61 and up to 36 hours (30% of the total training hours) under part 141 to count toward mandatory flight time. These provisions underline the recognition of simulator training as an effective part of the training process (eCFR, 2024, 2018).

Similarly, in the maritime domain, (Wulder et al., 1996) indicates that 40 hours of ship bridge simulator training can replace 30 days of sea time, with performance equivalent to 50%. With 80 hours of simulator training, participants achieve a performance level of 76%, surpassing that of a sea-only training group.

Introduce this credit hour framework where simulation-based training is recognised as equivalent to a proportion of mandatory sea time will improve the seafarers' performance, for example

40 simulator hour = 30 days of sea time for basic skill development

80 simulator hours = 60 days of sea time for advanced skill with scenarios including complex conditions.

The credit hours earned through simulator training can be integrated into the mandatory shipboard training, providing an opportunity to reduce the required sea time for officers. This approach optimises training efficiency and ensures that trainees meet certification requirements through a combination of advanced simulation and traditional onboard experience.

By aligning with industry standards and emphasising both technical and non-technical skill development, the proposed system offers a more flexible and streamlined pathway for officers to achieve competency, while maintaining the precision and quality essential to the maritime operation. This integration supports a modernised and adaptive training model that prepares seafarers for the complexities of contemporary bridge operation.

9.4 Limitation

During the research, some limitations occurred as follows:

- The ship bridge equipment did not arrive until the end of my second year. This delay postponed the experimental phase of the study, then
- The primary reason that impacts our research is the COVID-19 pandemic. The university's closure by the UK government redirected access to the facilities, especially after just the ship bridge simulator was installed. Therefore, we were unable to invite participants to conduct the experiments.
- The experiment study design was too long due to the complexities of creating realistic simulator scenarios and integrating EEG and eye-tracking technology. The use of both tools was challenging, as both the equipment setup and the scenario design needed careful planning and testing. These reasons increased the duration of the experiment by more than six months.
- Another challenge was inviting a suitable participant to participate in the experiments. The study required individuals with specific experience and qualifications, making participant recruitment time-consuming and difficult.
- The analysis of the result was challenging, requiring effort and time to ensure the finding met the acceptable academic standard.

- The use of EEG and eye tracking requires a large sample size to achieve statistical significance. However, the sufficient number of participants with a specific requirement was challenging in this case.
- There are different types of EEG and eye-tracking systems in the market. Each one has advantages and disadvantages to use. The researchers should consider the most suitable type that provides clear data for their research.

9.5 Recommendation and Future Work

During the study and the limitations that we faced, the recommendation and the future work for enhancing the maritime simulator training can be as follows:

- Standardise the simulator training program to develop a consistent training program that includes an objective assessment to ensure seafarers are well-trained and prepared for the complexities of modern ship bridge operation, and testing the minimum manning standards.
- More experiments should be done with a large number of participants and with different ranks from the bridge team to achieve more accurate results.
- Creating a data bank of safety-critical conditions provides a valuable resource for the simulator training to improve performance such as Table 5.1. This data bank could include diverse scenarios that replicate real-world challenges, allowing the trainees to develop their skills in a controlled environment.
- Design a structured framework and conduct an empirical study focused on credit-based simulator training. This would help to identify the existing gaps in the training and try to find the solution to improve the training.

For future study, some ideas can be done with the technology development:

- With technological advances and the proposal for simulator training using (AI), we can apply sensors and AI systems to measure the cognitive demand during training and real work in the

ship bridge. The idea is to do initial training using the proposed framework training and look for the challenges and deficiencies to solve them.

- With advances on the internet around the world. Ship bridge training can be connected between different maritime simulator centres using 5G internet in different countries in one scenario. This will significantly impact the training and make the trainee feel the real-life navigation and communication with the targets in the surroundings, As the targets in the surroundings are the other trainees in other countries.

9.6 Research outputs

As co-author, an article, and two conference papers were published during the research.

- Turan, O., Kurt, R., Navas de Maya, B., Flower, C., Bantan, H., Arslan, O. and Uflaz, E., 2022, June. Role of design and operational deficiencies on occupational accidents onboard merchant ships. In *SNAME International Marine Design Conference* (p. D031S005R004). SNAME.
- de Maya, B.N., Farag, Y., Bantan, H., Kurt, R., Turan, O., Uflaz, E., Basappa, R.D., Sotiralis, P. and Ventikos, N., 2022, June. Human factors' contribution into maritime accidents by applying the SHIELD HF taxonomy. In *SNAME 14th International Marine Design Conference*.
- Ronca, V., Uflaz, E., Turan, O., Bantan, H., MacKinnon, S.N., Lommi, A., Pozzi, S., Kurt, R.E., Arslan, O., Kurt, Y.B. and Erdem, P., 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 Sciences*, 13(9), p.1319.

Chapter 10 Conclusion

10.1 Conclusion of the research

Despite significant technological advancements aimed at reducing maritime accidents and improving safety, human factors remain a critical concern in the maritime industry. While efforts to modernise operations and implement advanced technologies have grown, less attention has been given to the operators who operate these advanced systems. This gap has introduced new risks to maritime safety, underscoring the importance of encouraging training standards with evolving technologies. The IMO reviewed the STCW and revealed the need to update training programs to integrate these advancements and improve safety outcomes.

This research identified human factors as the primary contributors to maritime accidents. The analysis of around 244 accidents reports from the MAIB using human factors taxonomy revealed that decision-making, communication, visual detection, risk assessment, leadership, procedural guidance, and team composition were key elements influencing these incidents. By addressing these factors, this research wanted to enhance cognitive demand management and behavioural response to improve performance and maritime safety.

To achieve these objectives, the study utilised an advanced full-mission simulator combined with the objective method, EEG and Eye-tracking to explore cognitive demand and operator behaviour and how team composition influences OOW performance. Two experimental setups were compared: solo navigation and navigation with an assistant as a lookout. A Five-event based analysis method was applied, examining key moments during the simulation to understand the variation of mental demand and individual behaviour. Each event was analysed using EEG and eye-tracking data to capture the OOW's cognitive and behavioural response, highlighting variations in MWL, stress, and attention levels. Eye-tracking heatmap and pupil dilation provided additional insight into visual focus and cognitive load during complex scenarios.

This study not only explores individual cognitive demand and behaviour with ship's bridge equipment interaction, but also highlights the critical role of teamwork, particularly the contributions of a lookout,

in reducing cognitive demand, enhancing situational awareness, and optimising resource utilisation on the ship bridge. The result demonstrates that the presence of the lookout mitigates the OOW's workload, enabling a more strategic and focused engagement with critical equipment and the surrounding environment, particularly in high-demand scenarios such as collision avoidance. The reduction in collision rate by 61% and a 56% decrease in communication frequency underscore the lookout's contribution to mitigating risks and making more efficient operations. By collaborating on the lookout for observations and reports, the OOW can prioritise navigation and other essential tasks, contributing to safer and more efficient bridge management.

These findings emphasise the importance of teamwork in managing cognitive demand and maintaining performance during a complex situation. Furthermore, the data suggest that the lookout not only supports situational awareness but also facilitates efficient resource utilisation by enabling the OOW to focus on high-priority tasks. Future research should consider a large sample size to increase the accuracy of the results and also explore additional physiological metrics, such as heart rate variability, to provide deeper insights into cognitive and emotional responses during navigation.

Furthermore, from the findings, we can answer the questions addressed in the sections 7.2 and 8.5.3 as follow

Q1: Do psychological factors such as mental workload or stress impact the concentration of the officer on the watch (OOW) during emergencies?

Yes, psychological factors impacted the OOW concentration during the emergencies. Even though EEG data revealed non-significant results in certain events, there was an improvement in the MWL during and stress in some events with high-demand scenarios, which affect the OOW's ability to focus, make decisions, and maintain situational awareness, particularly when operating alone. This variation supports the changeability of the psychological factors in the participants during complex conditions.

Q2: Does “lookout” influence the cognitive workload of the officer on the watch (OOW) so that the performance will be improved?

The presence of the lookout positively influenced the cognitive workload of the OOW, leading to improved performance. The study found that participants with lookout experience reduced mental workload with the complex situation even though it is not significant.

Q3: How can we use EEG and eye-tracking devices to explore human cognition and behaviour to improve it in the future?

EEG and eye-tracking devices provide valuable insight into the cognitive load, Stress, attention, and behavioural responses, enabling a deeper understanding of seafarer performance. These tools can identify patterns of mental workload and visual focus, which can inform training programs aimed at improving cognitive resilience, situational awareness, and stress management. Integrating these technologies into maritime training enables us to objectively assess and enhance human performance, particularly in high-risk scenarios.

Q4: Where does the OOW focus more during the experiment?

Eye-tracking revealed that the OOW's focus varied depending on the experimental setup and scenario. The main equipment that participants were focused on were RADAR, ECDIS, and visual screens. However, within the risk of the collision, participants with a lookout focused more on critical equipment, such as RADAR and top display units, utilising a broader range of resources across the bridge. on the other hand, solo participants were more constrained, focusing heavily on a conning display or direct visual observation due to increased cognitive and physical demands of monitoring multiple systems independently, especially in collision avoidance with complex situations that need hand steering.

Q5: How did the presence of the lookout influence the behaviour of the OOW during the experiment?

The lookout's presence significantly influenced the OOW's behaviour by enabling a more strategic approach to task management. With the lookout for handling environmental monitoring, the OOW could prioritise navigation, system checks, and decision-making. This support reduced the need for the OOW to remain stationary, allowing more dynamic engagement with the bridge equipment.

In addition, the proposed training framework introduced an approach to maritime education by integrating advanced technologies, such as AI-driven monitoring and bio-sensory tools, into ship simulator training. This framework emphasises cognitive and behavioural performance alongside technical skills, providing a comprehensive and structured pathway for seafarers to develop mental resilience and situational awareness.

10.2 Key conclusions

- The study identified critical gaps in maritime training, including the lack of standardised simulator scenarios and objective performance assessment methods.
- The SHIELD taxonomy provided a structured framework to classify human errors.
- Human factors, particularly decision-making, situational awareness, lack of manning, and organisational factors, were significant factors contributing to maritime accidents.
- Real-world collision scenarios in congested water were recreated using a full-mission ship bridge simulator, allowing the assessment of seafarers under realistic and high-stress conditions.
- The presence of the lookout was shown to reduce cognitive workload and improve situational awareness, which enhances decision-making during high-pressure situations.
- The presence of the lookout improved the OOW performance as a result of reducing the collision by 61%.
- The presence of the lookout makes the OOW focus more on navigation by reducing the communication with the other ships by 56%.
- The research successfully developed training scenarios informed by accident analysis, emphasising the need for realistic and rare event simulations in maritime training.
- The finding highlights the potential for standardised simulator training that integrates advanced assessments to improve individual and team performance, mitigating human errors in maritime navigation.

References

- Akca, M., Küçükoğlu, M.T., 2020. Relationships Between Mental Workload, Burnout, and Job Performance: A Research Among Academicians, in: Realyvásquez-Vargas, A., Arredondo-Soto, K.C., Hernández-Escobedo, G., González-Reséndiz, J. (Eds.), *Advances in Psychology, Mental Health, and Behavioral Studies*. IGI Global, pp. 49–68. <https://doi.org/10.4018/978-1-7998-1052-0.ch003>
- Akyuz, E., Celik, M., 2014. Utilisation of cognitive map in modelling human error in marine accident analysis and prevention. *Saf. Sci.* 70, 19–28. <https://doi.org/10.1016/j.ssci.2014.05.004>
- Albayrak, T. and Ziarati, R. (2010) ‘Training: Onboard and simulation-based familiarisation and skill enhancement to improve the performance of seagoing crew’, *International Conference on Human Performance at Sea*, (June), pp. 11–21
- Albayrak, T., 2012. ENCOURAGING RESEARCH IN MARITIME EDUCATION & TRAINING.
- Albayrak, T. and Ziarati, R., 2010, June. Training: Onboard and simulation based familiarisation and skill enhancement to improve the performance of seagoing crew. In *Human Performance At Sea (HPAS)-2010 Conference Proceedings* (p. 586).
- Ali, A., 2006. Simulator instructor-STCW requirements and reality. *Pomorstvo*, 20(2), pp.23-32.
- Ali, A., Tusher, H.M., Nazir, S., Ghosh, S., Rusli, R., 2023. Seeking the Best Practices of Assessment in Maritime Simulator Training. *TransNav* 17, 105–114. <https://doi.org/10.12716/1001.17.01.10>
- Allen, P.J., Josephs, O., Turner, R., 2000. A Method for Removing Imaging Artifact from Continuous EEG Recorded during Functional MRI. *NeuroImage* 12, 230–239. <https://doi.org/10.1006/nimg.2000.0599>
- Allianz, 2024. Shipping losses hit all-time low despite increasing risks for the whole sector [WWW Document]. Southeast Asia Emerges Marit. Reg. High. Total Losses. URL <https://commercial.allianz.com/news-and-insights/news/safety-shipping-review-2024.html#:~:text=Fires%20onboard%20vessels%20%E2%80%93%20a%20perennial,for%20a%20decade%20after%202022> (accessed 7.17.24).
- Alsurraykh, N.H., Wilson, M.L., Tennent, P., Sharples, S., 2019. How Stress and Mental Workload are Connected, in: *Proceedings of the 13th EAI International Conference on Pervasive Computing Technologies for Healthcare*. Presented at the PervasiveHealth’19: The 13th International Conference on Pervasive Computing Technologies for Healthcare, ACM, Trento Italy, pp. 371–376. <https://doi.org/10.1145/3329189.3329235>

- Andrzej Hejmlich, 2022. Impact of psychological components of human factors on the probability of committing an error during ship handling in restricted waters. 72 Scientific Journals of the Maritime University of Szczecin 144. <https://doi.org/10.17402/532>
- Arslan, O., Atik, O., Kahraman, S., 2021. Eye tracking in usability of electronic chart display and information system. J. Navig. 74, 594–604. <https://doi.org/10.1017/S0373463320000624>
- Arslan, O., Atik, O., Kahraman, S., 2021. Eye tracking in usability of electronic chart display and information system. J. Navigation 74, 594–604. <https://doi.org/10.1017/S0373463320000624>
- Arslan, O., Furusho, M. and Kum, S., 2005, October. Evaluating sea experience with an eye mark recorder in a ship handling simulator. In International Association of Maritime Universities (IAMU) 6th Annual General Assembly and Conference World Maritime University.
- Atik, O., 2020. Eye tracking for assessment of situational awareness in bridge resource management training. J. Eye Mov. Res. 12. <https://doi.org/10.16910/jemr.12.3.7>
- Atik, O., 2020. Eye tracking for assessment of situational awareness in bridge resource management training. JEMR 12. <https://doi.org/10.16910/jemr.12.3.7>
- Awal, Z.I., Hasegawa, K., 2017. A Study on Accident Theories and Application to Maritime Accidents. Procedia Eng. 194, 298–306. <https://doi.org/10.1016/j.proeng.2017.08.149>
- Ay, C., Seyhan, A., Bal Beşikçi, E., 2024. An overview of maritime psychology through bibliometric analysis: Present state and future prospects. Ocean Engineering 291, 116401. <https://doi.org/10.1016/j.oceaneng.2023.116401>
- Balfe, N., Sharples, S., Wilson, J.R., 2015. Impact of automation: Measurement of performance, workload and behaviour in a complex control environment. Appl. Ergon. 47, 52–64. <https://doi.org/10.1016/j.apergo.2014.08.002>
- Baric, M., Ćulin, J., Bielic, T., 2018. Problems that Occur in a Team: Learning From Maritime Accidents via Simulation Training. TransNav Int. J. Mar. Navig. Saf. Sea Transp. 12, 709–713. <https://doi.org/10.12716/1001.12.04.09>
- Bedny, G., & Meister, D. (1999). Theory of Activity and Situation Awareness. International Journal of Cognitive Ergonomics, 3(1), 63–72. https://doi.org/10.1207/s15327566ijce0301_5
- Bin Guo, F., Wu, B., Wah, M., Yang, Z., Blanco-Davis, E., Khalique, A., Bury, A., 2022. Towards An Ergonomic Interface In Ship Bridges: Identification of The Design Criteria. Presented at the 13th International Conference on Applied Human Factors and Ergonomics (AHFE 2022). <https://doi.org/10.54941/ahfe1001609>
- Binda, P., Murray, S.O., 2015. Spatial attention increases the pupillary response to light changes. Journal of Vision 15, 1–1. <https://doi.org/10.1167/15.2.1>

- Bodala, I.P., Li, J., Thakor, N.V., Al-Nashash, H., 2016. EEG and Eye Tracking Demonstrate Vigilance Enhancement with Challenge Integration. *Front. Hum. Neurosci.* 10. <https://doi.org/10.3389/fnhum.2016.00273>
- Bojko, A., 2013. *Eye tracking the user experience: A practical guide to research*. Rosenfeld Media.
- Brodje, A., Lundh, M., Jenvald, J., Dahlman, J., 2013. Exploring non-technical miscommunication in vessel traffic service operation. *Cogn. Technol. Work* 15, 347–357. <https://doi.org/10.1007/s10111-012-0236-5>
- Brooks, S.K., Greenberg, N., 2022. Mental health and psychological wellbeing of maritime personnel: a systematic review. *BMC Psychol* 10, 139. <https://doi.org/10.1186/s40359-022-00850-4>
- Brunner, C., Delorme, A., Makeig, S., 2013. Eeglab – an Open Source Matlab Toolbox for Electrophysiological Research. *Biomed. Eng. Biomed. Tech.* <https://doi.org/10.1515/bmt-2013-4182>
- Byrnes, J.P., 2002. The development of decision-making. *Journal of Adolescent Health* 31, 208–215. [https://doi.org/10.1016/S1054-139X\(02\)00503-7](https://doi.org/10.1016/S1054-139X(02)00503-7)
- Cain, B., 2007. A review of the mental workload literature. *DTIC Document*.
- Campisi, P., La Rocca, D., Scarano, G., 2012. EEG for Automatic Person Recognition. *Computer* 45, 87–89. <https://doi.org/10.1109/MC.2012.233>
- Carotenuto, A., Molino, I., Fasanaro, A.M. and Amenta, F., 2012. Psychological stress in seafarers: a review. *International maritime health*, 63(4), pp.188-194.
- Chauvin, C., Lardjane, S., Morel, G., Clostermann, J. P., & Langard, B. (2013). Human and organisational factors in maritime accidents: Analysis of collisions at sea using the HFACS. *Accident Analysis & Prevention*, 59, 26-37.
- Chen, J., Fan, S., Zhang, J., Tian, W., 2019. Feature Extraction of Seafarers' Workload Based on EEG Signals, in: 2019 Prognostics and System Health Management Conference (PHM-Qingdao). Presented at the 2019 Prognostics and System Health Management Conference (PHM-Qingdao), IEEE, Qingdao, China, pp. 1–6. <https://doi.org/10.1109/PHM-Qingdao46334.2019.8942941>
- Chopra, K., 2020. 30 Types of Navigation Equipment and Resources Used Onboard Modern Ships [WWW Document]. Marine Insight. URL <https://www.marineinsight.com/marine-navigation/30-types-of-navigational-equipment-and-resources-used-onboard-modern-ships/>
- Church, E., 2022. What Do Modern Ships Use to Navigate? [WWW Document]. Martide Pte. Ltd. URL <https://www.martide.com/en/blog/what-do-ships-use-to-navigate> (accessed 1.13.24).
- ClassNK, n.d. Topics at IMO and IACS [WWW Document]. URL https://www.classnk.or.jp/hp/en/info_service/imo_and_iacs/index.html

COLREG, 1972. Convention on the International Regulations for Preventing Collisions at Sea, 1972 (COLREGs) [WWW Document]. International Maritime Organization. URL <https://www.imo.org/en/About/Conventions/Pages/COLREG.aspx>

Ćorović, B., Djurović, P., 2013. BRANISLAV ĆOROVIĆ, Ph.D. 25.

Danielsen, B.-E., Lützhöft, M., Haavik, T.K., Johnsen, S.O., Porathe, T., 2022. “Seafarers should be navigating by the stars”: barriers to usability in ship bridge design. *Cogn. Technol. Work* 24, 675–691. <https://doi.org/10.1007/s10111-022-00700-8>

Danielsen, B.-E., Lützhöft, M., Haavik, T.K., Johnsen, S.O., Porathe, T., 2022. “Seafarers should be navigating by the stars”: barriers to usability in ship bridge design. *Cogn Tech Work* 24, 675–691. <https://doi.org/10.1007/s10111-022-00700-8>

Delorme, A., Makeig, S., 2004. EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *J. Neurosci. Methods* 134, 9–21. <https://doi.org/10.1016/j.jneumeth.2003.10.009>

Demirel, E., 2020. Maritime Education and Training in the Digital Era. *Univers. J. Educ. Res.* 8, 4129–4142. <https://doi.org/10.13189/ujer.2020.080939>

Dhami, H. and Grabowski, M. (2011) ‘Technology impacts on safety and decision making over time in marine transportation’, *Proceedings of the Institution of Mechanical Engineers, Part O: Journal of Risk and Reliability*, 225(3), pp. 269–292. doi: 10.1177/1748006XJRR359.

Ding, Y., Cao, Y., Duffy, V.G., Wang, Y., Zhang, X., 2020. Measurement and identification of mental workload during simulated computer tasks with multimodal methods and machine learning. *Ergonomics* 63, 896–908. <https://doi.org/10.1080/00140139.2020.1759699>

Dyer, R. F. (1976). Questionnaire construction manual annex: Literature survey and bibliography.

eCFR, 2018. Code of Federal Regulation [WWW Document]. Federal Aviation Administration, Department of Transportation. URL <https://www.ecfr.gov/current/title-14/part-61/section-61.129>

eCFR, 2024. Code of Federal Regulations [WWW Document]. Federal Aviation Administration, Department of Transportation. URL <https://www.ecfr.gov/on/2024-12-02/title-14/part-141>

EMAS, 2023. Annual Overview of Marine Casualties and Incidents 2023.pdf.

EMSA, 2014. Overview of marine casualties and incidents 2014.pdf.

EMSA, 2024. Accident Investigation [WWW Document]. European Maritime Safety Agency. URL <https://www.emsa.europa.eu/we-do/safety/accident-investigation.html> (accessed 2.10.24).

EMSA, 2024. Classification Societies [WWW Document]. European Maritime Safety Agency. URL <https://www.emsa.europa.eu/inspections/90-classification-societies.html#:~:text=Classification%20societies%20are%20organisations%20which,and%20inspections%20on%20board%20ships>. (accessed 8.13.24).

Endsley, M.R., 1995. Toward a theory of situation awareness in dynamic systems. *Human factors*, 37(1), pp.32-64.

Eyewear, 2022. Understanding Eye Tracking & How it Can Work for You: Definitions, Metrics, and Applications [WWW Document]. URL <https://eyeware.tech/blog/what-is-eye-tracking/> (accessed 10.9.24).

Fan, S., Blanco-Davis, E., Fairclough, S., Zhang, J., Yan, X., Wang, J., Yang, Z., 2023. Incorporation of seafarer psychological factors into maritime safety assessment. *Ocean Coast. Manag.* 237, 106515. <https://doi.org/10.1016/j.ocecoaman.2023.106515>

Fan, X., Zhao, C., Zhang, X., Luo, H., Zhang, W., 2020. Assessment of mental workload based on multi-physiological signals. *Technol. Health Care* 28, 67–80. <https://doi.org/10.3233/THC-209008>

Fitzgerald, M., 2024. Working at Sea: IMO review of STCW identifies new focus areas [WWW Document]. IMCA. URL <https://www.imca-int.com/working-at-sea-imo-review-of-stcw-identifies-new-areas-of-focus/#:~:text=The%201978%20STCW%20Convention%20entered,the%20last%20adopted%20in%202018.> (accessed 10.5.24).

Fitzgerald, M., 2024. Working at Sea: IMO review of STCW identifies new focus areas [WWW Document]. IMCA. URL <https://www.imca-int.com/working-at-sea-imo-review-of-stcw-identifies-new-areas-of-focus/#:~:text=The%201978%20STCW%20Convention%20entered,the%20last%20adopted%20in%202018.> (accessed 10.5.24).

Fraende, M., 2020. IMO Moves Closer to Standardisation And Safer Navigation. [online] Bimco.org. Available at: <<https://www.bimco.org/news/safety/20190130-imo-navigation>> [Accessed 7 December 2020].

Godwin, H.J., Hyde, S., Taunton, D., Calver, J., Blake, J.I.R., Liversedge, S.P., 2013. The Influence of Expertise on Maritime Driving Behaviour. *Appl. Cogn. Psychol.* 27, 483–492. <https://doi.org/10.1002/acp.2925>

Gommosani, M., 2021. Enhancing Navigational Safety Through Increasing Situational Awareness and Teamwork in the Bridge.

Grech, M.R., 2005. Human error in maritime operations: assessment of situation awareness, fatigue, workload and stress.

Grech, M.R., Horberry, T., Smith, A., 2002. Human Error in Maritime Operations: Analyses of Accident Reports Using the Leximancer Tool. *Proc. Hum. Factors Ergon. Soc. Annu. Meet.* 46, 1718–1721. <https://doi.org/10.1177/154193120204601906>

Hadnett, E., 2008. A Bridge Too Far? *J. Navig.* 61, 283–289. <https://doi.org/10.1017/S0373463307004675>

Hayward, B.Jb.G., Lowe, A.R., 2010. The Migration of Crew Resource Management Training Crew resource management, chapter 12. Academic Press/Elsevier, Amsterdam Boston Heidelberg [etc].

Hetherington, C., Flin, R., Mearns, K., 2006a. Safety in shipping: The human element. *J. Safety Res.* 37, 401–411. <https://doi.org/10.1016/j.jsr.2006.04.007>

Hjelmervik, K., Nazir, S., Myhrvold, A., 2018. Simulator training for maritime complex tasks: an experimental study. *WMU J. Marit. Aff.* 17, 17–30. <https://doi.org/10.1007/s13437-017-0133-0>

Hollnagel, E., Baldauf, M., Kataria, A., Hollnagel, E., Baldauf, M., 2013. Maritime human factors and IMO policy 8839. <https://doi.org/10.1080/03088839.2013.782974>

Hongtae Kim, Seong Na, Wookhyun Ha. (2011). A Case Study of Marine Accident Investigation and Analysis with Focus on Human Error. *Journal of the Ergonomics Society of Korea*,30(1),137-150.

Hopkins, J.M., 2024. Brain Anatomy and How the Brain Works [WWW Document]. The JohHopkins Hospital, and Johns Hopkins Health System. URL [https://www.hopkinsmedicine.org/health/conditions-and-diseases/anatomy-of-the-brain#:~:text=Each%20brain%20hemisphere%20\(parts%20of,Each%20lobe%20controls%20specific%20functions.](https://www.hopkinsmedicine.org/health/conditions-and-diseases/anatomy-of-the-brain#:~:text=Each%20brain%20hemisphere%20(parts%20of,Each%20lobe%20controls%20specific%20functions.) (accessed 9.25.24).

Hou, X., Liu, Y., Sourina, O., Tan, Y.R.E., Wang, L., Mueller-Wittig, W., 2015. EEG Based Stress Monitoring, in: 2015 IEEE International Conference on Systems, Man, and Cybernetics. Presented at the 2015 IEEE International Conference on Systems, Man, and Cybernetics (SMC), IEEE, Hong Kong, China, pp. 3110–3115. <https://doi.org/10.1109/SMC.2015.540>

I Motion Online, n.d. Different Types of Eye Trackers [WWW Document]. Eyr Teacking. URL https://imotions.com/eye-tracking/?utm_source=google&utm_medium=cpc&utm_campaign=Eye_Tracking&utm_content=Eye_Tracking&utm_term=eye%20tracking%20technology&gad_source=1&gclid=Cj0KCQjw05i4BhDiARIsAB_2wfA51qeJ2r95-foluiXXli-TzZ3emjumbgUFyCWyGzfLpD1otrQ0k80aAhtNEALw_wcB#virtual-reality-eye-tracking (accessed 10.10.24).

IMO, 1974. International Convention for the Safety of Life at Sea (SOLAS), 1974 [WWW Document]. URL [https://www.imo.org/en/About/Conventions/Pages/International-Convention-for-the-Safety-of-Life-at-Sea-\(SOLAS\),-1974.aspx](https://www.imo.org/en/About/Conventions/Pages/International-Convention-for-the-Safety-of-Life-at-Sea-(SOLAS),-1974.aspx) (accessed 10.5.24).

IMO, 1974. International Convention for the Safety of Life at Sea (SOLAS), 1974 [WWW Document]. URL [https://www.imo.org/en/About/Conventions/Pages/International-Convention-for-the-Safety-of-Life-at-Sea-\(SOLAS\),-1974.aspx](https://www.imo.org/en/About/Conventions/Pages/International-Convention-for-the-Safety-of-Life-at-Sea-(SOLAS),-1974.aspx) (accessed 10.5.24).

IMO, 2017. International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, 1978 [WWW Document]. URL <https://www.imo.org/en/OurWork/HumanElement/Pages/STCW-Convention.aspx> (accessed 10.5.24).

IMO, 2017. International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, 1978 [WWW Document]. URL <https://www.imo.org/en/OurWork/HumanElement/Pages/STCW-Convention.aspx> (accessed 10.5.24).

IMO, 2021. 9th International Maritime Conference - Development of Blue Economy under a Secure and Sustainable Environment [WWW Document]. URL <https://www.imo.org/en/MediaCentre/SecretaryGeneral/Pages/Pakistan-9th-international-maritime-.aspx> (accessed 7.16.24).

IMO, 2024. Sub-Committee on Human Element, Training and Watchkeeping (HTW 10), 5-9 February 2024 [WWW Document]. URL <https://www.imo.org/en/MediaCentre/MeetingSummaries/Pages/HTW-10th-session.aspx> (accessed 10.5.24).

IMO, 1978. International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) [WWW Document]. International Maritime Organization (IMO). URL [https://www.imo.org/en/About/Conventions/Pages/International-Convention-on-Standards-of-Training.-Certification-and-Watchkeeping-for-Seafarers-\(STCW\).aspx](https://www.imo.org/en/About/Conventions/Pages/International-Convention-on-Standards-of-Training.-Certification-and-Watchkeeping-for-Seafarers-(STCW).aspx) (accessed 9.23.23).

International Maritime Organization (IMO), 2019. Conventions: International Convention for the Safety of Life at Sea (SOLAS), 1974 [WWW Document]. Int. Marit. Organ. IMO.

Jamal, S., Cruz, M.V., Chakravarthy, S., Wahl, C., Wimmer, H., 2023. Integration of EEG and Eye Tracking Technology: A Systematic Review, in: SoutheastCon 2023. Presented at the SoutheastCon 2023, IEEE, Orlando, FL, USA, pp. 209–216. <https://doi.org/10.1109/SoutheastCon51012.2023.10115167>

Kahraman, S., Deveci, D.A., Öztura, İ., Mermi Dibek, D., 2023. Neuroscience Approach to Situational Awareness: A Research on Marine Navigation. J. ETA Marit. Sci. 11, 186–197. <https://doi.org/10.4274/jems.2023.67699>

Kandemir, C., Soner, O., Celik, M., 2018. Proposing a practical training assessment technique to adopt simulators into marine engineering education. WMU J Marit Affairs 17, 1–15. <https://doi.org/10.1007/s13437-018-0137-4>

Kannathal, N., Acharya, U.R., Lim, C.M., Sadasivan, P.K., 2005. Characterization of EEG—A comparative study. Comput. Methods Programs Biomed. 80, 17–23. <https://doi.org/10.1016/j.cmpb.2005.06.005>

- Karahalios, H., 2018. The severity of shipboard communication failures in maritime emergencies: A risk management approach. *Int. J. Disaster Risk Reduct.* 28, 1–9. <https://doi.org/10.1016/j.ijdr.2018.02.015>
- Kartoglu, C., Senol, Y. E., & Kum, S. (2022). Assessment of seafarers' mental workload (MWL): A study on high-speed craft (HSC). Available at SSRN 4230199
- Keskin, M., Ooms, K., Dogru, A.O., De Maeyer, P., 2020. Exploring the Cognitive Load of Expert and Novice Map Users Using EEG and Eye Tracking. *ISPRS Int. J. Geo-Inf.* 9, 429. <https://doi.org/10.3390/ijgi9070429>
- Kongsberg, 2024. Kongsberg Maritime Customer Training [WWW Document]. URL <https://training.km.kongsberg.com/Home> (accessed 10.6.24).
- Wärtsilä, 2024. Wärtsilä Navigational simulators [WWW Document]. Wärtsilä. URL <https://www.wartsila.com/marine/products/simulation-and-training/navigational-simulators> (accessed 10.6.24).
- Kramer, A.F., 1990. Physiological metrics of mental workload: A review of recent progress. In *Multiple-task performance* 279–328.
- Kranner, I., Minibayeva, F.V., Beckett, R.P., Seal, C.E., 2010. What is stress? Concepts, definitions and applications in seed science. *New Phytol.* 188, 655–673. <https://doi.org/10.1111/j.1469-8137.2010.03461.x>
- Kumar, J.S., Bhuvaneswari, P., 2012. Analysis of Electroencephalography (EEG) Signals and Its Categorization—A Study. *Procedia Eng.* 38, 2525–2536. <https://doi.org/10.1016/j.proeng.2012.06.298>
- Lee, J., Chung, H., 2018. A new methodology for accident analysis with human and system interaction based on FRAM: Case studies in maritime domain. *Saf. Sci.* 109, 57–66. <https://doi.org/10.1016/j.ssci.2018.05.011>
- Leppink, J., 2017. Cognitive load theory: Practical implications and an important challenge. *J. Taibah Univ. Med. Sci.* 12, 385–391. <https://doi.org/10.1016/j.jtumed.2017.05.003>
- Li, F., Chen, C.-H., Lee, C.-H., Feng, S., 2022. Artificial intelligence-enabled non-intrusive vigilance assessment approach to reducing traffic controller's human errors. *Knowledge-Based Syst.* 239, 108047. <https://doi.org/10.1016/j.knosys.2021.108047>
- Lim, W.L., Liu, Y., Harihara Subramaniam, S.C., Liew, S.H.P., Krishnan, G., Sourina, O., Konovessis, D., Ang, H.E., Wang, L., 2018. EEG-Based Mental Workload and Stress Monitoring of Crew Members in Maritime Virtual Simulator, in: Gavrilova, M.L., Tan, C.J.K., Sourin, A. (Eds.), *Transactions on Computational Science XXXII, Lecture Notes in Computer Science*. Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 15–28. https://doi.org/10.1007/978-3-662-56672-5_2

- Liu, Y., Lan, Z., Cui, J., Krishnan, G., Sourina, O., Konovessis, D., Ang, H.E., Mueller-Wittig, W., 2020. Psychophysiological evaluation of seafarers to improve training in maritime virtual simulator. *Adv. Eng. Inform.* 44, 101048. <https://doi.org/10.1016/j.aei.2020.101048>
- Longo, L., Wickens, C.D., Hancock, G., Hancock, P.A., 2022. Human Mental Workload: A Survey and a Novel Inclusive Definition. *Front. Psychol.* 13, 883321. <https://doi.org/10.3389/fpsyg.2022.883321>
- López-Gil, J.-M., Virgili-Gomá, J., Gil, R., García, R., 2016. Method for Improving EEG Based Emotion Recognition by Combining It with Synchronized Biometric and Eye Tracking Technologies in a Non-invasive and Low-Cost Way. *Front. Comput. Neurosci.* 10. <https://doi.org/10.3389/fncom.2016.00085>
- Luimula, M., Markopoulos, E., Kaakinen, J.K., Markopoulos, P., Laivuori, N., Ravyse, W., 2020. Eye Tracking in Maritime Immersive Safe Oceans Technology, in: 2020 11th IEEE International Conference on Cognitive Infocommunications (CogInfoCom). Presented at the 2020 11th IEEE International Conference on Cognitive Infocommunications (CogInfoCom), IEEE, Mariehamn, Finland, pp. 000245–000250. <https://doi.org/10.1109/CogInfoCom50765.2020.9237854>
- Luo, M., Shin, S.-H., 2019a. Half-century research developments in maritime accidents: Future directions. *Accid. Anal. Prev.* 123, 448–460. <https://doi.org/10.1016/j.aap.2016.04.010>
- Lützhöft, M. and Dukic, T., 2007, October. Show me where you look and I'll tell you if you're safe: Eye tracking of maritime watchkeepers. In *Proceedings of the 39th Nordic Ergonomics Society Conference* (pp. 75-78).
- Lutzhof, M., Bruno, K., Chalmers University of Technology, Sweden, 2009. Talk and Trust before Technology: First Steps Toward Shore-Based Pilotage, in: *Human Factors in Ship Design & Operation 2009*. Presented at the Human Factors in Ship Design & Operation 2009, RINA, pp. 47–54. <https://doi.org/10.3940/rina.hf.2009.13>
- Lützhöft, M.H., Dekker, S.W.A., 2002. On your watch: Automation on the bridge. *J. Navig.* 55, 83–96. <https://doi.org/10.1017/S0373463301001588>
- Ma, Y., Liu, Q., Yang, L., 2022. Exploring Seafarers' Workload Recognition Model with EEG, ECG and Task Scenarios' Complexity: A Bridge Simulation Study. *J. Mar. Sci. Eng.* 10, 1438. <https://doi.org/10.3390/jmse10101438>
- MacDonald, R., 2006. Safe manning of ships—Yesterday, today and tomorrow. *WMU Journal of Maritime Affairs*, 5, pp.143-151.
- MAIB, 2008. Collision between general cargo vessel Scot Isles and bulk carrier Wadi Halfa.

MAIB, 2009, "Report on the investigation of the collision between Scot Isles and Wadi Halfa in Dover Strait" Technical Report.

MAIB, 2015. Collision between MV Orakai and FV Margriet North Hinder Junction, North Sea.

Mallam, S.C., Lundh, M., MacKinnon, S.N., 2015. Integrating Human Factors & Ergonomics in large-scale engineering projects: Investigating a practical approach for ship design. *Int. J. Ind. Ergon.* 50, 62–72. <https://doi.org/10.1016/j.ergon.2015.09.007>

Manager, I. C. (2011, August 19). Theory of Accident Causes [WWW Document], n.d. URL <https://www.iloencyclopaedia.org/part-viii-12633/accident-prevention/item/894-theory-of-accident-causes> (accessed 5.5.24).

Mansson, J.T., Lutzhoft, M., Brooks, B., 2017. Joint Activity in the Maritime Traffic System: Perceptions of Ship Masters, Maritime Pilots, Tug Masters, and Vessel Traffic Service Operators. *J. Navig.* 70, 547–560. <https://doi.org/10.1017/S0373463316000758>

Marine Insight, 2020. Bridge of a Ship – Design And Layout [WWW Document]. Marine Insight. URL <https://www.marineinsight.com/naval-architecture/bridge-of-a-ship-design-and-layout/>

MARINE TRAFFIC. 2019. London, United Kingdom: © Copyright 2007 - 2019 MarineTraffic.com. Available: <https://www.marinetraffic.com> [Accessed 17 Jan

Martelli, M., ŻuŁkin, S., Zacccone, R., Rudan, I., 2023. A COLREGs-Compliant Decision Support Tool to Prevent Collisions at Sea. *TransNav Int. J. Mar. Navig. Saf. Sea Transp.* 17, 347–353. <https://doi.org/10.12716/1001.17.02.11>

Maya, N.D., 2021. A comprehensive analysis of human factors in maritime accidents by applying SHIELD HF Taxonomy.

Mechai, N., Wicaksono, H., 2024. Causal Inference in Supply Chain Management: How Does Ever Given Accident at the Suez Canal Affect the Prices of Shipping Containers? *Procedia Comput. Sci.* 232, 3173–3182. <https://doi.org/10.1016/j.procs.2024.02.133>

Meister, D., 1999. The History of Human Factors and Ergonomics. Lawrence Erlbaum Associates Inc, USA.

Melnyk, O., Bychkovsky, Y., Voloshyn, A., 2022. MARITIME SITUATIONAL AWARENESS AS A KEY MEASURE FOR SAFE SHIP OPERATION. *Sci. J. Silesian Univ. Technol. Ser. Transp.* 114, 91–101. <https://doi.org/10.20858/sjsutst.2022.114.8>

Menekse Dalveren, G.G., Cagiltay, N.E., 2019. Are left- and right-eye pupil sizes always equal? *J. Eye Mov. Res.* 12. <https://doi.org/10.16910/jemr.12.2.1>

Michaelson, R., Safi, M., 2021. Who pays for Suez blockage? Ever Given grounding could spark years of litigation [WWW Document]. URL <https://www.theguardian.com/business/2021/mar/30/years-of-litigation-could-lie-ahead-as-insurers-eye-cost-of-ever-given-grounding> (accessed 7.16.24).

Miseviciute, I., 2024. What is eye tracking? [WWW Document]. How do eye trackers work? URL <https://www.tobii.com/resource-center/learn-articles/how-do-eye-trackers-work> (accessed 10.6.24).

Mišković, D., Bielić, T., Čulin, J., 2018. Impact of Technology on Safety as Viewed by Ship Operators. *Trans. Marit. Sci.* 7, 51–58. <https://doi.org/10.7225/toms.v07.n01.005>

Morita, Y., Takano, H., Nakamura, K., 2015. Characteristics of Pupil Diameter Variation during Paying Attention to a Specific Image, in: 2015 IEEE International Conference on Systems, Man, and Cybernetics. Presented at the 2015 IEEE International Conference on Systems, Man, and Cybernetics (SMC), IEEE, Kowloon Tong, Hong Kong, pp. 2328–2332. <https://doi.org/10.1109/SMC.2015.407>

Montewka, J., Goerlandt, F., Innes-Jones, G., Owen, D., Hifi, Y., Puisa, R., 2017. Enhancing human performance in ship operations by modifying global design factors at the design stage. *Reliab. Eng. Syst. Saf.* 159, 283–300. <https://doi.org/10.1016/j.res.2016.11.009>

Muczyński, B., Gucma, M., Bilewski, M., Zalewski, P., 2013. Using eye tracking data for evaluation and improvement of training process on ship's navigational bridge simulator. *Zesz. Nauk. Akad. Morska W Szczecinie* nr 33 (105, 75–78.

Mukherjee, 2021. Understanding Bridge Resource Management And Its Key Elements On Board Ships [WWW Document], n.d. URL <https://www.marineinsight.com/guidelines/understanding-bridge-resource-management-and-its-key-elements-on-board-ships/> (accessed 5.5.24).

Müller-Plath, G., Lehleitner, J., Maier, J., Silva-Lóbling, J., Zhang, H., Zhang, X., Zhou, S., 2023. How Does Maritime Situation Awareness Depend on Navigation Automation and Mental Workload? A Sea Simulator Experiment. *TransNav Int. J. Mar. Navig. Saf. Sea Transp.* 17, 963–969. <https://doi.org/10.12716/1001.17.04.23>

Naderpour, M., Nazir, S., Lu, J., 2015. The role of situation awareness in accidents of large-scale technological systems. *Process Saf. Environ. Prot.* 97, 13–24. <https://doi.org/10.1016/j.psep.2015.06.002>

Navas de Maya, B., Farag, Y., Bantan, H., Kurt, R., Turan, O., Uflaz, E., Dandu Basappa, R., Sotiralis, P., Ventikos, N., 2022. Human Factors' Contribution into Maritime Accidents by Applying the SHIELD HF Taxonomy. Presented at the SNAME 14th International Marine Design Conference, p. D051S017R002. <https://doi.org/10.5957/IMDC-2022-336>

Navas De Maya, B., Khalid, H., Kurt, R.E., 2021. Application of card-sorting approach to classify human factors of past maritime accidents. *Marit. Policy Manag.* 48, 75–90. <https://doi.org/10.1080/03088839.2020.1754481>

Nazir, S., jungefeldt, S., 2017. 18th Annual General Assembly International Association of Maritime Universities [Nikola Vaptsarov Naval Academy, October 11-13, 2017]. Volume I: Global perspectives in MET: towards sustainable, green and integrated maritime transport. Nikola Vaptsarov Naval Academy, Varna, Bulgaria.

Nolte, D., Vidal De Palol, M., Keshava, A., Madrid-Carvajal, J., Gert, A.L., Von Butler, E.-M., Kömürlüoğlu, P., König, P., 2024. Combining EEG and eye-tracking in virtual reality: Obtaining fixation-onset event-related potentials and event-related spectral perturbations. *Atten. Percept. Psychophys.* <https://doi.org/10.3758/s13414-024-02917-3>

Nosov, P.S., Palamarchuk, I.V., Zinchenko, S.M., Popovych, I.S., Nahrybelnyi, Ya.A., Nosova, H.V., 2020. Development of means for experimental identification of navigator attention in ergatic systems of maritime transport. *Bull. Karaganda Univ. Phys. Ser.* 97, 58–69. <https://doi.org/10.31489/2020ph1/58-69>

Olsen, A.A., 2024. Introduction to Digital Navigation: Including Fundamentals of Navigation, Springer Series on Naval Architecture, Marine Engineering, Shipbuilding and Shipping. Springer Nature Switzerland, Cham. <https://doi.org/10.1007/978-3-031-47490-3>

Øvergård, K.I., Nazir, S., Solberg, A., 2017. Towards Automated Performance Assessment for Maritime Navigation. *TransNav Int. J. Mar. Navig. Saf. Sea Transp.* 11, 43–48. <https://doi.org/10.12716/1001.11.02.03>

Parasuraman, R., Riley, V., 1997. Humans and Automation: Use, Misuse, Disuse, Abuse. *Hum. Factors J. Hum. Factors Ergon. Soc.* 39, 230–253. <https://doi.org/10.1518/001872097778543886>

Pazouki, K. et al. (2018) ‘Investigation on the impact of human-automation interaction in maritime operations’, *Ocean Engineering*. Elsevier Ltd, 153(February 2017), pp. 297–304. doi: 10.1016/j.oceaneng.2018.01.103.

Pfleging, B., Fekety, D.K., Schmidt, A., Kun, A.L., 2016. A Model Relating Pupil Diameter to Mental Workload and Lighting Conditions, in: *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*. Presented at the CHI’16: CHI Conference on Human Factors in Computing Systems, ACM, San Jose California USA, pp. 5776–5788. <https://doi.org/10.1145/2858036.2858117>

Plimsoll, S., 1873. *Our seamen: an appeal*. Virtue & Company.

POPA, L.-V. 2015. Human Element in Shipping. *Constanta Maritime University Annals*, 23.

Raunek, 2021. Top 7 Websites for Maritime Accident Investigation Reports and Case Studies [WWW Document]. Mar. Insight. URL <https://www.marineinsight.com/marine-safety/top-7-websites-for-maritime-accident-investigation-reports-and-case-studies/>

MAIIF, 2010. MAIIF Investigation Manual [WWW Document]. Marine Accident Investigators' International Forum. URL <https://maiif.org/resources/> (accessed 4.5.23).

Reason, J., 1990. Human error. Cambridge university press.

Rodrigue, J.-P., 2024. The Geography of Transport Systems, 6th ed. Routledge, London. <https://doi.org/10.4324/9781003343196>

Ronca, V., Uflaz, E., Turan, O., Bantan, H., MacKinnon, S.N., Lommi, A., Pozzi, S., Kurt, R.E., Arslan, O., Kurt, Y.B., Erdem, P., Akyuz, E., Vozzi, A., Di Flumeri, G., Aricò, P., Giorgi, A., Capotorto, R., Babiloni, F., Borghini, G., 2023. Neurophysiological Assessment of An InNowative Maritime Safety System in Terms of Ship Operators' Mental Workload, Stress, and Attention in the Full Mission Bridge Simulator. *Brain Sci.* 13, 1319. <https://doi.org/10.3390/brainsci13091319>

Rothblum, A.M., 2000, March. Human error and marine safety. In *National Safety Council Congress and Expo, Orlando, FL* (Vol. 7).

SAFEMODE, 2020, “Deliverable 2.1-SHIELD human factors taxonomy for risk analysis”, Technical Report.

Salmon, P., Stanton, N., Walker, G., Green, D., 2006. Situation awareness measurement: A review of applicability for C4i environments. *Appl. Ergon.* 37, 225–238. <https://doi.org/10.1016/j.apergo.2005.02.001>

Salvendy, G. and Karwowski, W. eds., 2021. Handbook of human factors and ergonomics. John Wiley & Sons.

Sandhåland, H., Oltedal, H., Eid, J., 2015. Situation awareness in bridge operations – A study of collisions between attendant vessels and offshore facilities in the North Sea. *Saf. Sci.* 79, 277–285. <https://doi.org/10.1016/j.ssci.2015.06.021>

Saus, E.-R., Johnsen, B.H., Eid, J., Thayer, J.F., 2012. Who benefits from simulator training: Personality and heart rate variability in relation to situation awareness during navigation training. *Comput. Hum. Behav.* 28, 1262–1268. <https://doi.org/10.1016/j.chb.2012.02.009>

Schager, B. (2008) ‘When technology leads us astray: A broadened view of human error’, *Journal of Navigation*, 61(1), pp. 63–70. doi: 10.1017/S0373463307004493

Schröder-Hinrichs, J.-U., Hollnagel, E., Baldauf, M., 2012. From Titanic to Costa Concordia—a century of lessons not learned. *WMU J. Marit. Aff.* 11, 151–167. <https://doi.org/10.1007/s13437-012-0032-3>

Sellberg, C., 2017. Simulators in bridge operations training and assessment: a systematic review and qualitative synthesis. *WMU J. Marit. Aff.* 16, 247–263. <https://doi.org/10.1007/s13437-016-0114-8>

Sharma, A., Nazir, S., Ernstsen, J., 2019. Situation awareness information requirements for maritime navigation: A goal directed task analysis. *Safety Science* 120, 745–752. <https://doi.org/10.1016/j.ssci.2019.08.016>

Sharma, A., Nazir, S., Ernstsen, J., 2019a. Situation awareness information requirements for maritime navigation: A goal directed task analysis. *Saf. Sci.* 120, 745–752. <https://doi.org/10.1016/j.ssci.2019.08.016>

Sharma, A., Nazir, S., Ernstsen, J., 2019b. Situation awareness information requirements for maritime navigation: A goal directed task analysis. *Saf. Sci.* 120, 745–752. <https://doi.org/10.1016/j.ssci.2019.08.016>

Shkëlqim Sinanaj, 2020. The Impact of Shipping Accidents on Marine Environment in Albanian Seas. *J. Shipp. Ocean Eng.* 10. <https://doi.org/10.17265/2159-5879/2020.01.005>

Singh Viridi, S., Liu, Y., Zhang, D., 2022. EEG-based stress recognition in competency assessment using maritime navigation simulator. Presented at the 13th International Conference on Applied Human Factors and Ergonomics (AHFE 2022). <https://doi.org/10.54941/ahfe1002504>

Singh, D., Singh, B., 2020. Investigating the impact of data normalization on classification performance. *Appl. Soft Comput.* 97, 105524. <https://doi.org/10.1016/j.asoc.2019.105524>

Siuly, S., Li, Y., Zhang, Y., 2016. EEG Signal Analysis and Classification, Health Information Science. Springer International Publishing, Cham. <https://doi.org/10.1007/978-3-319-47653-7>

SO, P., Gore, B., 2020. NASA TLX, Task Load Index [WWW Document]. National Aeronautics and Space Administration. URL <https://humansystems.arc.nasa.gov/groups/tlx/#:~:text=Originally%20developed%20as%20a%20paper,a%20wide%20range%20of%20applications.>

Soufineyestani, M., Dowling, D., Khan, A., 2020. Electroencephalography (EEG) Technology Applications and Available Devices. *Appl. Sci.* 10, 7453. <https://doi.org/10.3390/app10217453>

Sri, K.S., Rajapakse, J.C., 2008. Extracting EEG rhythms using ICA-R, in: 2008 IEEE International Joint Conference on Neural Networks (IEEE World Congress on Computational Intelligence).

Presented at the 2008 IEEE International Joint Conference on Neural Networks (IJCNN 2008 - Hong Kong), IEEE, Hong Kong, China, pp. 2133–2138. <https://doi.org/10.1109/IJCNN.2008.4634091>

Stellman, J. M. (Ed.). (1998). *Encyclopaedia of occupational health and safety* (Vol. 1). International Labour Organization

STRANKS, J. W. 2007. *Human factors and behavioural safety*, Routledge.

Stranks, J.W., 2007. *Human factors and behavioural safety*, 1. ed. ed, Health & Safety Management. Butterworth-Heinemann, Amsterdam Heidelberg.

Stroeve, S., Kirwan, B., Turan, O., Kurt, R.E., Van Doorn, B., Save, L., Jonk, P., Navas De Maya, B., Kilner, A., Verhoeven, R., Farag, Y.B.A., Demiral, A., Bettignies-Thiebaut, B., De Wolff, L., De Vries, V., Ahn, S.I., Pozzi, S., 2023. SHIELD Human Factors Taxonomy and Database for Learning from Aviation and Maritime Safety Occurrences. *Safety* 9, 14. <https://doi.org/10.3390/safety9010014>

suraykh, N.H., Wilson, M.L., Tennent, P., Sharples, S., 2019. How Stress and Mental Workload are Connected, in: *Proceedings of the 13th EAI International Conference on Pervasive Computing Technologies for Healthcare*. Presented at the PervasiveHealth'19: The 13th International Conference on Pervasive Computing Technologies for Healthcare, ACM, Trento Italy, pp. 371–376. <https://doi.org/10.1145/3329189.3329235>

Szajerman, D., Napieralski, P., Lecointe, J.-P., 2018. Joint analysis of simultaneous EEG and eye tracking data for video images. *COMPEL - Int. J. Comput. Math. Electr. Electron. Eng.* 37, 1870–1884. <https://doi.org/10.1108/COMPEL-07-2018-0281>

Tatler, B.W., Kirtley, C., Macdonald, R.G., Mitchell, K.M.A., Savage, S.W., 2014. The Active Eye: Perspectives on Eye Movement Research, in: Horsley, M., Eliot, M., Knight, B.A., Reilly, R. (Eds.), *Current Trends in Eye Tracking Research*. Springer International Publishing, Cham, pp. 3–16. https://doi.org/10.1007/978-3-319-02868-2_1

Torsten, S., n.d. Certification of maritime simulator systems [WWW Document]. DNV. URL <https://www.dnv.com/services/certification-of-maritime-simulator-systems-2862/> (accessed 10.8.24).

Turan, O., Kurt, R.E., Arslan, V., Silvagni, S., Ducci, M., Liston, P., Schraagen, J.M., Fang, I., Papadakis, G., 2016. Can We Learn from Aviation: Safety Enhancements in Transport by Achieving Human Orientated Resilient Shipping Environment. *Transp. Res. Procedia* 14, 1669–1678. <https://doi.org/10.1016/j.trpro.2016.05.132>

Tusher, H.M., Nazir, S., Ghosh, S., Rusli, R., 2023. Seeking the Best Practices of Assessment in Maritime Simulator Training. *TransNav Int. J. Mar. Navig. Saf. Sea Transp.* 17, 105–114. <https://doi.org/10.12716/1001.17.01.10>

Tusher, H.M., Nazir, S., Mallam, S., Rusli, R., Botnmark, A.K., 2022. Learning from accidents: Nontechnical skills deficiency in the European process industry. *Process Saf. Prog.* 41. <https://doi.org/10.1002/prs.12344>

Uflaz, E., 2023. SIMULATOR-BASED EVALUATION OF HUMAN RESPONSE IN EMERGENCIES. *Istanb. Tech. Univ. □ Grad. Sch.*

UNCTAD, 2022, Review of maritime transport / United Nations Conference on Trade and Development, Geneva. United Nations, Geneva.

UNCTAD, 2023. Towards a green and just transition, Review of maritime transport / United Nations Conference on Trade and Development, Geneva. United Nations, Geneva.

Van Der Wel, P., Van Steenbergen, H., 2018. Pupil dilation as an index of effort in cognitive control tasks: A review. *Psychon. Bull. Rev.* 25, 2005–2015. <https://doi.org/10.3758/s13423-018-1432-y>

Virdi, S.S., Ng, Y.T., Liu, Y., Tan, K., Zhang, D., 2022. Assessment of Situation Awareness for Seafarers Using Eye-Tracking Data, in: Volume 1: Offshore Technology. Presented at the ASME 2022 41st International Conference on Ocean, Offshore and Arctic Engineering, American Society of Mechanical Engineers, Hamburg, Germany, p. V001T01A011. <https://doi.org/10.1115/OMAE2022-80754>

Wang, Zhikang, Zhang, J., Mao, Z., Fan, S., Wang, Zongcai, Wang, H., 2021. Emotional State Evaluation during Collision Avoidance Operations of Seafarers Using Ship Bridge Simulator and Wearable EEG, in: 2021 6th International Conference on Transportation Information and Safety (ICTIS). Presented at the 2021 6th International Conference on Transportation Information and Safety (ICTIS), IEEE, Wuhan, China, pp. 415–422. <https://doi.org/10.1109/ICTIS54573.2021.9798643>

Wärtsilä, 2020. Wärtsilä to supply Europe’s most modern simulator for inland shipping training [WWW Document]. URL <https://www.wartsila.com/media/news/04-06-2020-wartsila-to-supply-europe-s-most-modern-simulator-for-inland-shipping-training-2722550>

Wärtsilä, 2024. Wärtsilä Navigational simulators [WWW Document]. Wärtsilä. URL <https://www.wartsila.com/marine/products/simulation-and-training/navigational-simulators> (accessed 10.6.24).

Wearable Sensing. (2015). DSI-Streamer: Data acquisition software user manual (Version 0.8.05) Wearable Sensing. Retrieved from <https://www.wearablesensing.com>

Xu, M., Pan, Q., Xia, H., Masuda, N., 2020. Estimating international trade status of countries from global liner shipping networks. *R. Soc. Open Sci.* 7, 200386. <https://doi.org/10.1098/rsos.200386>

- Xue, H., Røds, J.-F., Batalden, B.-M., 2023. The impact of safety factors on decision-making in maritime navigation. Presented at the 14th International Conference on Applied Human Factors and Ergonomics (AHFE 2023). <https://doi.org/10.54941/ahfe1003950>
- Yan, S., Wei, Y., Tran, C.C., 2019. Evaluation and prediction mental workload in user interface of maritime operations using eye response. *Int. J. Ind. Ergon.* 71, 117–127. <https://doi.org/10.1016/j.ergon.2019.03.002>
- Yang, S., Xinya, P., Zexuan, D., 2020. Maritime Education Training Assessment Based Electronic Chart Display and Information System. *Adv. Appl. Sci.* 5, 28. <https://doi.org/10.11648/j.aas.20200502.12>
- Yoshida, M., Shimizu, E., Sugomori, M., Umeda, A., 2021. Identification of the Relationship between Maritime Autonomous Surface Ships and the Operator's Mental Workload. *Appl. Sci.* 11, 2331. <https://doi.org/10.3390/app11052331>
- Zagorodnia, Y.V., Pozdniakova, V.V., Marukhnenko, O.M., 2021. БЕЗПЕКА СУДНОВОДІННЯ ЯК ЧИННИК ПІДВИЩЕННЯ ЕФЕКТИВНОСТІ КОМЕРЦІЙНОЇ ЕКСПЛУАТАЦІЇ СУДНА. *Transp. Dev.* 62–69. <https://doi.org/10.33082/td.2021.1-8.06>
- Zhang, N., Bao, C., Wang, X., Han, Q., Deng, Y., Zhang, Y., Li, Z., 2023. A Mental Workload Control Method Based on Human Performance or Safety Risk, in: Harris, D., Li, W.-C. (Eds.), *Engineering Psychology and Cognitive Ergonomics, Lecture Notes in Computer Science*. Springer Nature Switzerland, Cham, pp. 168–177. https://doi.org/10.1007/978-3-031-35392-5_13
- Zhu, L., Lv, J., 2023. Review of Studies on User Research Based on EEG and Eye Tracking. *Appl. Sci.* 13, 6502. <https://doi.org/10.3390/app13116502>
- Ziarati, R. and Ziarati, M. (2011) 'SURPASS – A Response to the Increasing Automation Failures at Sea and in Ports', (July 2014), pp. 389–398.

Appendices

Appendix A Consent Form

Consent Form

Project Description: The aim of SAFEMODE project is to develop a novel Human Risk Informed design (HURID) framework in order to identify, collect and assess Human Factors data to inform risk-based design of systems and operations. The simulator test is a part of the implementation that will validate this project.

Researcher Information: Esma Uflaz is a visiting researcher from Istanbul Technical University, Hadi Bantan, a PhD student studying Maritime Human Factors in Bridge Simulator. Gianluca Borghini is an assistant professor at Sapienza- University of Rome. He is responsible for collecting and managing the EEG data. Osman Turan is a full professor at the University of Strathclyde, he is the project manager.

Risks/Discomforts: There are two instruments that will fit on the head of the participant. The first one is Electroencephalography (EEG) instrument which records the brain signal. The second instrument is Eye Tracking which detects and records the person's presence in real-time. There are no foreseeable risks. However, the EEG and Eye tracking will be fit on the head, and that might create some discomfort, but the scenario will last 20 min, which is a suitable time for the participant to keep these instruments.

Benefits: There are no direct benefits for participants. However, it is hoped that through your participation, we will learn more about how to make the maritime sector safer, and more efficient.

I will be participating in a research project conducted by Esma Uflaz, Hadi Bantan, Gianluca Borghini and Osman Turan at the University of Strathclyde. I understand that the project is designed to gather information about workload and stress during navigation onboard a ship in order to identify human factors.

Before we ask for your participation in the experiments, we want to inform you about the ethical rules that apply to the project.

- 1- This is completely voluntary; I understand that I may withdraw and discontinue participation at any time.
- 2- I understand that most participants will find the study interesting and think-provoking. If, however, I feel uncomfortable in any way during the study, I have the right to decline to continue the study.
- 3- Participation involves being observed by staff from the University of Strathclyde. The study will take approximately 2.5 hours. The entire study will be video and audio recorded (purely for research purposes, anonymous; and any video and voice records will not be passed on to anyone else and will be deleted after the analysis). If I don't want to be recorded, I will not be able to participate in the study.
- 4- I am aware that the study is completely anonymous, and the analysis of the collected data will be reported anonymously without connection to a person, vessel, or company/shipping company.

5- I have read and understand the explanation provided to me. I have had all my questions answered to my satisfaction, and I agree to participate in this study.

☐ **I understand that I will be recorded with an audio and video recording device.**

☐ **I agree to participate in this study.**

Print Name

Signature

Date

For further information, please contact:

Esma Uflaz (esma.uflaz@strath.ac.uk)

Osman Turan (o.turan@strath.ac.uk)

Hadi Bantan (hadi.bantan@strath.ac.uk)

Appendix B Orientation Script for Bridge Experiment

Introduction and Declaration.

We appreciate your participation in this study.

My name is Esma Uflaz. My colleagues are Dr. Gianluca Borghini and Mr. Hadi Bantan. We will be present throughout the period of the research. If you require clarification on any phase of the experiment, please feel free to ask us.

The role of the human factor (crew) and its response play a critical part in mitigating the consequences and effects of emergencies. In this context, we will examine the role of HFs and investigate human response in emergencies by using real-time full mission simulators. This study also aims to determine which brain regions are active while seafarers execute different types of activities in the bridge simulator. Regarding experimental activities, actual seafarers and pilots will be recruited. Prior to each experiment's session, the participants will familiarise themselves with the operational equipment (RADAR, ECDIS, ENGINE, WHEEL, etc.). Key participants (OOW) within the bridge crew will be fitted with EEG and eye-tracking measuring equipment.

Each experimental study will consist of 3 important phases;

1. Briefing

Participants will be given specific information about the navigation area with many relevant parameters and information (ship particulars, environmental conditions, and weather conditions). As part of the briefing, the people being tested will be given an hour to get used to the simulator.

2. Actual execution of the exercises

You are considered a key person in this experimental study and will wear an eye tracker and an EEG device. In this step, the scenario will be performed.

During exercises, the key person will be equipped with EEG and eye-tracking devices to record their brainwaves and eye movements. During the exercises, your communications and simulator logs will also be recorded so that they can be used later for more evaluations.

1. Your eye movements will be recorded with the use of an eye tracker that is positioned like a pair of glasses. At the beginning of the scenario, the eye tracker will be adjusted to account for the unique characteristics of each participant.

2. Your brain activity and eye movements will be recorded during the experiment.

On your head will be placed an EEG headset that will be used to measure your brain activity. To do so,

1. Your skull will be measured to verify that the EEG cap is properly positioned.
2. After you put the cap on, the electrodes will be checked to make sure they are getting the right signals.

During the simulation exercise, your eye movements and brain activity will be monitored while you execute activities. Please act as if you are doing your job on a real ship and use all the rules and tools for navigation well so you can experience real bridge team spirit.

1. Please use the bridge equipment (ECDIS, RADAR, and Conning Display unit) with their current settings, especially since the eye-tracking device will perform visual processing. Each user should work with the same interface.
2. During the simulation, target vessels, VTS, Engine Team, Master, and Deck team (mooring & anchoring) will be ready if you need to communicate with them or need assistance/advice/reporting.

3. De-briefing

The scenario record will be re-played to the participants, After the completion of the experiments, I would also like you to complete a questionnaire and a NASA TLX form that will help us understand your background and workload.

Additionally, your data will be processed in an anonymous manner.

As a final note, I request that each user read and sign this paper. This document grants permission to record and utilise your data-in this case, your eye movements and brain signals.

Print Name

Signature

Date

Appendix C NASA TLX

NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand

How mentally demanding was the task?

|

Very LowVery High

Physical Demand

How physically demanding was the task?

|

Very LowVery High

Temporal Demand

How hurried or rushed was the pace of the task?

|

Very LowVery High

Performance

How successful were you in accomplishing what you were asked to do?

|

PerfectFailure

Effort

How hard did you have to work to accomplish your level of performance?

|

Very LowVery High

Frustration

How insecure, discouraged, irritated, stressed, and annoyed were you?

|

Very LowVery High

Appendix D Participants Analysis of First set

- **Participant 4 (P4)**

During the simulator experiment, Participant 4 was navigating on the ideal course, which is the green line, Figure 0.1 P4 . Participant 4 did not pass clear and was involved in a collision with the ship Scot Isles. The accident occurred during the participant's interaction with five events:

Event 1 Baseline: Participant 4 in this event was moving around and checking all the navigation equipment. Participant 4 used the radar and the ECDIS during the baseline and this might be the Participant 4 needs to get familiar with the equipment, but Participant 4 mentioned loudly “I do not feel very confident” which indicates she is stressed or frustrated.

Event 2 MV Nowa: participant 4 detected the MV Nowa visually but she did not acquire in the radar, and she spoke loudly “I would be asking for some assistance because no gyro feeding in my radar at the moment”. This could explain why Participant 4 got stressed and needed some assistance to support her concern. Participant 4 monitored MV Nowa visually, and after (01m:50s) was, trying to acquire the target to check the information, but it showed that she did not know how to get the information quickly, then participant 4 received a call from MV Nowa instructed her to keep the course and the speed. Participant 4 confirmed the manoeuvring.

Event 3 MV Diamond: Participant 4 did not detect MV Diamond and was not aware of the MV Diamond. Participant 4 was monitoring MV Nowa on the radar and speaking loudly to herself about the situation. After that, MV Diamond communicated the Participant 4, but she was not aware of the call and did not respond. Then, she detected MV Scot Isles visually, in the meantime, participant 4 received a second call from MV Diamond and she answered the call and confirmed the manoeuvring, then participant 4 used the visualisation panel to observe MV Diamond visually.

MV Scot Isles: Participant detects MV Scot Isles before MV Dimond visually at (09m:17s). After that, Participant 4 received the second call from MV Diamond and answered the call. Then, she moved to observe MV Diamond visually. Then, participant 4 got concerned about MV Scot Isles and acquired it

on the radar at (11m:50s). Participant 4 complained that her EBL and VRM on the radar did not work, but when she tried again, it worked again. While monitoring the Scot Isles, Participant 4 spoke loudly that ‘the target should not pass my ahead and I should call the master for assistance’. Participant 4 kept monitoring Scot Isles on the radar and visually and speaking loudly about the situation but she did not try to communicate or ask for assistance. Then, at (18m:11s), Participant 4 starts to take action.

Event 5: Collision Avoidance: at (18m:11s), participant 4 spoke loudly that she would reduce the speed, and she reduced slowly and said, “That would be better and not comfortable at all” Then she looked at the MV Diamond location and observed the Scot Isles until collided on the port side. This suggests that the participant was confused and did not know what to do when she felt frustrated.

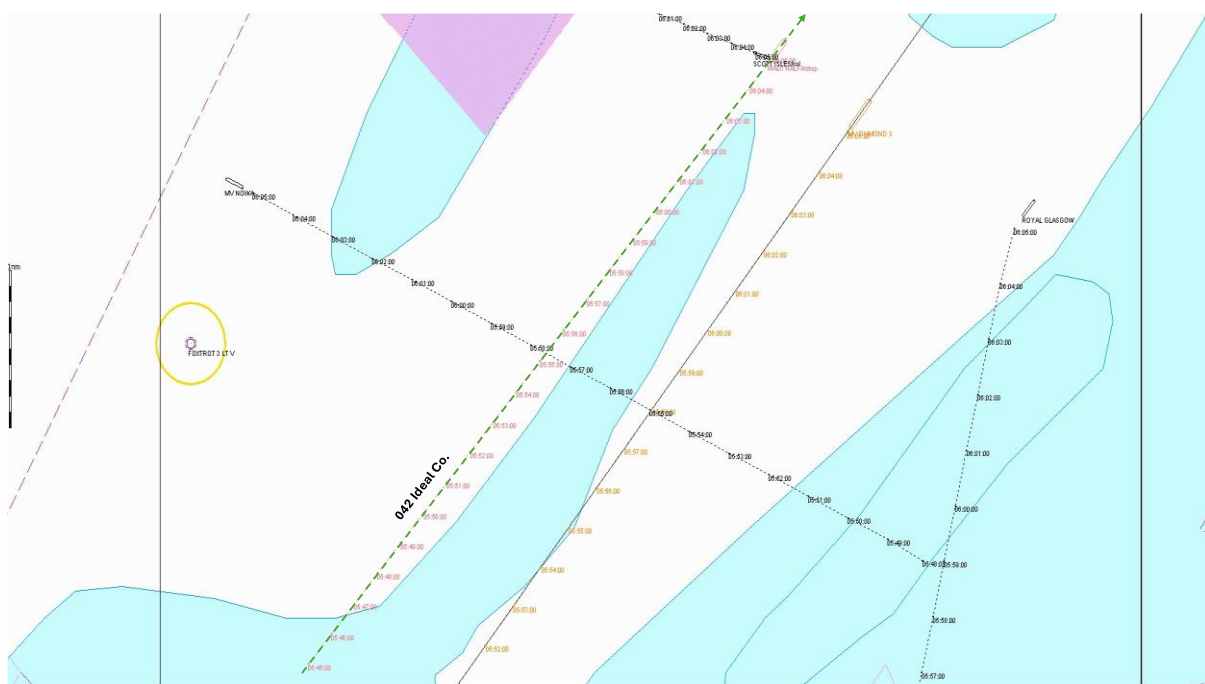


Figure 0.1 P4 Navigation chart

In addition, the heat map provides the participant’s visual attention distribution during the ship bridge training simulation in Figure 0.2, which offers a clear visual focus throughout the events. The red zones indicate the area with high focus, suggesting that the participant concentrated heavily on the radar and rarely used visual observation which indicates that the participant was over-relied on automation. Also,

the central navigation display shows the participant was focusing on the Scot Isles approaching a head could at the last moment when it approached. The green regions show less intense focus, indicating that the participant was aware of his surroundings, but he spent less time monitoring these targets.



Figure 0.2 P4 Heat map

Based on the EEG result and participant's performance metrics illustrated in Table 0.1 Figure 0.3, we can observe how the cognitive demand (MWL, Stress, and attention) differentiation across the different events in the simulator experiments as follows:

Table 0.1 P4 EEG Data

Time		Event	Duration	MWL	Stress	Attention
00:00.0	02:35.2	Baseline	02:35.2	1.00	0.0027	1.0000
02:52.9	06:31.9	Nowa	03:39.1	0.21	0.0021	0.0031
09:34.1	13:34.0	Diamond	03:59.9	0.00	0.0012	0.0000
09:17.5	15:03.0	Scot Isles	05:45.6	0.01	1.0000	0.0166
15:03.1	19:46.8	Collision Avoidance	04:43.8	0.03	0.0000	0.0030

- **Event 1 Baseline:**

During the baseline, the participant showed a high mental workload while stress level was very low, and attention was high. This suggests that the participant was engaged with high attention because there were no targets, and no immediate risk existed. However, MWL was high

suggesting that Participant 4 due to her movement and use of the navigation equipment within the baseline, Participant 4 increased her cognitive especially when she said “I do not feel confident “

- **Event 2 MV Nowa:**

Moving to event 2 MV Nowa, there was a decrease in the MWL and a decrease in stress and attention. This is when the scenario starts and targets appear. The participants began to blame and speak loudly that there was no gyro and that there should be an assistant to support her; this impacted her cognition and attention.

- **Event 3 MV Diamond:**

The next event, MV Diamond, shows very low stress with no MWL and no attention. The participant was not aware of the target until received a second call from MV Diamond, indicating that the sudden detection of the MV Diamond and when the communication commenced may have created low stress for the participant, despite the still no risk of collision.

- **Event 4 MV Scot Isles:**

In the Scot Isles event, the stress increased significantly during this event, and this might be due to the detection of the risk of collision and failure in the communication attempts. However, the MWL level and attention level are very low.

- **Event 5 Collision Avoidance:**

In the last event, collision avoidance, after taking action, there was a very low MWL, no stress, and very low attention, which reflects that the participant was frustrated when the collision approached and stopped to take action.

In this experiment, Participant 4 mostly complained and spoke loudly, saying that she did not feel comfortable with the situation. I believe this all impacts the performance and the result of her EEG data.

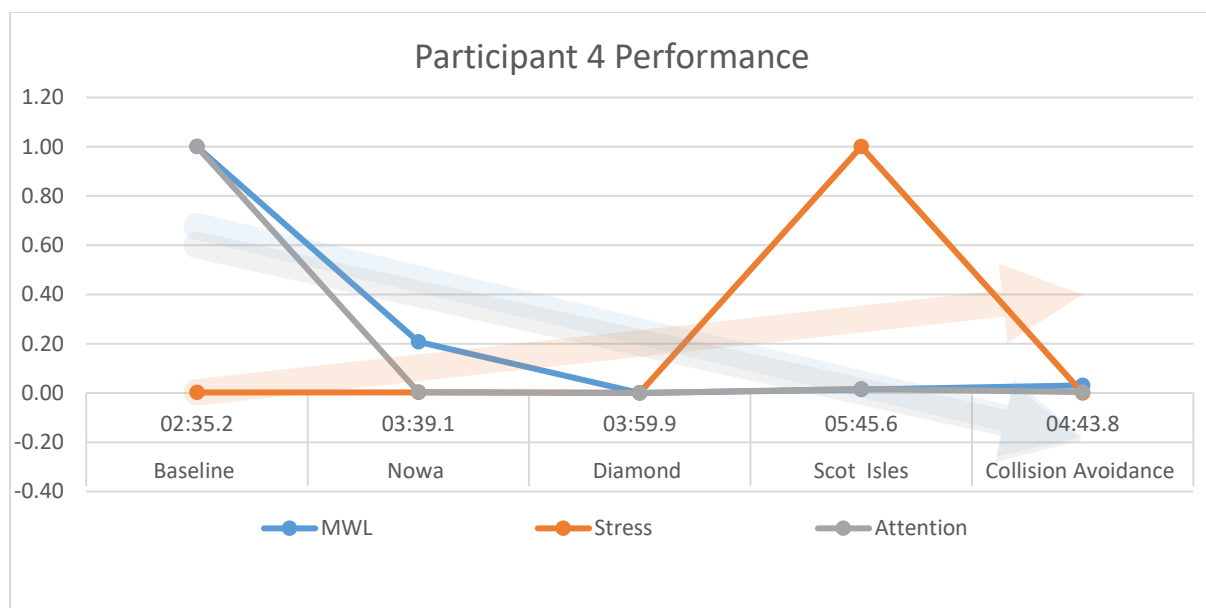


Figure 0.3 P4 EEG Data

The pupil diameters for both eyes show a constant decrease during the events. After that, during the Scot Isles, the eye pupil increased slightly and kept increasing until the end of the Collision indicating that the MWL was decreasing with the situation as presented and increasing in the difficult conditions in Figure 0.4. The participant's eye pupil dilation was changed as shown in Figure 0.10 and Table 0.2 for each event as follows:

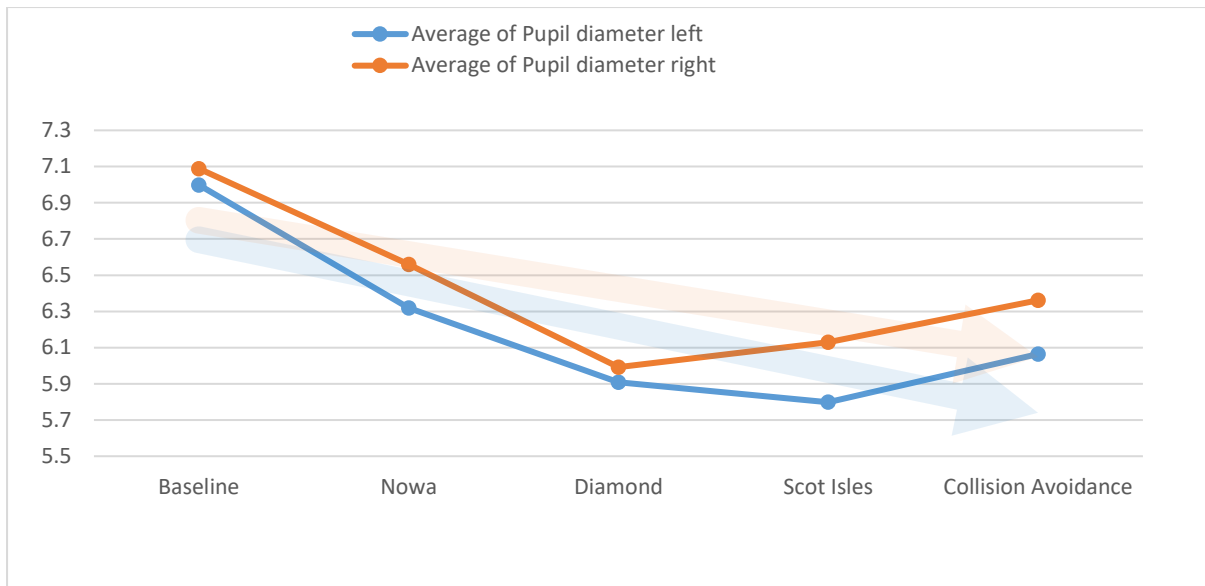


Figure 0.4 P4 Eye pupils' diameter

- **Event 1 Baseline:**

During the baseline event, the participant demonstrated the highest average pupils with (6.70) and (7.09) for the left and right eyes respectively. The participant was not under pressure as there were no external targets to deal with, which should made her calm and low MWL state. However, the increase in the pupil's eye suggests that Participant 4 gets more MWL in addition to attention due to her movement and use of the navigation equipment within the baseline, Participant 4 increased her cognitive especially when she said “I do not feel confident “

The baseline duration is around (15%) of the scenario time, and the participant in the baseline event spent around (8%) of the event time focusing on the radar and (15%) of the event on ECDIS, and around (72%) of the event time visually scanned the surrounding area to check the situation in the surrounding area. Additionally, a small amount of attention was put on the display unit and top display unit, which are (4%) and (1%) of the event indicating an initial information check before the targets appear and indicates that Participant 4 used this time to get familiar with the navigation equipment Figure 0.5



Figure 0.5 P4 Heat map for baseline event

- **Event 2 MV Nowa:**

As the MV Nowa appeared on the radar and was visually detected, the participant's eye pupil diameters decreased to (6.32 mm) and (6.56 mm) for the left and right sides respectively. This was due to the participant showing low cognitive engagement prior, maybe because of the sudden appearance of the MV Nowa and Participant 4 was surprised by the situation. In addition, Participant 4 spent around (19%) of the experiment time monitoring the MV Nowa. Participant 4 has shown a strong reliance on radar, with (71%) of the event time, and (28%) of the event time observed visually on the screen. However, Participant 4 did not use the ECDIS which indicates that he prefers to use the radar as a navigation system to monitor the target Figure 0.6.



Figure 0.6 P4 Heat map for MV Nowa

- **Event 3 MV Diamond:**

During this event, pupil dilation decreased slightly further to (5.91 mm) and (6.01 mm), indicating that the participant still got less cognitive load when the MV diamond appeared. This event took around (26%) of the experiment time, The participant shows that (47%) of event time remained focused on the radar. However, (50%) of the event time also was focused on screens for visualization and this was caused when the MV Diamond communicated with the participant for the second time and Participant 4 tried to observe visually to ensure the location of the MV Diamond and the situation awareness. In addition, there was a small attention (3%) during the event time on the ECDIS and Display unit, indicating that the participant was focusing on different systems during communication. The MV diamond duration was shorter because the participant failed to detect the target until receiving a call from MV diamond. Immediately, the participant checked the radar and the screen for visualisation, which suggests that the participant did not pay attention to the radar for monitoring the targets, but instead, he used his visuals for observation, Figure 0.7.



Figure 0.7 P4 Heat map for MV Diamond

- **Event 4 MV Scot Isles:**

Still, with this event, the participant's eye diameter slightly increased to (5.80 mm) for the left eye and (6.13 mm) for the right, indicating that the participant started to have high MWL, especially when the participant communicated with the Scot Isles and assessed the risk of collision. This event took around (11%) of the experiment time. The participant focused approximately (72%) of the event time on the radar during this event to assess the situation with the Scot Isles, which still indicates that the participant relied on radar to monitor the situation. However, Participant 4 also checked the situation visually with (23%) of the event time checking the external environment, and (1%) of the event time using the ECDIS to support navigational checks. This suggests that the participant distributes his attention in the ship bridge environment between the navigation equipment and the external observation, indicating he is aware of the situation and trying to improve her situation awareness. Figure 0.8



Figure 0.8 P4 Heat Map for MV Scot Isles

- **Event 5 Collision Avoidance:**

The pupil diameter remained elevated at (6.06 mm) on the left and (6.36 mm) on the right, demonstrating a high cognitive load when he took action to avoid the risk of collision. The collision avoidance action took around (29%) of the experiment time. During this event, the participant distributed his attention more widely across the bridge systems. The participant focused this time less on the radar with (57%) of the event time while (16%) on the ECDIS, and (24%) of the event time on screen for visualization. This means that Participant 4 distributed her attention on the ship bridge environment when she saw the risk of the collision to monitor the target and tried to take imminent action. Unfortunately, the delay in the decision to take action caused a collision, Figure 0.9.



Figure 0.9 P4 Heat map for collision avoidance

Table 0.2 P4 Point of focus at different scenario events

Row Labels	Display Unit	ECDIS	Engine	VHF	RADAR	Visualisation	Top Display Unit
Baseline	4%	15%	1%	0%	8%	72%	1%
Nowa	0%	0%	0%	1%	71%	28%	0%
Diamond	1%	6%	0%	0%	47%	45%	0%
Scot Isles	4%	1%	0%	0%	72%	23%	0%
Collision Avoidance	1%	16%	1%	0%	57%	24%	0%

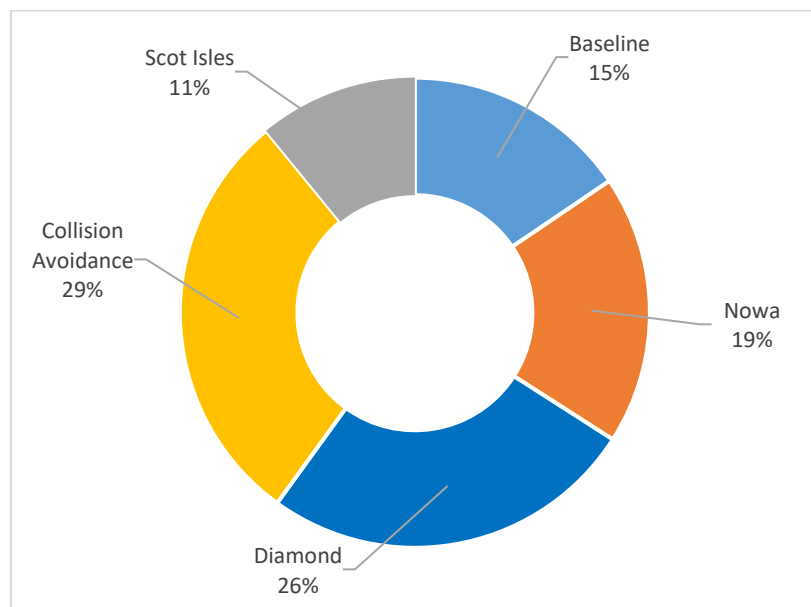


Figure 0.10 P4 duration time for each event

The combined analysis of EEG and eye tracking data provides a comprehensive view of Participant 4's performance and cognitive demand during the simulator experiment, as shown in the recording. Both results for Participant 4 offer a valuable understanding of how the participant responded to each event and the complexity of the scenario from the baseline to the collision avoidance as shown in Figure 0.11 which demonstrates the brain activity across four channels (F4-PZ, P4-Pz, P3-Pz, and F3-Pz) that illustrate the cognitive demand.

The EEG data reveals cognitive engagement, during the baseline, the EEG signals a low variability, indicating a calm state. However, there is some engagement in (F4-Pz), I believed this when Participant 4 engaged and used the navigation equipment for familiarisation. During MV Nowa and the progress of the event, there is a visible fluctuation that appears with the front channel, which requires cognitive engagement, decision-making, and communication, indicating that Participant 4 got involved and increased her MWL. During MV Dimond and Scot Isles, Participant 4 was engaged with tasks and communicated with the lookout and the targets, and she was not stable in her action, which indicates that the parietal lobe channel showed remarkable fluctuation, lining up with the tasks that involved sensory processing and spatial awareness. In the last event, the signals began to be calmed, and this was when the collision approached, and Participant 4 stopped any action.

Similarly, the pupil diameter from eye tracking is closely aligned with EEG findings. During the baseline, the pupil diameter was small and stable and increased, indicating that the participant was calm and increased her attention. As the scenario proceeded to the MV Nowa event, the eye pupil began to fluctuate, reflecting greater cognitive engagement especially when Participant 4 began to blame the gyro that was not available. During the MV Diamond and Scot Isles, the eye pupil fluctuated and decreased in some points related to Participant 4 starting to become frustrated, and this could be a result of the task complexity. During collision avoidance, there are increases, which indicate an increase in MWL and attention, and then a decrease when the collision approached and the participant felt frustrated again.

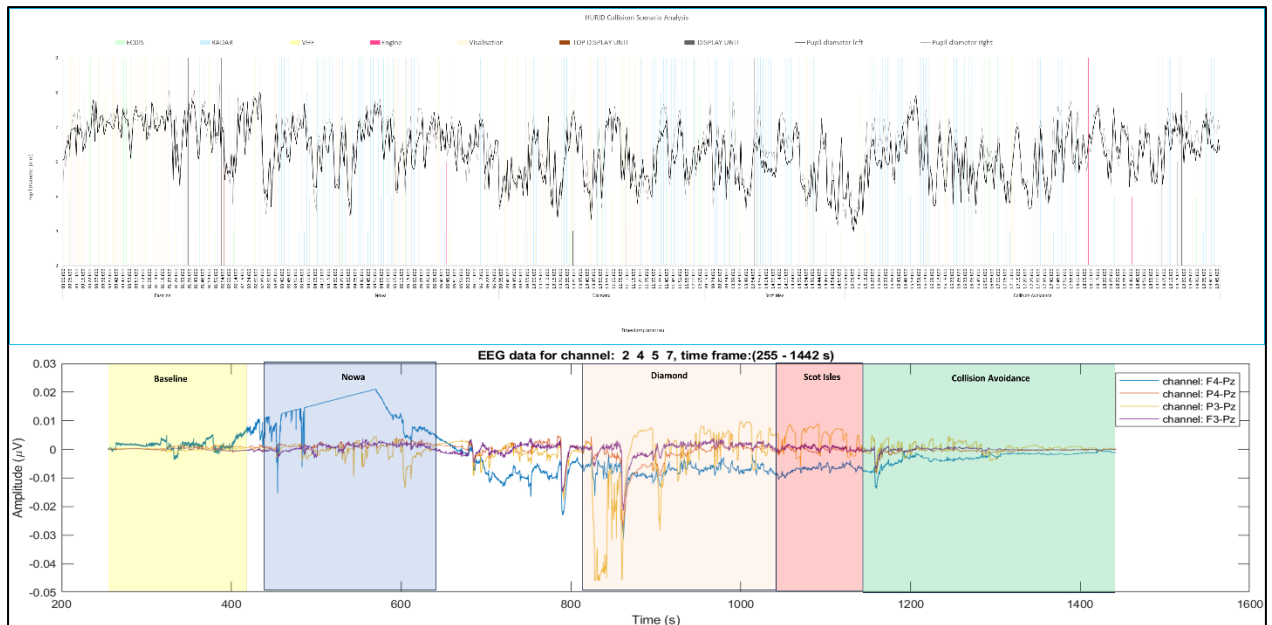


Figure 0.11 P4 EEG and Eye-Tracking

in addition, Figure 0.12 shows significant activity in the delta in the parietal region, which indicates that Participant 4 has a strong cognitive process, especially when she was communicating with the lookout most of the time, and that she did not feel comfortable with the actions she made.

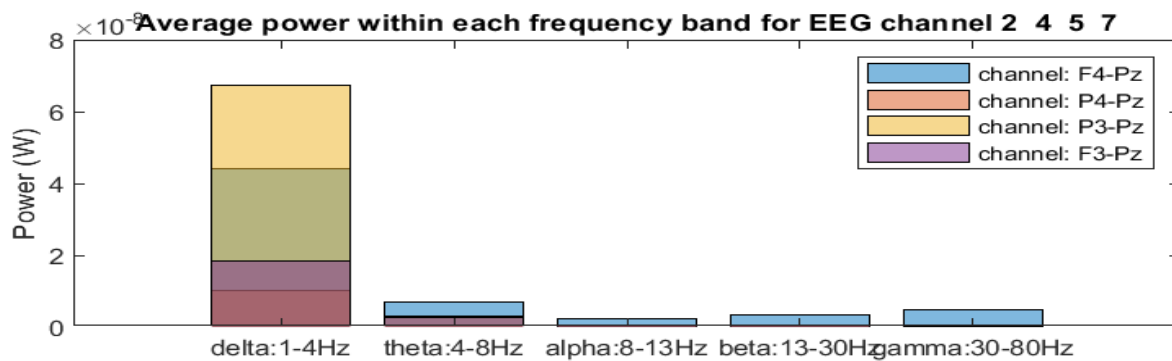


Figure 0.12 P4 Power band

- **Participant 7 (P7)**

During the simulator experiment, participant 7 was navigating on the ideal course, which is the green line, Figure 0.13. It shows that Participant 7 reduced speed and passed clear without being involved in a collision with the ship Scot Isles. The experiment occurred during the participant's interaction with five events:

Event 1 Baseline: Participant 7 was moving around and checking the ship's environment and also, and Participant 7 used the autopilot in the baseline, which suggested that the participant wanted to check the ship's manufacturing characteristics.

Event 2 MV Nowa: after the baseline, the targets started to appear, and Participant 7 was surprised. After (00m:30s), Participant 7 detected MV Nowa visually and said, “he is most interested” and then acquired the target on the radar later. After that, participant 7 altered the course to starboard using autopilot and kept monitoring the target on radar. During his monitoring, Participant 7 received a call from MV Nowa, who instructed him to keep the course and speed to pass from a stern. Participant 7 confirmed and informed MV Nowa that he had altered course to Starboard to avoid the ships ahead, which indicates that he was aware of the situation.

Event 3 MV Diamond: Participant 7 detected MV Scot Isles visually and said, “he should pass behind me”, before becoming aware of the MV Diamond. Then, Participant 7 received a call from MV Diamond informing him to keep course and speed. The participant asked MV Diamond if she would pass ahead or stern of MV Nowa, but the answer from MV Diamond was just “please course and speed”, and Participant 7 confirmed. After that, Participant 7 observed the MV diamond visually and acquired it on the radar, then altered the course to the port side.

Event 4 MV Scot Isles: Participant 7, after finishing communication with MV Diamond, noticed the Scot Isles and monitored on the radar. Then Participant 7 moved to EDCIS and checked the name of the ship, as well as the CPA and TCPA of the Scot Isles. Afterwards, at (12m:10s), Participant 7 communicated with the Scot Isles and waited for a response. At

(12m:30s), Participant 7 reduced the speed and made full stern when he did not get a response from Scot Isles. This indicated that Participant 7 was aware of the risk of the collision.

Event 5 Collision Avoidance: after taking the action, Participant 7 communicated with the captain but did not get a response and spoke loudly, “If I had an AB, I would not wake the captain”. Then, Participant 7 tried to communicate with Scot Isles, and also no response. Therefore, Participant 7 called MV Dimond to explain the situation and then called MV Scot Isles again and used sound signals for emergencies. After that, Participant 7 kept monitoring the Scot Isles until passed clear from ahead. Participant 7's reaction indicates that he was aware of the situation, which made him aware of his reaction and behaviour.



Figure 0.13 P7 Chart navigation

In addition, the heat map provides the participant's 7 visual attention distributions during the ship bridge training simulation in Figure 0.14, which offers a clear visual focus throughout the events. The red zones indicate the area with high focus, suggesting that the participant concentrated heavily on the radar and rarely used visual observation which indicates that the participant was over-relied on automation. Also, the central navigation display shows the participant was focusing on the Scot Isles approaching a

head could at the last moment when it approached. The green regions show less intense focus, indicating that the participant was aware of his surroundings, but he spent less time monitoring this target. In addition, the conning display also shows effective monitoring, and this suggests that participants monitor the information on the ship.



Figure 0.14 P7 Heat map

Based on the EEG result and participant's performance metrics illustrated in, we can observe how the cognitive demand (MWL, Stress, and attention) differentiation across the different events in the simulator experiments as follows: Table 0.3 and Figure 0.15.

Table 0.3 P7 EEG data

Time	Event	Duration	MWL	Stress	Attention
00:00 - 03:04	Baseline	03:04	1.00	0.0000	0.9591
03:25 - 05:58	Nowa	02:33	0.09	0.2990	0.0000
07:44 - 09:51	Scot Isles	02:07	0.07	1.0000	0.1702
09:51 - 12:51	Diamond	03:00	0.01	0.7080	1.0000
12:51 - 20:17	Collision Avoidance	07:25	0.00	0.0082	0.5523

- **Event 1 Baseline:**

During the baseline, Participant 7 showed a high mental workload while stress level was very low, and attention was high. This suggests that the participant was engaged with high attention

because there were no targets, and no immediate risk existed. However, MWL was high, indicating that Participant 7's movement and use of the navigation equipment within the baseline were due to his use of the navigation equipment.

- **Event 2 MV Nowa:**

Moving to event 2 MV Nowa, there was a decrease in the MWL and an increase in stress and attention. This is when the scenario starts, and targets appear. The participants began to engage in the experiment and used autopilot for manoeuvring despite no risk of collision.

- **Event 3 MV Diamond:**

The next event, MV Diamond, shows very low MWL with high stress and high attention. Participant 7 was not aware of the target until received a call from MV Diamond, indicating that the sudden detection of the MV Diamond and when the communication commenced may have created increased stress for Participant 7. However, Participant 7 detected MV Scot Isles before getting aware of the MV Diamond, despite the still no risk of collision.

- **Event 4 MV Scot Isles:**

In the Scot Isles event, the stress increased significantly during this event, and this might be due to the detection of the risk of collision and failure in the communication attempts. However, the MWL level becomes very low, and a very low attention level.

- **Event 5 Collision Avoidance:**

In the last event collision avoidance, after reduced speed for taking the action, there was a very low MWL and stress, with moderate attention which reflects that Participant 7 was aware of the situation and took early action to avoid collision.

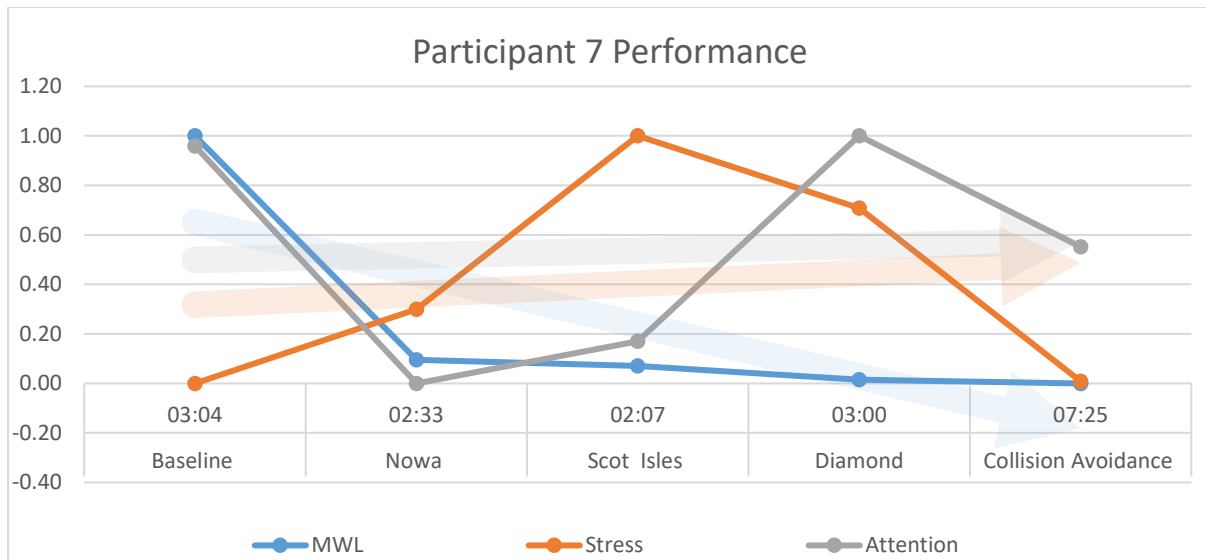


Figure 0.15 P7 EEG data

The pupil diameters for both eyes show a fluctuation during the events. During the MV Nowa, the eye pupil increased slightly indicating that the MWL and attention increased with the situation as presented by the target. After that, it decreased with monitoring the scenario, and when the participant became aware of Scot Isles and Dimond, the eye increased for more attention, then decreased during the collision avoidance, reflecting that Participant 7 began to feel calm after taking early action and avoiding the collision, Figure 0.16. Participant 7's eye pupil dilation was changed, as shown in Figure 0.16 and Table 0.4, for each event as follows:

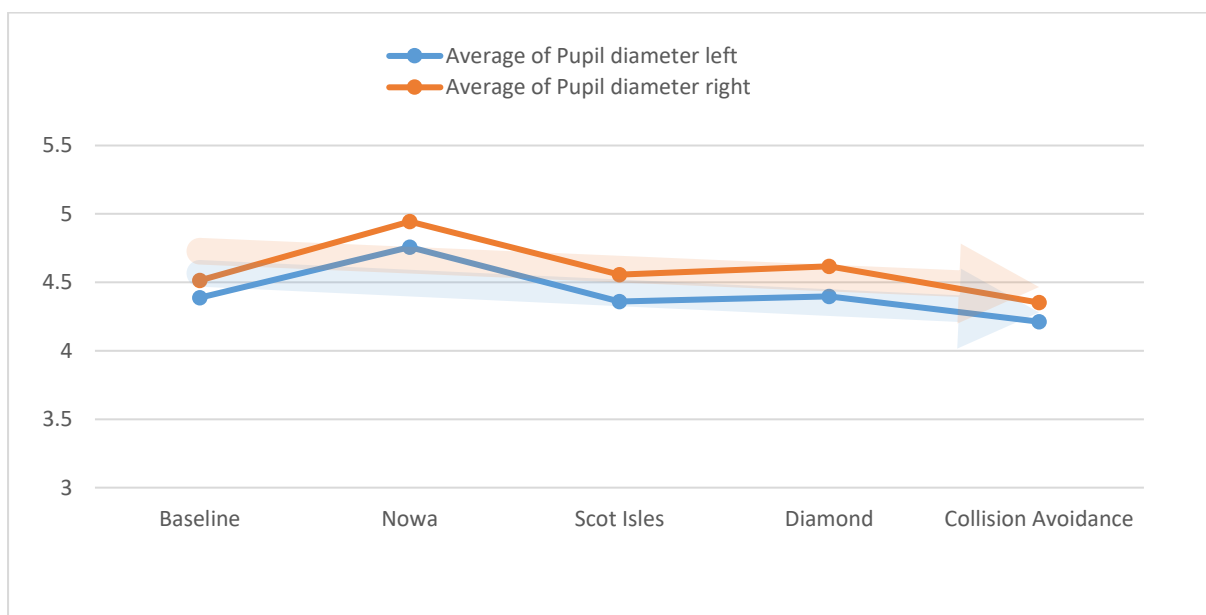


Figure 0.16 P7 Eye pupil diameter

- **Event 1 Baseline:**

During the baseline event, the participant demonstrated average pupils with (4.39mm) and (4.51mm) for the left and right eyes respectively. The participant was not under pressure as there were no external targets to deal with which should made, her calm and low MWL state. However, the increase in the pupil's eye suggests that Participant 7 gets more MWL in addition to attention due to her movement and use of the navigation equipment within the baseline.

The baseline duration is around (18%) of the scenario time, and the participant in the baseline event spent around (9%) of the event time focusing on the radar, (14%) of the event on ECDIS, and around (51%) of the event time visually scanned the surrounding area to check the situation in the surrounding area. Additionally, a small attention was put on the display unite and top display unite which are (17%) and (2%) of the event indicating an initial information check before the targets appear and indicates that Participant 7 used this time to get familiar with the navigation equipment, Figure 0.17



Figure 0.17 P7 Heat map for baseline

- **Event 2 MV Nowa:**

As the MV Nowa appeared on the radar and was visually detected, the participant's eye pupil diameters increased to (4.76 mm) and (4.94 mm) for the left and right sides respectively. This was due to Participant 7 showing increasing in cognitive engagement, maybe because of the sudden appearance of the MV Nowa. In addition, the participant spent around (17%) of the

experiment time monitoring the MV Nowa. The participant has shown a strong reliance on radar, with (51%) of the event time, and (40%) of the event time observed visually on the screen. However, Participant 7 did not use the ECDIS, which indicates that he prefers to use the radar as a navigation system to monitor the target, Figure 0.18.



Figure 0.18 P7 Heat map for MV Nowa

- **Event 3 MV Diamond:**

Participant 7 detected MV Diamond after Scot Isles's detection. During this event pupil dilation decreased slightly to (4.40 mm) and (4.62 mm) indicating that Participant 10 mitigated his cognitive load when the MV diamond appeared with MV Scot. This event took around (19%) of the experiment time. The participant shows that (51%) of event time remained focused on the radar. However, (37%) of the event time also was focused on screens for visualization and this was caused when the MV Diamond communicated with the participant for Participant 7 tried to observe visually to ensure the location of the MV Diamond and the situation awareness. In addition, there was a small attention (5%) during the event time on the ECDIS and (4%) on the Display unit, indicating that the participant was focusing on different systems during communication. The MV diamond duration was shorter because the participant failed to detect the target until receiving a call from MV diamond. Immediately the participant checked the radar and the screen for visualisation, which suggests that the participant did not put his

attention on the Radar for monitoring the targets and he used his visual for observation. Figure 0.19



Figure 0.19 P7 Heat map for MV Diamond

- **Event 4 MV Scot Isles:**

Participant 7 detected MV Scot Isles after MV Nowa detection, the participant's eye diameter slightly decreased to (4.76mm) for the left eye and (4.56 mm) for the right, indicating that the participant started to get lower MWL because participant 7 still did not detect many targets and was talking loudly about the situation to improve his situational awareness. This event took around (14%) of the experiment time. The participant focused approximately (45%) of the event time on the radar during this event to assess the situation with the Scot Isles. However, participant 7 also checked the situation visually with (52%) of the event time checking the external environment, which indicates that participant 7 relied on visual observation to monitor the situation. This suggests that the participant distributes his attention in the ship bridge environment between the navigation equipment and the external observation which indicates he is aware of the situation. Figure 0.20



Figure 0.20 P7 Heat map for MV Scot Isles

- **Event 5 Collision Avoidance:**

The pupil diameter decreased to (4.21 mm) on the left and (4.35 mm) on the right, demonstrating a low cognitive load when he took action to avoid the risk of collision. The collision avoidance action took around (32%) of the experiment time. The participant distributed his attention more widely across the bridge systems during this event. The participant focused this time less on the radar, with (44%) of the event time while (4%) on the ECDIS and (48%) of the event time on screen for visualisation. This means that Participant 7 distributed his attention to the ship bridge environment when he saw the risk of the collision to monitor the target and tried to take imminent action, Figure 0.21



Figure 0.21 P7 Heat map for collision avoidance

Table 0.4 P 7 Point of focus at different scenario events

Row Labels	Display Unit	ECDIS	Engine	VHF	RADAR	Visualization	Top Display Unit
Baseline	17%	14%	8%	0%	9%	51%	2%
Nowa	8%	0%	1%	0%	51%	40%	0%
Scot Isles	2%	0%	0%	0%	45%	52%	0%
Diamond	4%	5%	2%	0%	51%	37%	0%
Collision Avoidance	3%	4%	0%	0%	44%	48%	0%

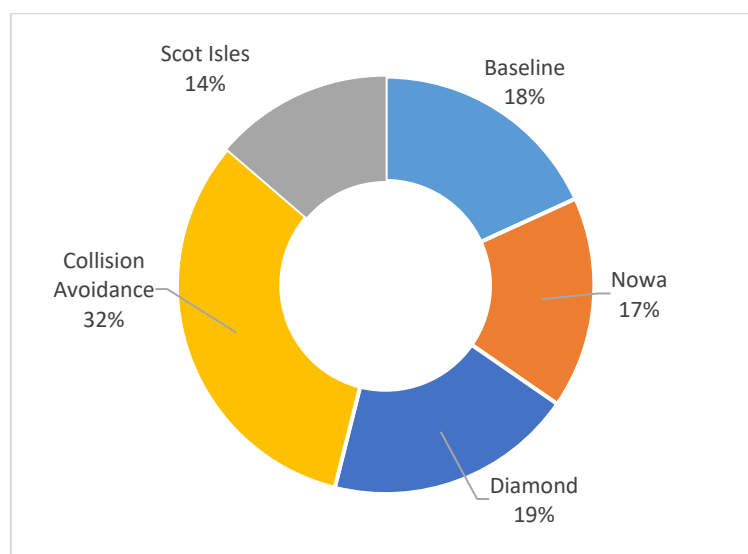


Figure 0.22 P7 Duration time for each event

The combined analysis of EEG and eye tracking data provides a comprehensive view of Participant 7's performance and cognitive demand during the simulator experiment, as shown in the recording. Both results for Participant 7 offer a valuable understanding of how participant respond to each event and the complexity of the scenario from the baseline to the collision avoidance as shown in Figure 0.23 which demonstrates the brain activity across four channels (F4-Pz, P4-Pz, P3-Pz, and F3-Pz) that illustrate the cognitive demand.

The EEG data reveals cognitive engagement, during the baseline, the EEG signals a low variability, indicating a calm state. During MV Nowa and the progress of the event, there is a visible fluctuation

that appears with the front channel which requires cognitive engagement, decision-making, and communication indicating that Participant 7 got involved and increased her MWL. During MV Dimond and Scot Isles, participant 7 was engaged with tasks and communicated with the targets and he was not stable in his action, which indicates that the parietal lobe channel showed remarkable fluctuation, lining up with the tasks that involved sensory processing and spatial awareness. In the last event, the signals began to be calmed, and this was when the collision approached, and Participant 7 took action to avoid the collision.

Similarly, the pupil diameter from eye tracking is closely aligned with EEG findings. During the baseline, the pupil diameter began to be small and stable and increased indicating that the participant was calm. As the scenario proceeded to the MV Nowa event, the eye pupil began to fluctuate, reflecting greater cognitive engagement and attention. During the MV Diamond and Scot Isles, the eye pupil fluctuated and decreased in some points related to Participant 7 starting to be frustrated and this could be a result of the task complexity. During the collision avoidance, there is a bit of stable cognitive demand, which indicates that Participant 7 is aware of the situation, which made him take early action to avoid the collision.

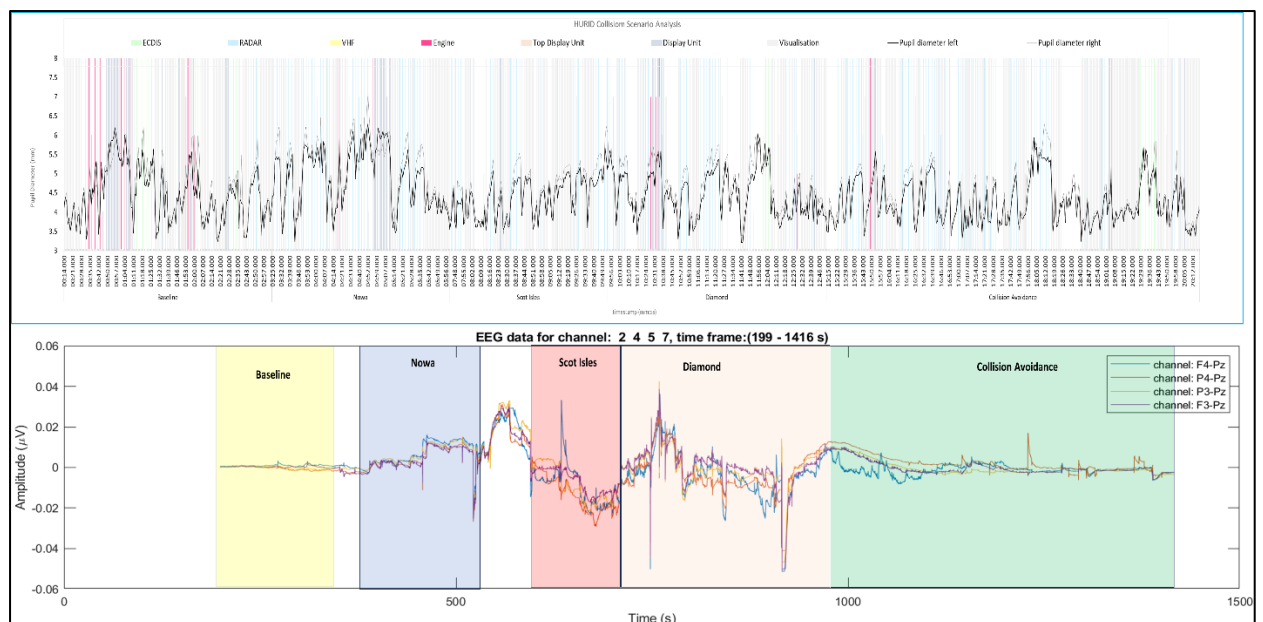


Figure 0.23 P7 EEG and Eye-Tracking

in addition, Figure 0.24 shows significant activity in the delta in the frontal region, which indicates that Participant 7 had a strong cognitive process, especially when he was speaking loudly about the situation to improve his situational awareness.

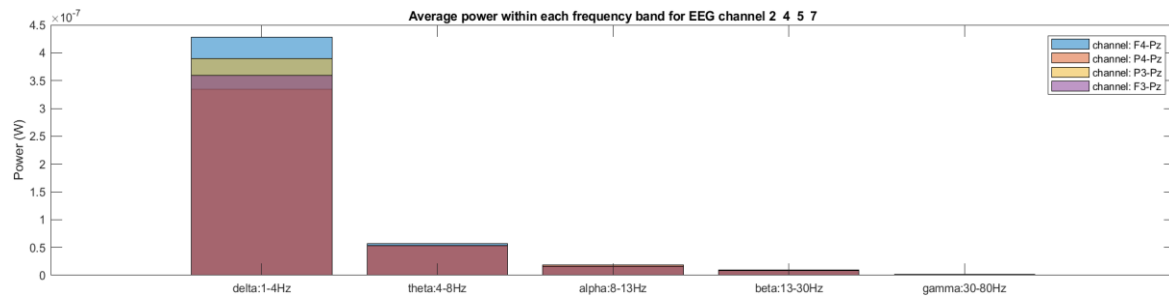


Figure 0.24 P7 Power band

- **Participant 8 (P8)**

During the simulator experiment, participant 8 was navigating on the ideal course, which is the green line, Figure 0.25 shows that Participant 8 passed clear without being involved in a collision with the ship Scot Isles but with a near miss. The experiment occurred during the participant's interaction with five events:

Event 1 Baseline: Participant 8 was just standing in the middle of the ship bridge behind the conning display and just looking around the ship environment without moving. This indicates that participant8 tries to get familiar with the ship environment.

Event 2 MV Nowa: when the targets appeared, participant 8 moved to the radar and detected MV Now visually and then moved to the ECDIS looked at the targets, and back again to the radar and acquired MV Nowa to check the information. He kept monitoring MV Nowa until he received a call from MV Nowa informing him to keep course and speed, and he confirmed. Participant 8 was calm and did not take any action.

Event 3 MV Diamond: Participant 8 was not aware of the MV Diamond. He was just monitoring the targets ahead of the ship on the radar. Then, participant 8 received a call from MV Diamond informing him to keep course and speed, which the participant confirmed. After that, participant 8 became aware of the MV diamond and acquired it on the radar.

Event 4 Mv Scot Isles: While Participant 8 was monitoring the MV Diamond, he observed MV Scot Isles visually at (09m:57s); immediately, participant 8 looked at the target on the radar and acquired it. Then, participant 8 moves to the ECDIS and checks the surroundings on the screen and back to the radar again, monitoring the Scot Isles and other ships ahead. After that, Participant 8 kept moving around to the ECDIS, checking the surroundings, and went back to the radar again. This suggests Participant 8 increased his situation awareness.

Event 5 Collision Avoidance: at (16m:28s), participant 8 reduced speed and back to the radar to monitor the target. Then, participant 8 increased the speed again and monitored the target visually and on the radar. After that, participant 8 moved to the steering, changed the steering to manual, and started to alter the course to starboard until the pass was clear from MV Scot Isles. Even though Participant 8 took action by reducing the speed after around 07 minutes which was considered late, he was aware of the risk of collision and increased the speed again and used manual steering to avoid the collision.



Figure 0.25 P8 Navigation chart

In addition, the heat map provides the participant's visual attention distribution during the ship bridge training simulation in Figure 0.26 , which offers a clear visual focus throughout the events. The red zones indicate the area with high focus, suggesting that the participant concentrated heavily on the radar and rarely used visual observation, which indicates that Participant 8 was over-reliant on automation. Also, the central navigation display shows the participant was focusing on the Scot Isles approaching ahead, indicating his visual observation of the target. The green regions show less intense focus, indicating that the participant was aware of his surroundings, but he spent less time monitoring.



Figure 0.26 P8 Heat map

Based on the EEG result and participant's performance metrics illustrated in Table 0.5, we can observe how the cognitive demand (MWL, Stress, and attention) differentiation across the different events in the simulator experiments as follows, Table 0.5 and Figure 0.27

Table 0.5 P8 EEG data

Time	Event	Duration	MWL	Stress	Attention
00:00 - 03:02	Baseline	03:02	1.00	0.0000	0.64
03:21 - 06:35	Nowa	03:14	0.14	0.0039	0.63
08:57 - 09:57	Diamond	01:00	0.00	1.0000	0.00
09:57 - 16:28	Scot Isles	06:31	0.08	0.0281	0.83
16:28 - 20:28	Collision Avoidance	04:00	0.13	0.0707	1.00

- **Event 1 Baseline:**

During the baseline, the participant showed a high MWL, indicating that Participant 8 was adjusting himself in the bridge environment. The low stress caused by the lack of risk of collision and the high attention suggested that Participant 8 focused on the idea of familiarisation.

- **Event 2 MV Nowa:**

Moving to event 2 MV Nowa, there was a decrease in the MWL and a decrease in stress and high attention. This was when the scenario started, and targets appeared. This suggests that Participant 8 maintained his MWL and Stress when he handled the situation. In addition, the high attention showed that Participant 8 actively monitored the situation.

- **Event 3 MV Diamond:**

The next event, MV Diamond, shows a significant increase in stress with no MWL and no attention. The participant was not aware of the target until he received a call from MV Diamond, indicating that the sudden detection of the MV Diamond and when the communication commenced may have created this stress for the participant despite the no risk of collision.

- **Event 4 MV Scot Isles:**

In the Scot Isles event, the stress decreased with low MWL during this event and high attention. This might be due to the detection of the risk of collision.

- **Event 5 Collision Avoidance:**

In the last event, collision avoidance, after taking the action, there was a low MWL, very low stress, and High attention, which reflects the increasing awareness of Participant 8.

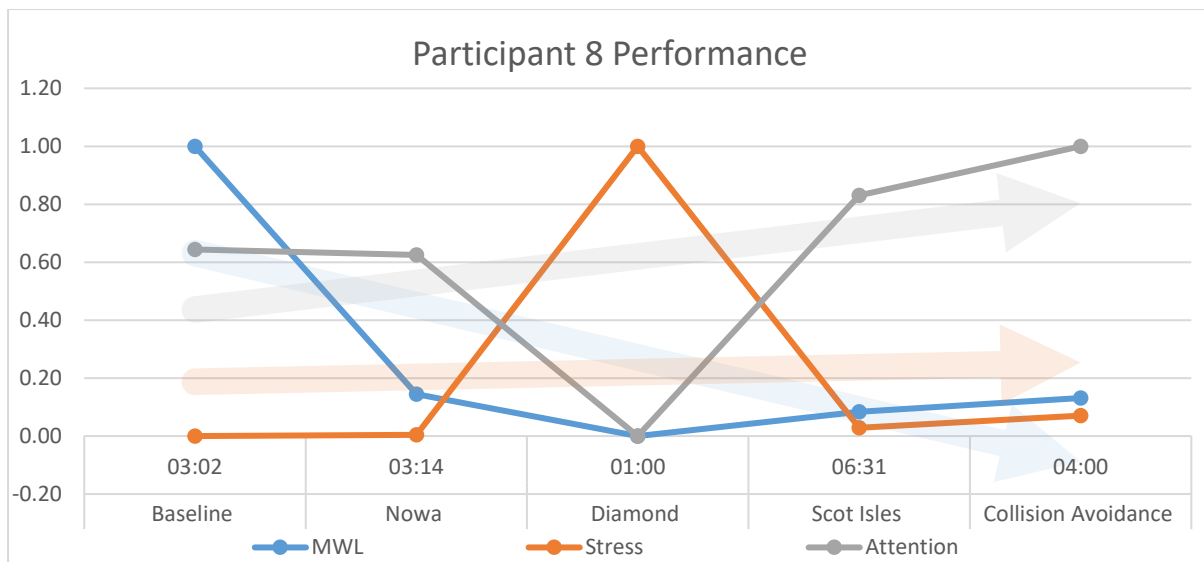


Figure 0.27 P8 EEG Data

The pupil diameters for both eyes show a constant variation during the events. After that, during the Scot Isles, the eye pupil increased slightly until the Collision avoidance event, indicating that the MWL and attention were increased during difficult situations. In Figure 0.28, Figure 0.34 and Table 0.6. The participant's eye pupil dilation was changed as follows:

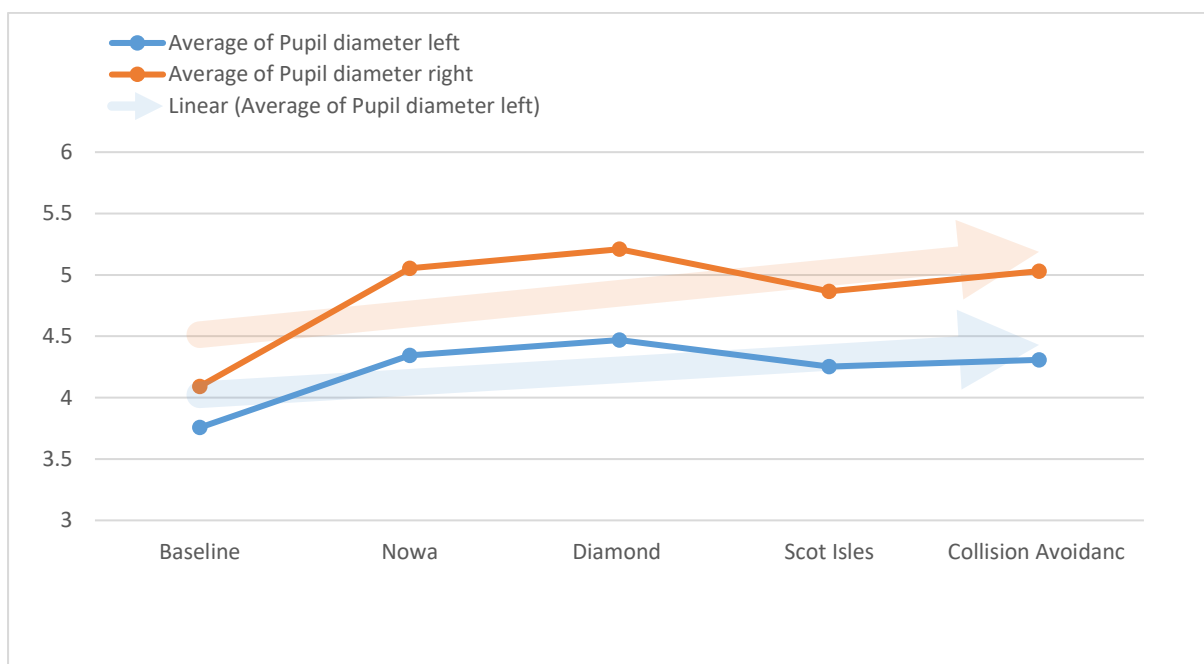


Figure 0.28 P8 Eye Tracking result

- **Event 1 Baseline:**

During the baseline event, the participant demonstrated the lowest average eye pupils with (3.76) and (4.10) for the left and right eyes, respectively. Participant 8 was not under pressure as there were no external targets to deal with, which should have made the participant calm and in a low MWL state.

The baseline duration is around (17%) of the scenario time, and the participant in the baseline event spent around (1%) of the event time focusing on the radar, (5%) of the event on ECDIS, and around (71%) of the event time he visually scanned the surrounding area to check the situation in the surrounding area. Additionally, a small amount of attention was put on the display unit and top display unit, which are (17%) and (4%) of the event time, indicating an initial information check before the targets appear and indicates that Participant 8 used this time to get familiar with the navigation equipment, Figure 0.29



Figure 0.29 P8 Heat Map for Baseline

- **Event 2 MV Nowa:**

As the MV Nowa appeared on the radar and was visually detected, the participant's eye pupil diameters increased to (4.35 mm) and (5.10 mm) for the left and right sides, respectively. Participant 8 was monitoring MV Nowa almost of the time on radar, indicating the increase in the eye pupil size in this event. In addition, the participant spent around (18%) of the experiment

time monitoring the MV Nowa. The participant has shown a strong reliance on radar with (86%) of the event time, and (9%) of the event time observed visually on the screen. However, Participant 8 used the ECDIS only (5%), indicating that he prefers to use the radar as a navigation system to monitor the target, Figure 0.30



Figure 0.30 P8 Heat map for MV Nowa

- **Event 3 MV Diamond:**

During this event, pupil dilation increased slightly to (4.47 mm) and (5.21 mm) indicating that Participant 8 got more workload and attention. This occurred because Participant 8 detected the MV Diamond and also observed MV Nowa visually in this event. This event took around (6%) of the experiment time. In addition, the participant shows that (93%) of the event time remained focused on the radar. However, (3%) of the event time was also focused on screens for visualisation, and this was caused when Participant 8 detected MV Scot Isles and ensured visually that MV Nowa passed clear, which suggests improving the situation awareness. In addition, there was no monitoring of the ECDIS and Display unit because Participant 8 was not aware of the MV Diamond until receiving a communication, which was the end of this event Figure 0.31.



Figure 0.31 P8 Heat map for MV Diamond

- **Event 4 MV Scot Isles:**

In this event, the participant's eye diameter slightly decreased to (4.25 mm) for the left eye and (4.87 mm) for the right, indicating that the participant's 8 MWL decreased. This occurred when the previous targets cleared and only one target, participant 8, focused on MV Scot Isles. This event took around (37%) of the experiment time. The participant focused approximately (72%) of the event time on the radar during this event to assess the situation with the Scot Isles, which still indicates that the participant relied on radar to monitor the situation. However, participant 8 also checked the situation visually, with (8%) of the event time checking the external environment and (16%) of the event time using the ECDIS to support navigational checks. In addition, (1%) was on the engine, which occurred when Participant 8 used the engine for collision avoidance. This suggests that the participant distributes his attention in the ship bridge environment between the navigation equipment and the external observation, which indicates he is aware of the situation and is trying to improve her situation awareness. Figure 0.32



Figure 0.32 P8 Heat Map for MV Scot Isles

- **Event 5 Collision Avoidance:**

The pupil diameter began to decrease to (4.31 mm) on the left and (5.03 mm) on the right, demonstrating a decrease in cognitive load and attention when Participant 8 took action to avoid the risk of collision. The collision avoidance action took around (22%) of the experiment time. The participant distributed his attention more widely across the bridge systems during this event. Participant 8 focused this time less on the radar, with (40%) of the event time, while (1%) on the ECDIS and (16%) of the event time on screen for visualisation. Moreover, Participant 8 was focused (42%) on the display unit when he took the action and used the steering manually and on Auto. This means that Participant 8 distributed his attention to the ship bridge environment when he saw the risk of the collision to monitor the target and tried to take imminent action or avoid the collision Figure 0.33



Figure 0.33 P8 Heat map for collision avoidance

Table 0.6 P8 Points of focus at different scenario events

Row Labels	Display Unit	ECDIS	Engine	VHF	RADAR	Visualisation	Top Display Unit
Baseline	17%	5%	2%	0%	1%	71%	4%
Nowa	0%	5%	0%	1%	86%	9%	0%
Diamond	0%	0%	0%	4%	93%	3%	0%
Scot Isles	2%	16%	1%	0%	72%	8%	0%
Collision Avoidance	42%	1%	1%	0%	40%	16%	1%

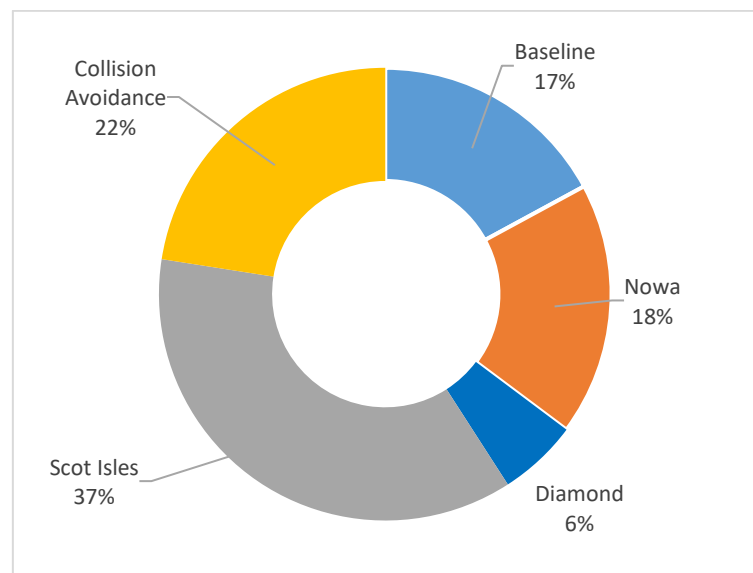


Figure 0.34P8 Duration time for each event

The combined analysis of EEG and eye tracking data provides a comprehensive view of Participant 8's performance and cognitive demand during the simulator experiment, as shown in the recording. Both results for Participant 8 offer a valuable understanding of how Participant 8 responded to each event and the complexity of the scenario from the baseline to the collision avoidance, as shown in Figure 0.35, which demonstrates the brain activity across four channels (F4-PZ, P4-Pz, P3-Pz, and F3-Pz) that illustrate the cognitive demand.

The EEG data reveals cognitive engagement, during the baseline, the EEG signals showed minimum variability, indicating a calm state. During MV Nowa and the beginning of the event, there is a visible fluctuation in the Parietal channel (P3-Pz), which requires cognitive engagement communication. During MV Dimond and Scot Isles, participant 8 was engaged with tasks and communicated with the targets. He moved around the ship's bridge, which indicates that the frontal and parietal lobe channels showed large fluctuation, lining up with the tasks that involved sensory processing and spatial awareness. In the last event, the signals began to calm, especially when MV Scot Isles became clear.

Similarly, the pupil diameter from eye tracking is closely aligned with EEG findings. During the baseline, the pupil diameter was small and stable and increased, indicating that the participant was calm and increased her attention. As the scenario proceeded, MV Nowa appeared and the participant's eye pupil eyes started to increase, which indicated that Participant 8 engaged with the target. During the MV Diamond and Scot Isles, the eye pupil fluctuated and decreased at some points related to the time when Participant 8 started to be frustrated, and this could be a result of the task complexity. During collision avoidance, there are increases, which indicate the increase of the MWL, and attention suggests the improvement of the situation awareness.

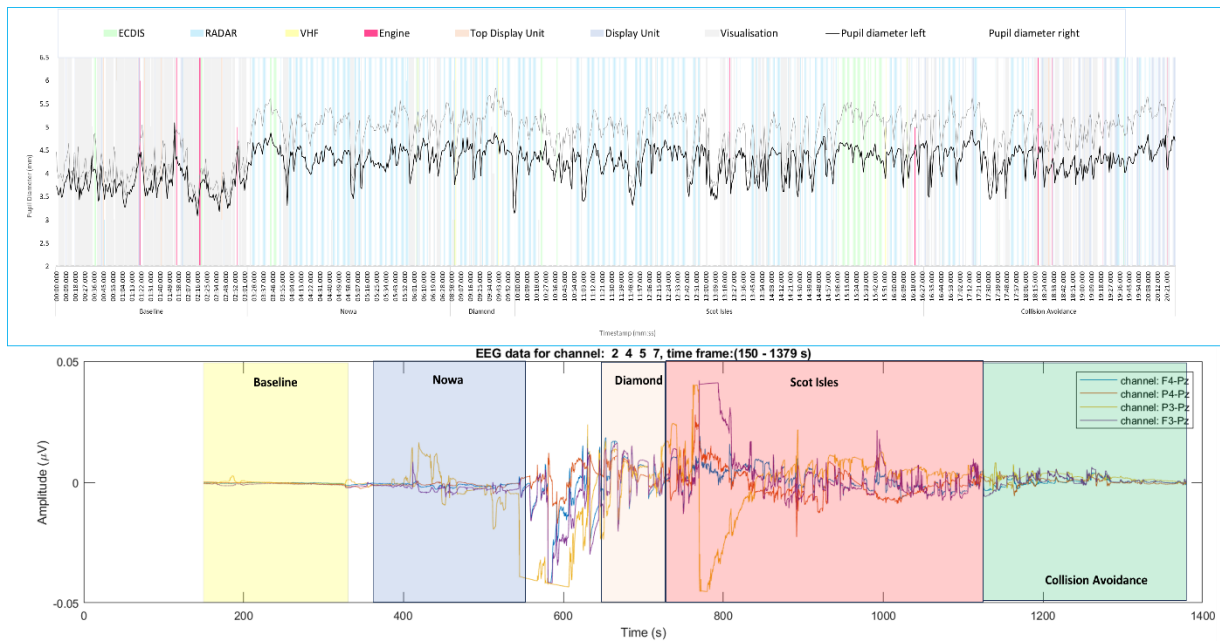


Figure 0.35 P8 EEG and Eye-Tracking

in addition, Figure 0.36 shows fluctuation in EEG bands (delta, theta, alpha, and beta) activity within all channels, which indicates that Participant 8 was engaging in high demand, highlighting improvement after taking action to avoid collision.

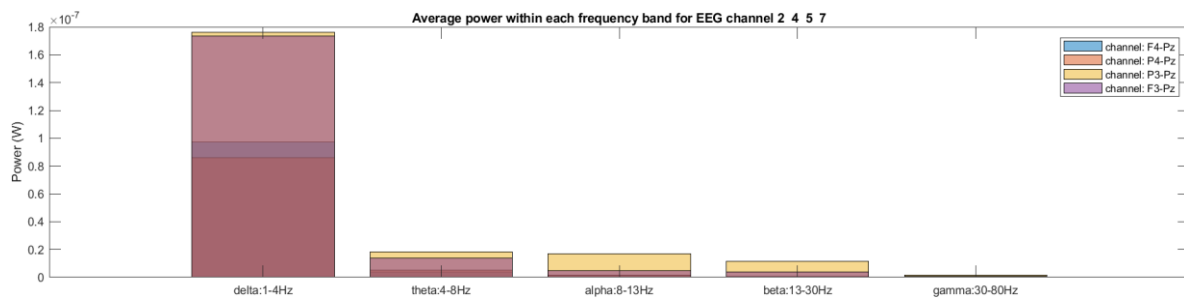


Figure 0.36 P8 Power band

- **Participant 9 (P9)**

During the simulator experiment, participant 9 was navigating on the ideal course, which is the green line, Figure 0.37 shows that Participant 9 passed clear without being involved in a collision with the ship Scot Isles but with a near miss. The experiment occurred during the participant's interaction with five events:

Event 1 Baseline: Participant 9 was moving around and checking the ship's environment and the surroundings until the targets started to appear, which suggested that Participant 9 wanted to get familiar with the environment.

Event 2 MV Nowa: when the targets started to appear, Participant 9 moved to the radar and scanned the targets and checked the conning display. At (04m:45s), Participant 9 tried to acquire the target on the radar, but suddenly asked the support team for help, then said, “ok thank you, no need” when the target information appeared on the radar. After that, participant 9 received a call from MV Nowa informing him to maintain course and speed, which was confirmed by Participant 9.

Event 3 MV Diamond: after communication with MV Nowa closed, Participant 9 was observing the targets ahead on the radar and was not aware of the MV Diamond until receiving a call from MV Diamond informing Participant 9 to maintain the course and speed, which was confirmed by Participant 9.

Event 4 Mv Scot Isles: after communication terminated with MV diamond, participant 9 checked the surroundings and detected MV Scot Isles visually, then acquired on the radar at (10m:33s). Participant 9 kept monitoring the Scot Isles on the radar and contact Scot Isles after (01m:20s) and did not get any response.

Event 5 Collision Avoidance: When Participant 9 did not get any response, he reduced the speed gradually until the engine. Then, participant 9 tried to communicate with Scot Isles again but still did not get any response. Therefore, participant 9 manually altered the course to starboard and then returned the steering to autopilot. After that, Participant 9 monitored the target visually and on the radar. Participant 9 also checked the surroundings until Scot Isles passed a head with a near miss. This suggests that Participant 9 when he took action, was still



Figure 0.38 P9 Heat Map

Based on the EEG result and participant's performance metrics illustrated in Table 0.7 and Figure 0.39, we can observe how the cognitive demand (MWL, Stress, and attention) differentiation across the different events in the simulator experiments as follows:

Table 0.7 P9 EEG data

Time	Event	Duration	MWL	Stress	Attention
00:00 - 03:02	Baseline	03:02	0.04	0.0044	0.88
04:51 - 05:50	Nowa	00:59	0.00	1.0000	1.00
08:33 - 08:49	Diamond	00:16	0.12	0.7829	0.17
10:21 - 11:52	Scot Isles	01:31	1.00	0.0027	0.39
12:31 - 20:49	Collision Avoidance	05:18	0.06	0.0000	0.00

- **Event 1 Baseline:**

During the baseline, the participant showed a low mental workload while stress level was very low, and attention was high. This suggests that the participant was engaged with high attention because there were no targets, and no immediate risk existed.

- **Event 2 MV Nowa:**

Moving to event 2 MV Nowa, there was no MWL and a significant increase in stress and attention. This was when the scenario started, and targets appeared. Participant 9, at the beginning of the Nowa event, asked for support to use the RADAR, which suggests an increase in stress.

- **Event 3 MV Diamond:**

The next event, MV Diamond, shows low stress with no MWL with high stress and low attention. The participant was not aware of the target until he received a call from MV Diamond, indicating that the sudden detection of the MV Diamond and when the communication commenced may have made the stress still high.

- **Event 4 MV Scot Isles:**

In the Scot Isles event, the stress was reduced significantly during this event, and MWL increased with moderate attention. This might be due to the detection of the risk of collision and failure in the communication attempts.

- **Event 5 Collision Avoidance:**

In the last event, collision avoidance, after taking action, there was a very low MWL, no stress, and no attention, which reflects that Participant 9 was frustrated when the collision approached. However, Participant 9 reduced the speed and monitored the Scot Isles until passed too close from ahead.

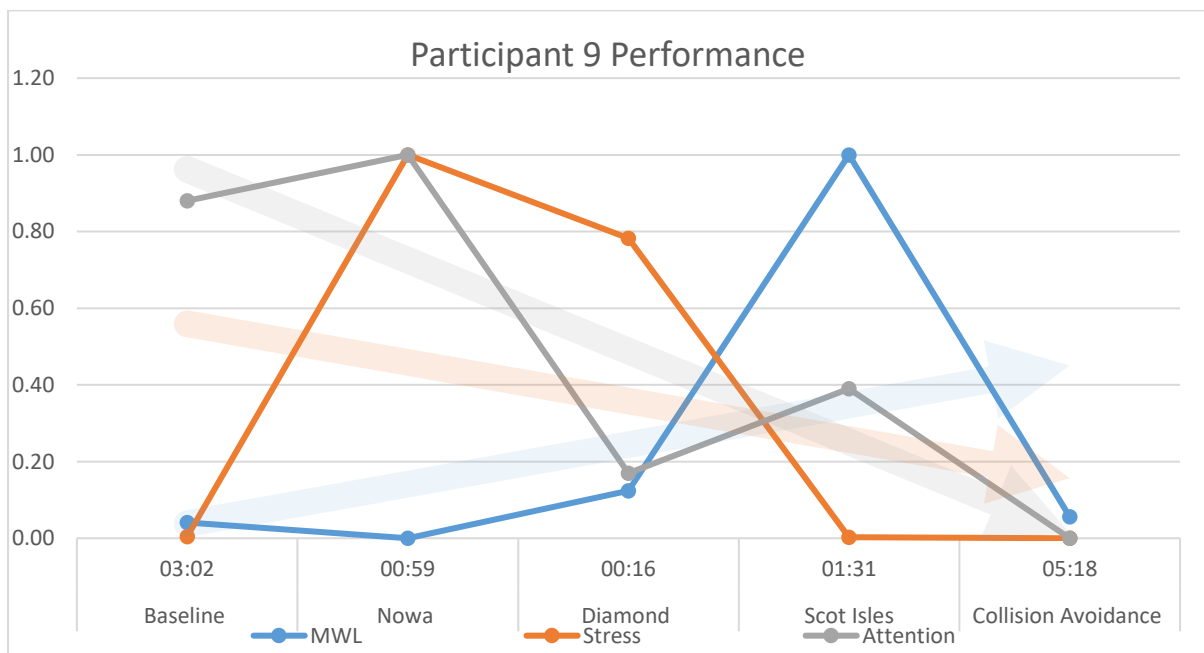


Figure 0.39 P9 EEG data

The pupil diameters for both eyes show a constant increase until the MV Diamond event. After that, during the Scot Isles, the eye pupil decreased slightly and kept decreasing until the end of the Collision, indicating that the MWL increased with the situation as presented and decreased when Participant 9 finished communication with MV Diamond. The participant's eye pupil dilation was changed, as shown in Figure 0.40 and Figure 0.46 for each event as follows:

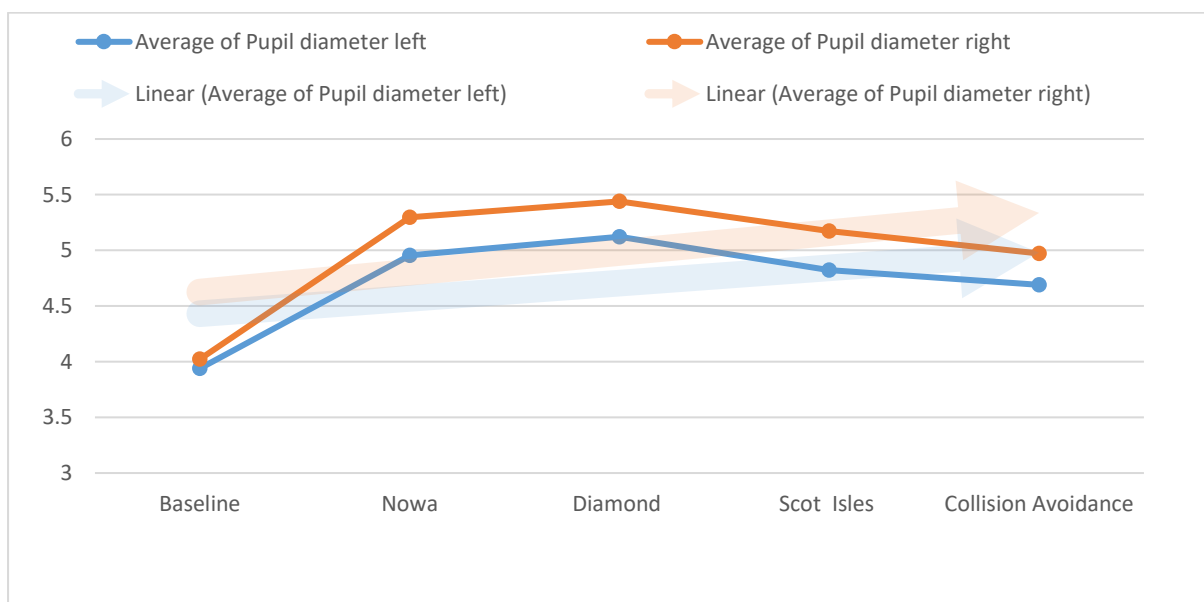


Figure 0.40 P9 Eye-Tracking result

- **Event 1 Baseline:**

During the baseline event, the participant demonstrated the lowest average pupils with (3.93) and (4.02) for the left and right eyes, respectively. The participant was not under pressure as there were no external targets to deal with, which made her calm and in a low MWL state.

The baseline duration is around (21%) of the scenario time, and the participant in the baseline event spent around (16%) of the event time focusing on the radar (23%) of the event on ECDIS, and around (27%) of the event time visually scanned the surrounding area to check the situation

in the surrounding area. Additionally, a small amount of attention was put on the display unit and top display unit, which are (16%) and (18%) of the event indicating an initial information check before the targets appear and indicates that Participant 9 used this time to get familiar with the navigation equipment, Figure 0.41



Figure 0.41 P9 Heat map for baseline

- **Event 2 MV Nowa:**

As the MV Nowa appeared on the radar and was visually detected, the participant's eye pupil diameters increased to (4.95 mm) and (5.29 mm) for the left and right sides, respectively. This was due to the participant showing cognitive engagement, maybe because of the sudden appearance of the MV Nowa. In addition, the participant spent around (7%) of the experiment time monitoring the MV Nowa. The participant has shown a strong reliance on radar, with (98%) of the event time, and (2%) of the event time observed visually on the screen. However, Participant 9 did not use the ECDIS, which indicates that he prefers to use the radar as a navigation system to monitor the target, Figure 0.42 Figure 0.42.



Figure 0.42 P9 Heat map for MV Nowa

- **Event 3 MV Diamond:**

During this event, pupil dilation increased slightly further to (5.12 mm) and (5.44 mm), indicating that the participant had a higher cognitive load when the MV Diamond appeared. This event took around (5%) of the experiment time. The participant shows that (99%) of the event time remained focused on the radar. However, (1%) of the event time, Participant 9 was also focused on screens for visualisation, and the short period of the experiment time of this event was because Participant 9 was not aware. Immediately, Participant 9, after receiving the call, checked the radar and the screen for visualisation, which indicated that Participant 9 was monitoring the RADAR during the communication, Figure 0.43



Figure 0.43 P9 Heat map for MV Diamond

- **Event 4 MV Scot Isles:**

Still, with this event, the participant's eye diameter slightly decreased to (4.82 mm) for the left eye and (5.17 mm) for the right, indicating that Participant 9 MWL started to decrease, especially when the participant communicated with the Scot Isles and assessed the risk of collision. This event took around (10%) of the experiment time, the participant focused approximately (97%) of the event time on the radar during this event to assess the situation with the Scot Isles, which still indicates that the participant relied on radar to monitor the situation. However, participant 4 also checked the situation visually, with (3%) of the event time checking the external environment. This suggests that the participant distributes his attention in the ship bridge environment between the navigation equipment and the external observation only, which indicates he is trying to improve his situation awareness, Figure 0.44.

Figure 0.44



Figure 0.44 P9 Heat map for MV Scot Isles

- **Event 5 Collision Avoidance:**

The pupil diameter remained decreased to (4.69 mm) on the left and (4.97 mm) on the right, demonstrating that Participant 9 cognitive load slightly reduced. The collision avoidance action took around (57%) of the experiment time. During this event, the participant distributed his attention more widely across the bridge systems. The participant focused this time less on the radar, with (67%) of the event time, while (1%) on the ECDIS and (13%) of the event time on the screen for visualisation. This means that Participant 9 focused his attention on the ship bridge environment when he saw the risk of the collision to monitor the target and tried to take imminent action. After taking action and the ship began to be cleared, Participant 9 MWL reduced, Figure 0.45



Figure 0.45 P9 Heat map for collision avoidance

Table 0.8 P9 Points of focus at different scenario events

Row Labels	Display Unit	ECDIS	Engine	VHF	RADAR	Visualisation	Top Display Unit
Baseline	16%	23%	0%	1%	16%	27%	18%
Nowa	0%	0%	0%	0%	98%	2%	0%
Diamond	0%	0%	0%	0%	99%	1%	0%
Scot Isles	0%	0%	0%	0%	97%	3%	0%
Collision Avoidance	12%	1%	0%	0%	72%	14%	1%

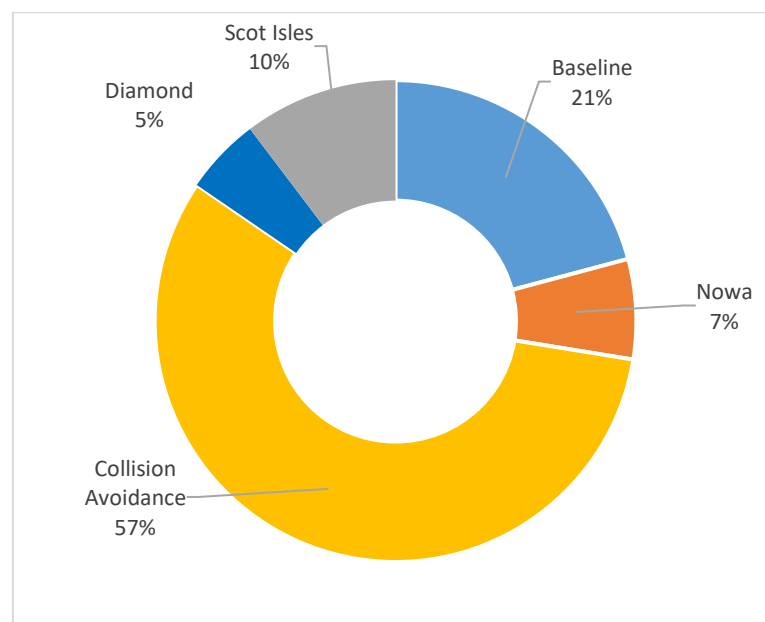


Figure 0.46 P9 Duration time for each event

The combined analysis of EEG and eye tracking data provides a comprehensive view of Participant 9's performance and cognitive demand during the simulator experiment, as shown in the recording. Both results for Participant 9 offer a valuable understanding of how the participant responded to each event and the complexity of the scenario from the baseline to the collision avoidance, as shown in Figure 0.47 which demonstrates the brain activity across four channels (F4-PZ, P4-Pz, P3-Pz, and F3-Pz) that illustrate the cognitive demand.

The EEG data reveals cognitive engagement, during the baseline, the EEG signals a low variability, indicating a calm state. However, there is some engagement in all channels when the targets appear until the collision avoidance event. During MV Nowa and the progress of the event, there is a visible fluctuation that appears with all channels, which requires cognitive engagement, decision-making, and communication, indicating that Participant 9 got involved and increased her MWL. During MV Diamond and Scot Isles, Participant 9 was engaged with tasks and communicated with the lookout and the targets and he was not sure in his action, which indicates that the parietal lobe channel showed remarkable fluctuation, lining up with the tasks that involved sensory processing and spatial awareness. In the last event, the signals began to be calmed, and this was when the collision approached, and Participant 9 began to take action to avoid collision.

Similarly, the pupil diameter from eye tracking is closely aligned with EEG findings. During the baseline, the pupil diameter was small and stable and increased, indicating that the participant was calm and increasing his attention. As the scenario proceeded to the MV Nowa event, the eye pupil began to fluctuate, reflecting greater cognitive engagement, especially when Participant 9 began to acquire the targets. During the MV Diamond and Scot Isles, the eye pupil fluctuated and decreased in some points related to Participant 9, starting to frustrate, and this could be a result of the task complexity. During collision avoidance, there are some increases that indicate the increase of the MWL and attention.

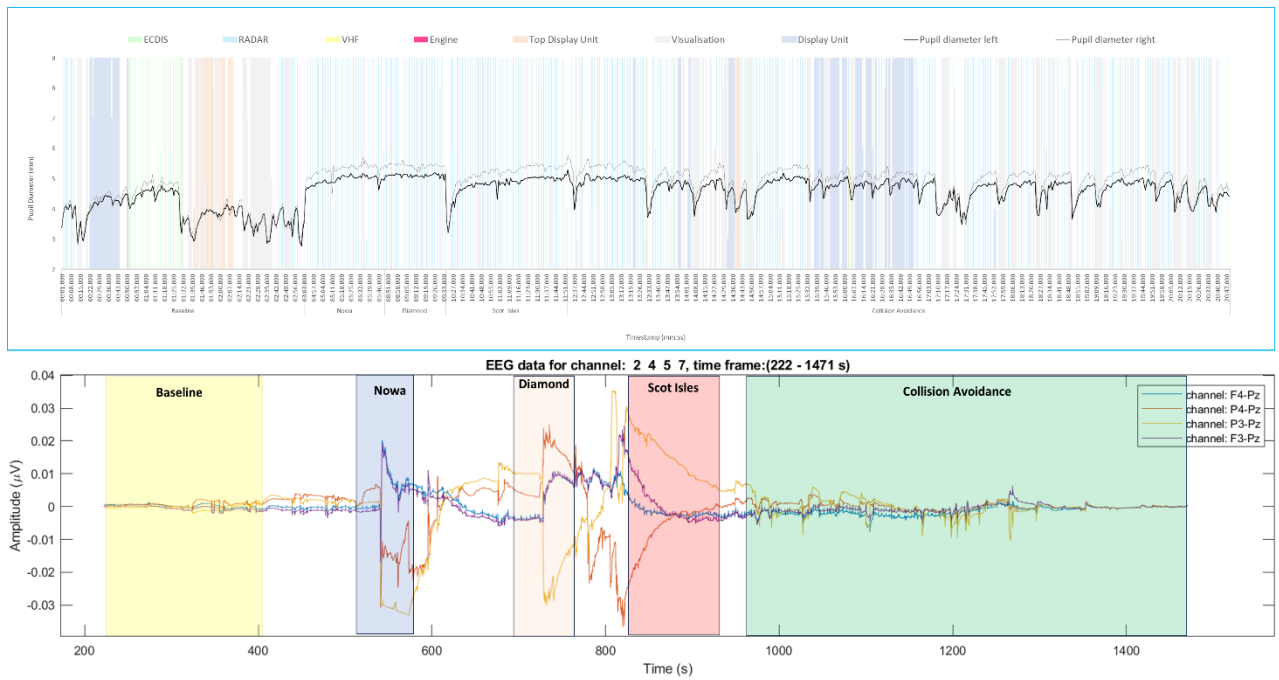


Figure 0.47 P9 EEG and Eye Tracking

In addition, Figure 0.48 shows significant activity in the parietal region, indicating that Participant 9 had strong cognitive process. The parietal lobe channel showed remarkable fluctuation, lining up with the tasks involving sensory processing and spatial awareness.

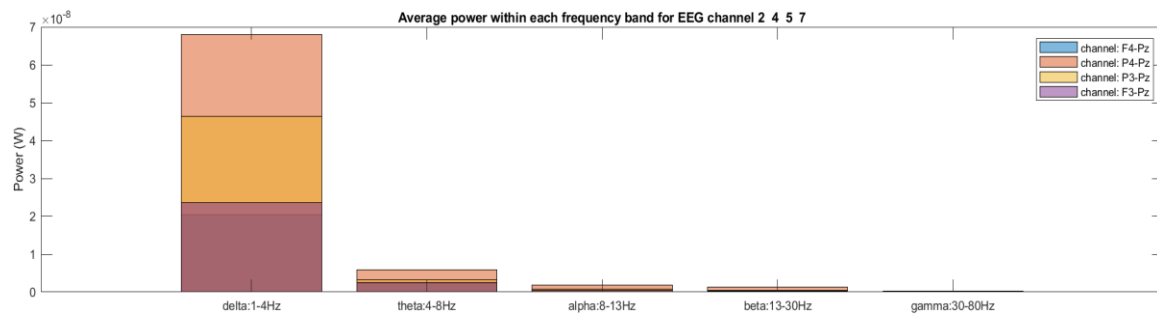


Figure 0.48 P9 Power band

- **Participant 10 (P10)**

During the simulator experiment, participant 10 was navigating on the ideal course, which is the green line, Figure 0.49 shows that Participant 10 passed clear without being involved in a collision and made a sharp manoeuvre. The experiment occurred during the participant's interaction with five events:

Event 1 Baseline: Participant 10 was moving around the ship environment checking the equipment to get familiar.

Event 2 MV Nowa: when the targets start to appear, participant 10 detects the MV Scot Isles on the radar before MV Nowa. Then, participant 10 detected MV Nowa visually and acquired it on the radar. It shows that Participant 10 was monitored by both MV Scot Isles and MV Nowa on the radar until communication from MV Nowa informed Participant 10 to maintain course and speed, which was confirmed by Participant 10.

Event 3 MV Diamond: after finishing communication with MV Nowa, participant 10 acquired the MV Diamond on the radar and observed the targets ahead. Afterwards, participant 10 altered the course to the port side using autopilot and then changed it to manual steering, continuing to alter the course. While steering the ship manually, participant 10 received a call from Mv Diamond requesting him to maintain course and speed. In the meantime, malfunctioning screens started to appear, but the support team fixed it.

Event 4 MV Scot Isles: while the support team fixed the screens, participant 10 monitored MV Scot Isles on the radar. Then, the participant10 checked the surroundings using the screen visualisation panel. After that, participant 10 moved to steering, changed it to manual, and then started to alter the course to starboard.

Event 5 Collision Avoidance: participant 10 kept altering to starboard and tried to call his own ship's captain but did not get an answer. However, Participant 10 kept altering and checking the surroundings on the starboard side until the ship became parallel with MV Scot Isles and passed clear.

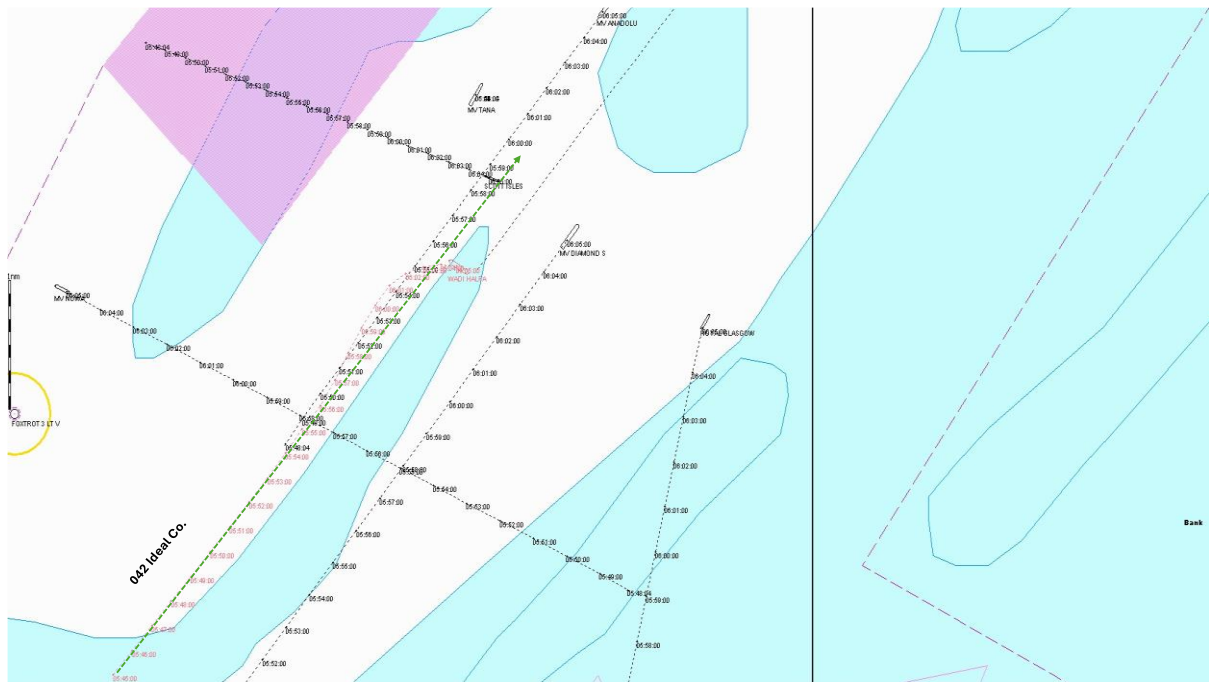


Figure 0.49 P10 Navigation Chart

In addition, the heat map provides the participant's visual attention distribution during the ship bridge training simulation in Figure 0.50 , which offers a clear visual focus throughout the events. The red zones indicate the area with high focus, suggesting that the participant concentrated heavily on the radar and rarely used visual observation, which indicates that the participant was over-reliant on automation. Also, the central navigation display shows the participant was focusing on the Scot Isles approaching a head could at the last moment when it approached. The green regions show less intense focus, indicating that the participant was aware of his surroundings, but he spent less time monitoring these targets.



Figure 0.50 P10 Heat map for baseline

Based on the EEG result and participant's performance metrics illustrated in Table 0.9 and Figure 0.51, we can observe how the cognitive demand (MWL, Stress, and attention) differentiation across the different events in the simulator experiments as follows:

Table 0.9 P10 EEG result

Time	Event	Duration	MWL	Stress	Attention
00:00 - 03:02	Baseline	03:02	0.11	0.0250	0.93
04:51 - 05:50	Nowa	00:59	0.00	0.1579	1.00
08:33 - 08:49	Diamond	00:16	1.00	0.0000	0.03
10:21 - 11:52	Scot Isles	01:31	0.92	1.0000	0.73
12:31 - 20:49	Collision Avoidance	05:18	0.37	0.0068	0.00

- **Event 1 Baseline:**

During the baseline, the participant showed a low mental workload while stress level was very low, and attention was high. This suggests that the participant was engaged with high attention because there were no targets, and no immediate risk existed.

- **Event 2 MV Nowa:**

Moving to event 2 MV Nowa, there was no MWL and a slight increase in stress and attention. This was when the scenario started, and targets appeared. The participants detected the MV Nowa visually and acquired it on the radar immediately.

- **Event 3 MV Diamond:**

The next event, MV Diamond, shows increased MWL and reduced stress and attention. Participant 10 acquired the MV Diamond on the RADAR. Afterwards, Participant 10 altered the course to the port and used the steering manually. In addition, the screen had some issues during the event, which suggests an increase in the MWL.

- **Event 4 MV Scot Isles:**

In the Scot Isles event, the MWL and stress increased significantly during this event with increased attention. This might be because of the screens' issues and the participant could not monitor the targets appropriately. During this event, the screens were fixed, and Participant 10 used the steering manually to keep the ship on the course.

- **Event 5 Collision Avoidance:**

In the last event, collision avoidance, after taking action, there was a very low MWL, no stress, and very low stress and attention, reflecting that the participant was frustrated when the collision approached. However, Participant 10 kept taking action and tried to call the captain, but there was no answer.

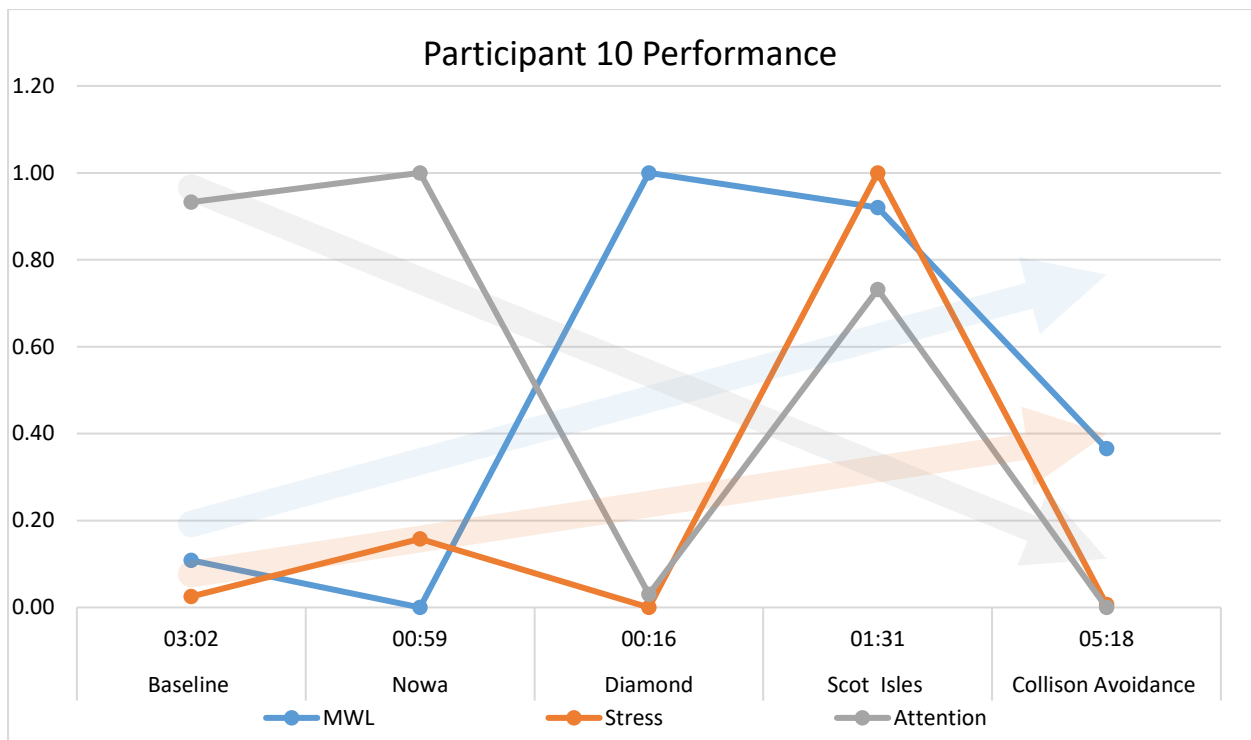


Figure 0.51 P10 EEG result

The pupil diameters for both eyes showed an increase when the targets appeared. After that, during and at the end of the MV Nowa event, the eye pupil decreased slightly and kept decreasing until the end of the collision avoidance event, Figure 0.52 In addition, Table 0.30 and Figure 0.58 showed the distribution of Participant 10's attention.

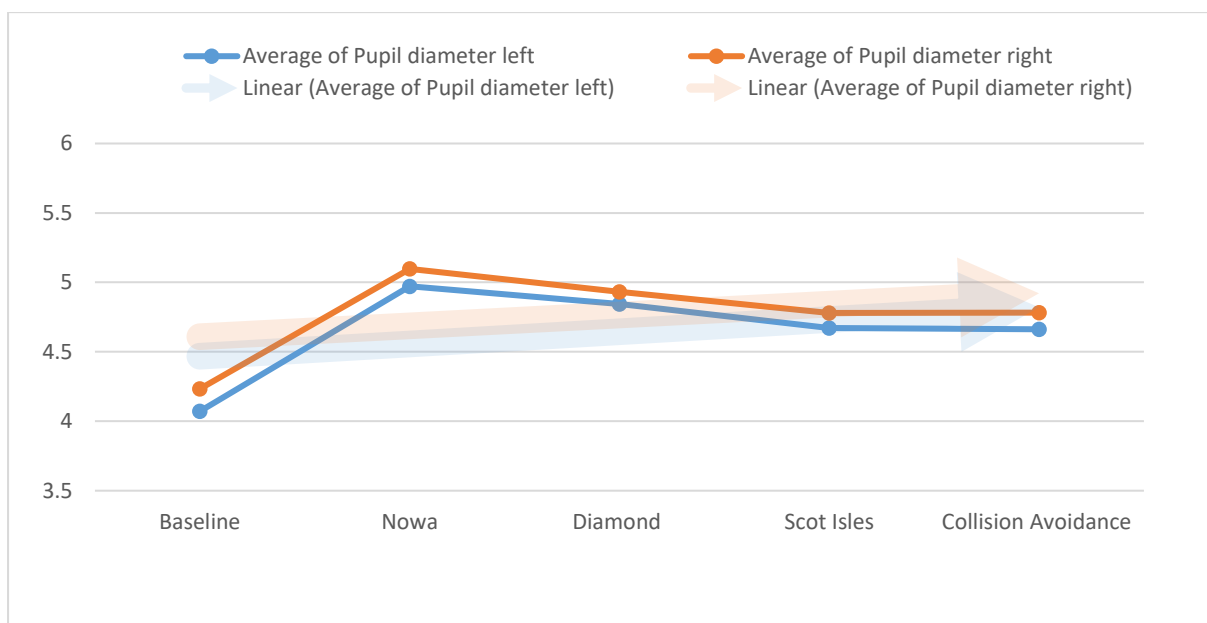


Figure 0.52 P10 Eye-Tracking result

- **Event 1 Baseline:**

During the baseline event, the participant demonstrated the lowest average pupils with (4.07) and (4.23) for the left and right eyes, respectively. The participant was not under pressure as there were no external targets to deal with, which should made her calm and low MWL state. However, the low of the pupil's eye suggests that Participant 10 gets minimum MWL in addition to attention. The baseline duration is around (23%) of the scenario time, and the participant in the baseline event spent around (34%) of the event time focusing on the radar, (20%) of the event on ECDIS, and around (38%) of the event time visually scanning the surrounding area to check the situation in the surrounding area. Additionally, a small amount of attention was put on the display unit, with (6%) of the event indicating initial information check before the targets appeared and indicates that Participant 10 used this time to get familiar with the navigation equipment Figure 0.53



Figure 0.53 P10 Heat map for baseline

- **Event 2 MV Nowa:**

As the MV Nowa appeared on the radar and was visually detected, the participant's eye pupil diameters increased to (4.98 mm) and (5.10 mm) for the left and right sides, respectively. This was due to the participant showing an increase in cognitive engagement, maybe because of the

sudden appearance of the MV Nowa, and Participant 10 was surprised by the situation. In addition, the participant spent around (13%) of the experiment time monitoring the MV Nowa. The participant has shown a strong reliance on radar, with (81%) of the event time, and (18%) of the event time observed visually on the screen. However, Participant 10 did not use the ECDIS which indicates that he prefers to use the radar as a navigation system to monitor the target Figure 0.54,



Figure 0.54 10 Heat map for MV Nowa

- **Event 3 MV Diamond:**

During this event, pupil dilation decreased slightly further to (4.84 mm) and (4.93 mm), indicating that Participant 10 was getting less cognitive load when the MV diamond appeared. This event took around (19%) of the experiment time. The participant shows that (31%) of event time focused on the radar, indicating less attention on the radar. However, (32%) of the event time, Participant 10 also focused on screens for visualisation, and this was caused when the MV Diamond communicated with Participant 10. Participant 10 tried to observe visually to ensure the location of the MV Diamond and the situation awareness. In addition, no attention was paid to the ECDIS. The display unit and Engine got the attention of (23%) and (14%) of the event time, indicating that Participant 10 was using the speed and getting the ship

information from the display unit and was distributing his attention around the bridge Figure 0.55



Figure 0.55 P10 Heat map for MV Diamond

- **Event 4 MV Scot Isles:**

Still, with this event, the participant's eye diameter slightly decreased to (4.67 mm) for the left eye and (4.78 mm) for the right, indicating that Participant 10 cognitive load started to reduce after taking some action during MV Diamond. This event took around (25%) of the experiment time. The participant focused approximately (57%) of the event time on the radar during this event to assess the situation with the Scot of Isle. However, participant 10 also checked the situation visually, with (26%) of the event time checking the external environment, (11%) of the event time monitoring the display unit to support navigational information and (6%) of the event time still observing the engine for speed. This suggests that the participant distributes his attention in the ship bridge environment between the navigation equipment and the external observation, which indicates he is aware of the situation and trying to improve her situation awareness, Figure 0.56



Figure 0.56 P10 Heat map for MV Scot Isles

- **Event 5 Collision Avoidance:**

The pupil diameter remained at (4.66 mm) on the left and (4.78 mm) on the right, demonstrating the same cognitive load when taking action to avoid the risk of collision. The collision avoidance action took around (20%) of the experiment time. During this event, the participant distributed his attention more widely across the bridge systems. The participant focused, this time, less on the radar with (30%) of the event time while (1%) on the ECDIS, and (33%) of the event time on screen for visualisation, and (28%) on the display unit. This means that Participant 10 distributed her attention on the ship bridge environment when he saw the risk of the collision to monitor the target and tried to take imminent action, Figure 0.57



Figure 0.57 P10 Heat map for collision avoidance

Table 0.10 P10 points of focus at different scenario events

Row Labels	Display Unit	ECDIS	Engine	VHF	RADAR	Visualisation	Top Display Unit
Baseline	6%	20%	0%	1%	34%	38%	0%
Nowa	0%	0%	0%	1%	81%	18%	0%
Diamond	23%	0%	14%	0%	31%	32%	0%
Scot Isles	11%	0%	6%	0%	57%	26%	0%
Collision Avoidance	28%	1%	8%	0%	30%	33%	0%

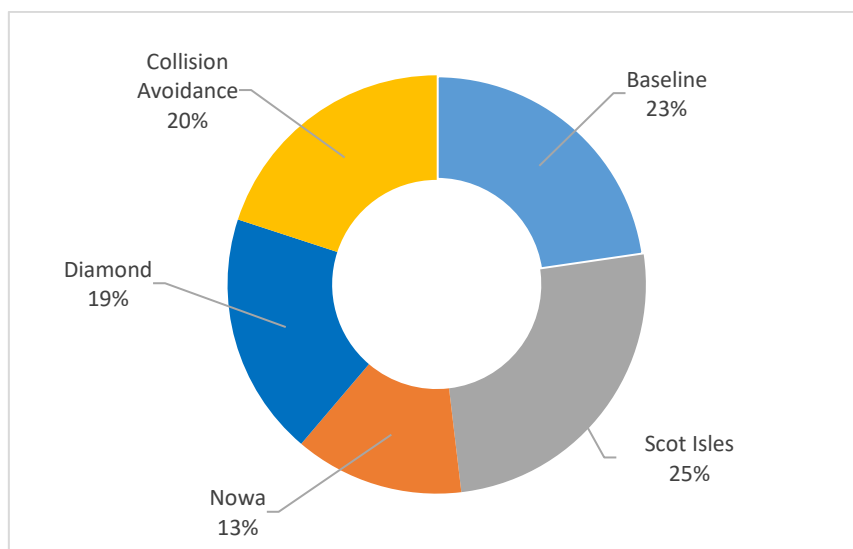


Figure 0.58 P10 Duration time for each event

The combined analysis of EEG and eye tracking data provides a comprehensive view of Participant 10's performance and cognitive demand during the simulator experiment, as shown in the recording. Both results for Participant 10 offer a valuable understanding of how the participant responded to each event and the complexity of the scenario from the baseline to the collision avoidance, as shown in Figure 0.59 which demonstrates the brain activity across four channels (F4-PZ, P4-Pz, P3-Pz, and F3-Pz) that illustrate the cognitive demand.

The EEG data reveals cognitive engagement, during the baseline, the EEG signals a low variability, indicating a calm state. However, there is some engagement in (P4-Pz and F4-Pz), I believed this when Participant 10 engaged and used the navigation equipment. During the MV Nowa event, Participant 10 detected MV Scot Isles and MV Dimond, which suggest visible fluctuation that appears with the Parietal channel, which requires cognitive engagement, decision-making, and communication, indicating that Participant 10 got involved and increased her MWL.

Similarly, the pupil diameter from eye tracking is closely aligned with EEG findings. During the baseline event, the pupil diameter was small and stable and increased, indicating that the participant was calm and increased her attention. As the scenario proceeded to the MV Nowa event, the eye pupil began to fluctuate, reflecting greater cognitive engagement. During the MV Diamond and Scot Isles events, the eye pupil fluctuated and decreased in some points related to Participant 10 starting to be frustrated, which could be a result of the task complexity.

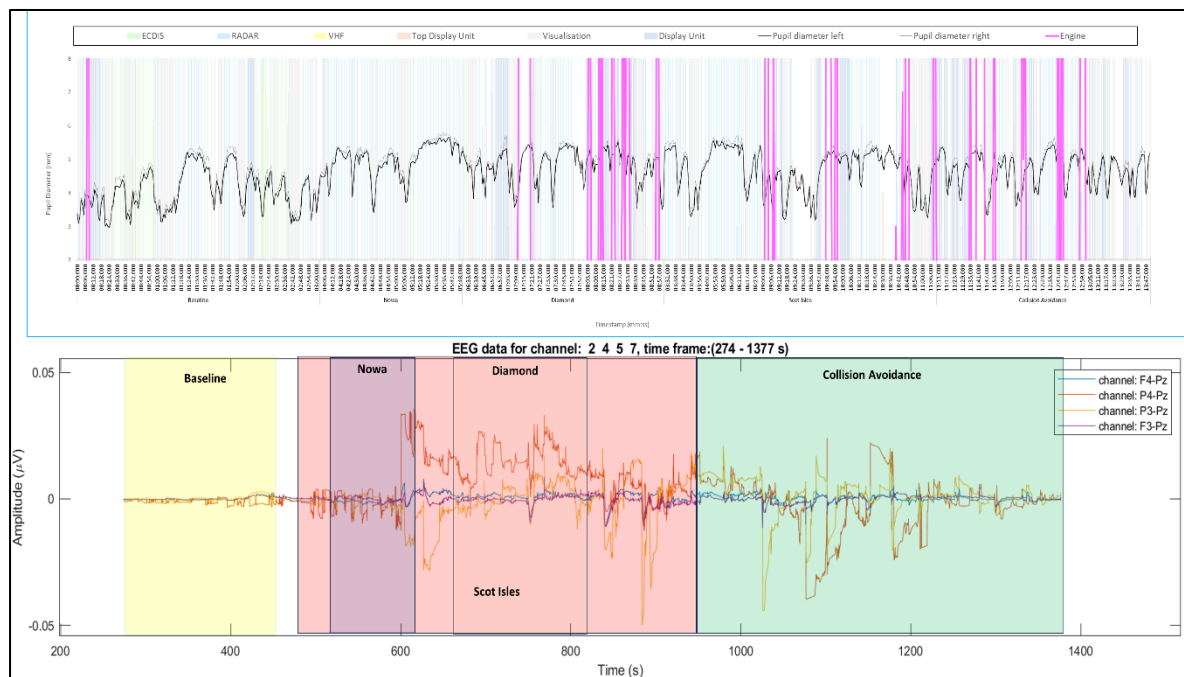


Figure 0.59 P10 EEG and Eye-Tracking

In addition, Figure 0.60 shows significant activity in the parietal region delta, indicating that Participant 10 had a strong cognitive process, which indicates that the parietal lobe channel showed remarkable fluctuation, lining up with tasks involving sensory processing and spatial awareness.

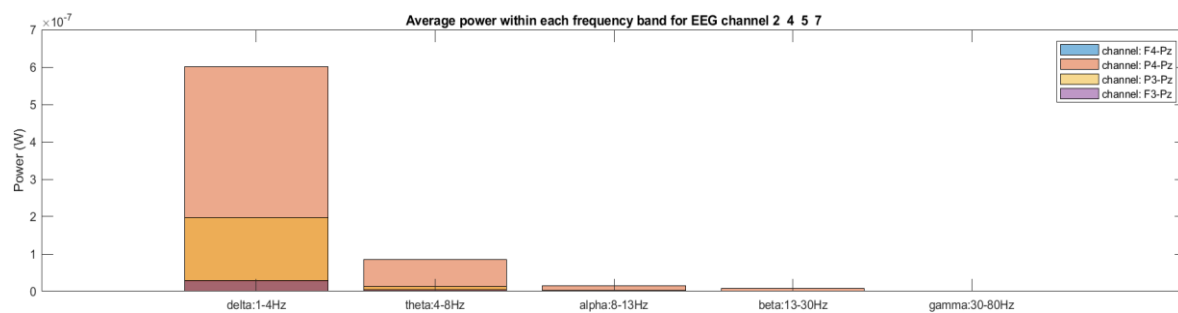


Figure 0.60 P10 Power Band

- **Participant 11 (P11)**

During the simulator experiment, participant 11 was navigating on the ideal course, which is the green line, Figure 0.61 shows that Participant 11 passed clear without being involved in a collision and made a sharp manoeuvre. The experiment occurred during the participant's interaction with five events:

Event 1 Baseline: participant 11 was moving around, checking the surroundings, and focusing on the ECDIS and radar, which suggests that the participant tried to get familiar with the ship bridge environment.

Event 2 MV Nowa: when the targets appeared, the first thing Participant 11 did was reduce the speed, then change the steering to manual and alter the course to the starboard side. After that, Participant 11 detected MV Nowa, acquired it on the radar, and returned to steering. Then, he went back to the radar for monitoring and received a call from MV Now informing him to maintain course and speed. Participant 11 confirmed this after asking MV Nowa about her attention a second time.

Event 3 MV Diamond: the participant was monitoring the MV Nowa and was not aware of MV Diamond until he received a call from MV Diamond informing him to maintain the course and speed. In the meantime, participant 11 acquired MV Scot Isles on the radar and replied to MV Diamond to stand by. After that, participant 11 checked the surroundings and observed the MV Diamond visually and back to communicate with the MV Diamond to confirm the manoeuvring.

Event 4 Mv Scot Isles: after communication was done with MV Diamond, participant 11 monitored Mv Scot Isles and tried to call MV Scot Isles but did not get any response. Therefore, Participant 11 communicated with MV Diamond to explain his attention and actions to reduce speed and alter the course to starboard gradually and passed from MV Diamond's stern to avoid collision with MV Scot Isles.

Event 5 Collision Avoidance: After confirmation with MV Dimond about the action, participant 11 started to reduce speed and alter the course manually. In the meantime,

participant 11 communicated with the Dover Coast Guard, explained his attention and kept updating the Dover Coast Guard about his situation until it became parallel with MV Scot Isles and passed clear. Participant 11 was running on the bridge and speaking very quickly, indicating he was stressed and nervous during the experiment. This would impact his performance, especially when navigating solo and with no assistance, which made him calm. Fortunately, Participant 11 improved his situation and passed clearly.

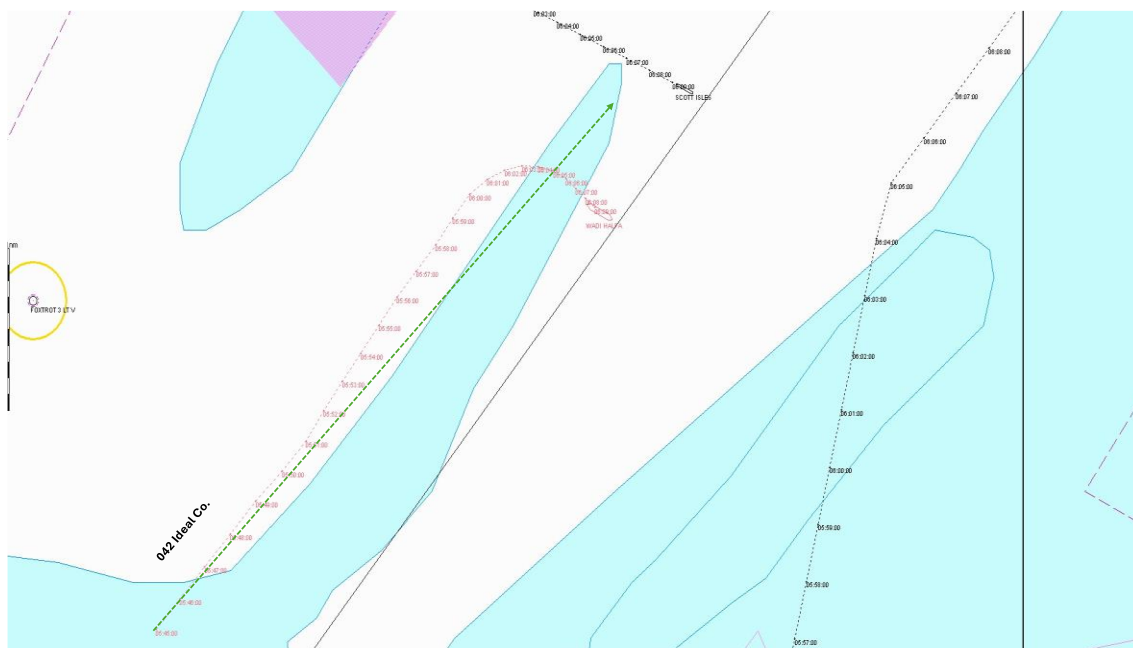


Figure 0.61 P11 Navigation chart

In addition, the heat map provides the participant's visual attention distribution during the ship bridge training simulation in Figure 0.62 , which offers a clear visual focus throughout the events. The red zones indicate the area with high focus, suggesting that the participant concentrated heavily on the radar. Also, the central navigation display shows the participant was focusing on the Scot Isles approaching a head could at the last moment when it approached. This suggests that Participant 11 has an effective situation awareness with his visual distribution. The green regions show less intense focus, indicating that the participant was aware of his surroundings, but he spent less time monitoring these targets.



Figure 0.62 P11 Heat map

Based on the EEG result and participant's performance metrics illustrated in Figure 0.63 and Table 0.11 we can observe how the cognitive demand (MWL, Stress, and attention) differentiation across the different events in the simulator experiments as follows:

Table 0.11 P 11 EEG result

Time	Event	Duration	MWL	Stress	Attention
00:00 - 03:02	Baseline	03:02	0.00	0.0097	0.53
03:08 - 06:04	Nowa	03:02	0.66	0.0493	0.54
09:22 - 10:23	Diamond	01:01	1.00	0.5857	0.00
06:52- 11:38	Scot Isles	04:46	0.07	1.0000	0.40
12:59 - 22:57	Collision Avoidance	09:56	0.52	0.0000	1.00

- **Event 1 Baseline:**

During the baseline, the participant showed a low mental workload while stress level was very low, and attention was moderate. This suggests that the participant was engaged with high attention because there were no targets, and no immediate risk existed.

- **Event 2 MV Nowa:**

Moving to event 2 MV Nowa, there was an increase in the MWL and a slight increase in stress and moderate attention. When the scenario started and targets appeared, Participant 11 had a higher cognitive load.

- **Event 3 MV Diamond:**

The next event, MV Diamond, shows increasing in MWL and stress to moderate with no attention. The participant was not aware of the target until he received a call from MV Diamond, who told them to stand by until the location was checked visually and then back to confirm with MV Diamond. In addition, Participant 11 acquired MV Scot Isles, indicating that the sudden detection of the MV Diamond and when the communication commenced with detecting MV Scot Isles may have created increasing cognitive load and reduced attention

- **Event 4 MV Scot Isles:**

In the Scot Isles event, the stress increased significantly during this event, and this might be due to the detection of the risk of collision and failure in the communication attempts. However, the MWL level becomes very low, and the attention level is moderate.

- **Event 5 Collision Avoidance:**

In the last event, collision avoidance, after taking action, there was Moderate MWL, no stress, and high attention, which reflects improved situation awareness after taking action and keeping clear with other ships.

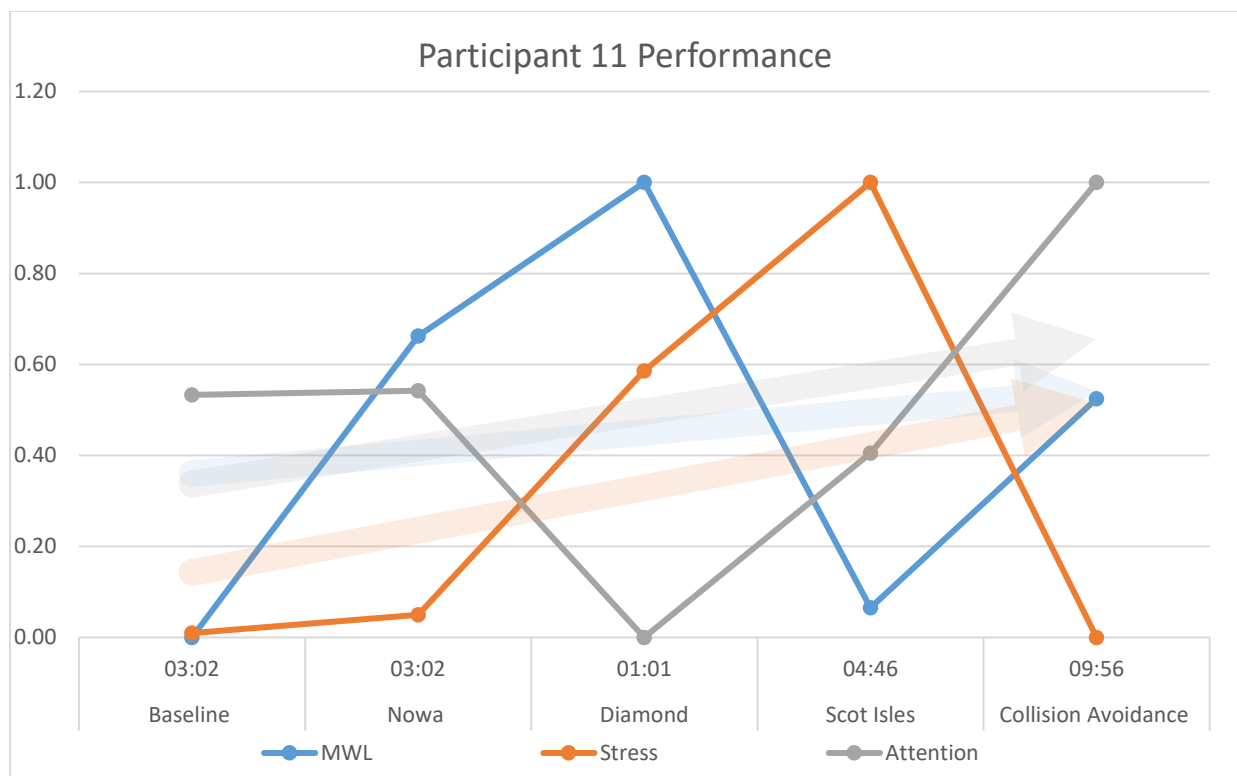


Figure 0.63 P11 EEG result

The pupil diameters for both eyes show a constant increase during the events. After that, during the MV Dimond, the eye pupil decreased slightly and kept decreasing until the end of the Collision, indicating that the MWL fluctuated with the situation as presented in Figure 0.64. The participant's eye pupil dilation was changed, as shown in Table 0.12 and Figure 0.70, for each event as follows:

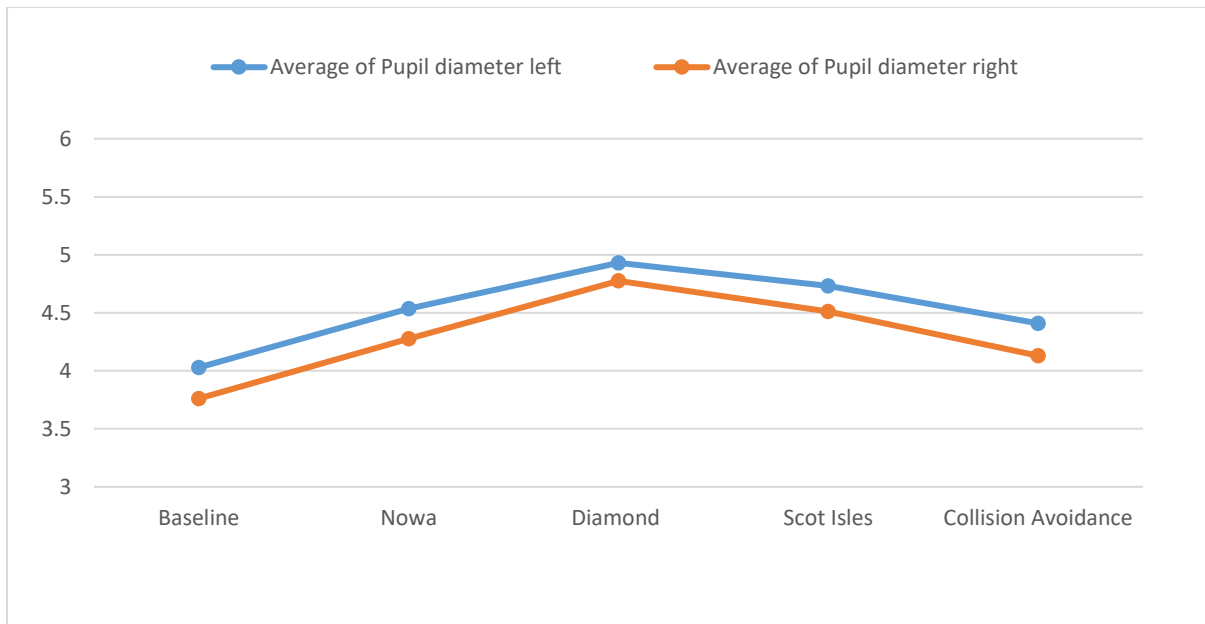


Figure 0.64 P11 Eye-Tracking result

- **Event 1 Baseline:**

During the baseline event, the participant demonstrated the lowest average pupils with (4.02) and (3.76) for the left and right eyes, respectively. The participant was not under pressure as there were no external targets to deal with, which should make her calm and low MWL state. However, the low of the pupil's eye suggests that Participant 10 gets minimum MWL in addition to attention. The baseline duration is around (15%) of the scenario time, and the participant in the baseline event spent around (8%) of the event time focusing on the radar, (39%) of the event on ECDIS, and around (50%) of the event time visually scanned the surrounding area to check the situation in the surrounding area. Additionally, a small amount of attention was put on the display unit, with (2%) of the event indicating an initial information check before the targets appeared and indicated that Participant 11 used ECDIS this time to get familiar with the navigation equipment, Figure 0.65



Figure 0.65 P11 Heat map for baseline

- **Event 2 MV Nowa:**

As the MV Nowa appeared on the radar and was visually detected, the participant's eye pupil diameters increased to (4.53 mm) and (4.27 mm) for the left and right sides, respectively. This was due to the participant showing an increase in cognitive engagement, maybe because of the sudden appearance of the MV Nowa, and Participant 11 was surprised by the situation. In addition, the participant spent around (14%) of the experiment time monitoring the MV Nowa. The participant has shown a strong reliance on radar, with (43%) of the event time, and (41%) of the event time observed visually on the screen. The display unit was around (11%) of the event time. However, Participant 11 did not use the ECDIS, which indicates that he prefers to use the radar as a navigation system to monitor the target, Figure 0.66



Figure 0.66 P11 Heat map for MV Nowa

- **Event 3 MV Diamond:**

During this event, pupil dilation increased slightly further to (4.93 mm) and (4.77 mm), indicating that Participant 11 was getting more cognitive load when the MV diamond appeared. This event took around (5%) of the experiment time. The participant shows that (94%) of the event time focused on the radar, indicating high attention on the radar. However, (17%) of the event time, Participant 11 also focused on screens for visualisation, and this was caused when the MV Diamond communicated with Participant 11. Participant 11 tried to observe visually to ensure the location of the MV Diamond and the situation awareness. In addition, there was little attention on the ECDIS with (1%) of the event time. The display unit got the attention of (16%) of the event time, indicating that Participant 11 was getting the ship information from the display unit and was distributing his attention around the bridge, Figure 0.67



Figure 0.67 P11 Heat map for MV Diamond

- **Event 4 MV Scot Isles:**

With this event, the participant's eye diameter slightly decreased to (4.73 mm) for the left eye and (4.51 mm) for the right, indicating that Participant 11 cognitive load started to reduce after taking some action during MV Diamond. This event took around (18%) of the experiment time. The participant focused approximately (94%) of the event time on the radar during this event to assess the situation with the Scot of Isle. However, participant 11 also checked the situation visually with (4%) of the event time checking the external environment, and (1%) of the event time monitoring the display unit to support navigational information. This suggests that Participant 11 relied on the radar to monitor the target, Figure 0.68.



Figure 0.68 P11 Heat Map for MV Scot Isles

- **Event 5 Collision Avoidance:**

The pupil diameter decreased to (4.41 mm) on the left and (4.13 mm) on the right, demonstrating reduced cognitive load when taking action to avoid the risk of collision. The collision avoidance action took around (48%) of the experiment time. The participant distributed his attention more widely across the bridge systems during this event. The participant focused this time less on the radar, with (12%) of the event time while (11%) on the ECDIS, and (74%) of the event time on screen for visualisation, and (3%) on the display unit. This means that Participant 11 distributed his attention on the ship bridge environment and relied on his visual observation when he saw the risk of the collision to monitor the target and tried to take imminent action, Figure 0.69



Figure 0.69 P11 Heat map for collision avoidance

Table 0.12 P11Points of focus at different scenario events

Row Labels	Display Unit	ECDIS	Engine	VHF	RADAR	Visualisation	Top Display Unit
Baseline	2%	39%	0%	0%	8%	50%	1%
Nowa	11%	0%	3%	1%	43%	41%	0%
Diamond	16%	1%	0%	1%	59%	17%	5%
Scot Isles	1%	0%	0%	1%	94%	4%	0%
Collision Avoidance	3%	7%	0%	2%	12%	74%	1%

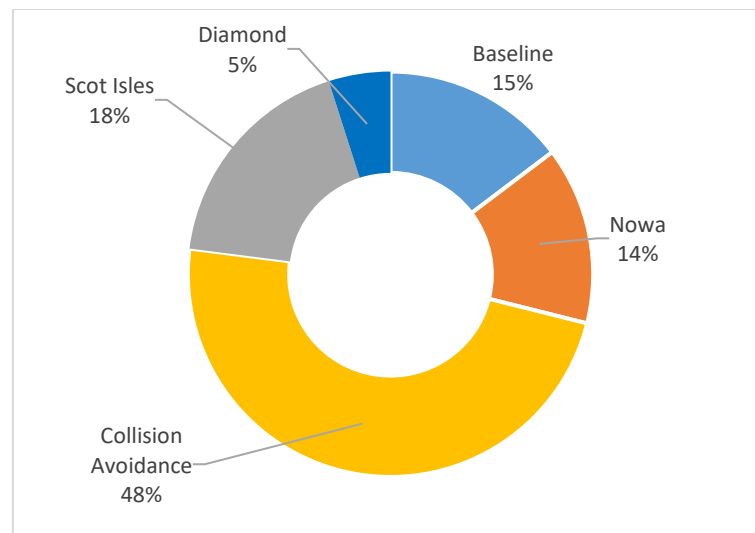


Figure 0.70 P11 duration time for each event

The combined analysis of EEG and eye tracking data provides a comprehensive view of Participant 11's performance and cognitive demand during the simulator experiment, as shown in the recording. Both results for Participant 11 offered a valuable understanding of how Participant 11 responded to each event and the complexity of the scenario from the baseline to the collision avoidance, as shown in Figure 0.71, which demonstrates the brain activity across four channels (F4-Pz, P4-Pz, P3-Pz, and F3-Pz) that illustrate the cognitive demand.

The EEG data reveals cognitive engagement, during the baseline, the EEG signals a low variability, indicating a calm state. However, there is some engagement in (P3-Pz), I believed this when Participant 11 engaged and used the navigation equipment for familiarisation. During MV Nowa and the progress of the event, there is a visible fluctuation that appears with the Parietal channel, which requires cognitive engagement, decision-making, and communication, indicating that Participant 11 got involved and increased her MWL.

Similarly, the pupil diameter from eye tracking is closely aligned with EEG findings. During the baseline, the pupil diameter was small and stable and increased, indicating that the participant was calm and increased her attention. As the scenario proceeded to the MV Nowa event, the eye pupil began to fluctuate, reflecting greater cognitive engagement. During the MV Diamond, the eye pupil fluctuated and decreased in some points related to Participant 11 starting to be frustrated, and this could be a result

of the task complexity. During collision avoidance, eye pupils decrease, indicating a decrease in the MWL and attention.

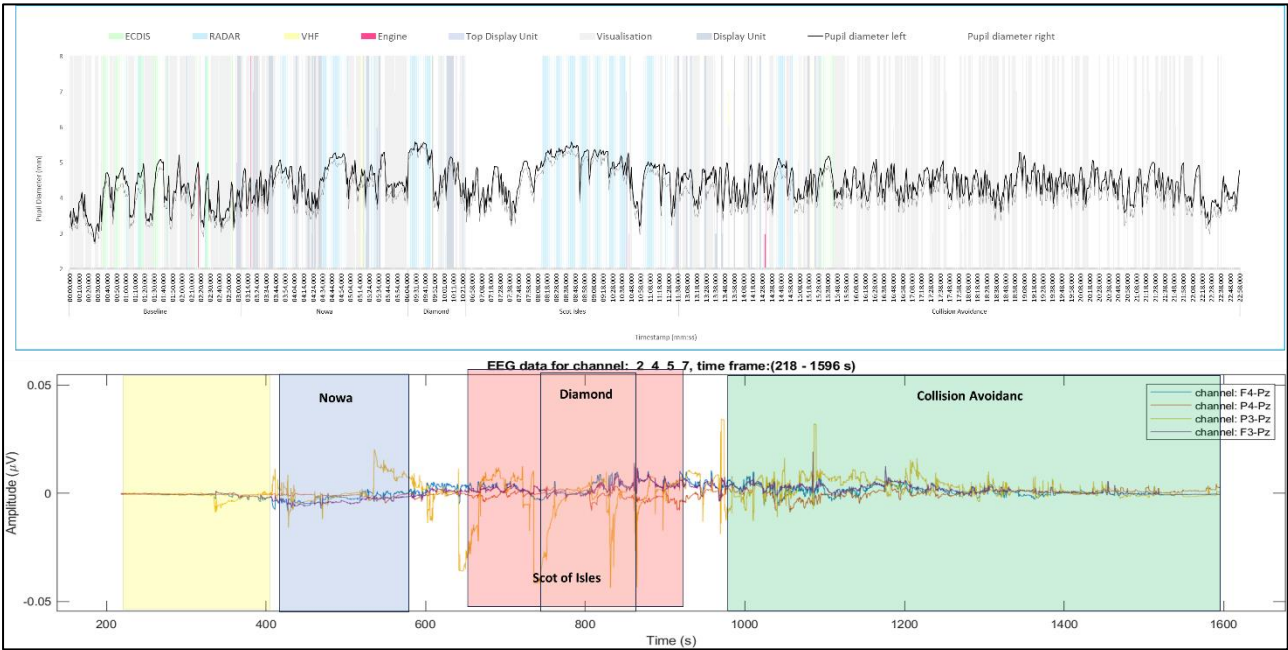


Figure 0.71 P11 EEG and Eye-Tracking

In addition, Figure 0.72 shows significant activity in the parietal region, which indicates that Participant 11 had a strong cognitive process, especially when he *communicated* with the Coast Guard and took action at the same time.

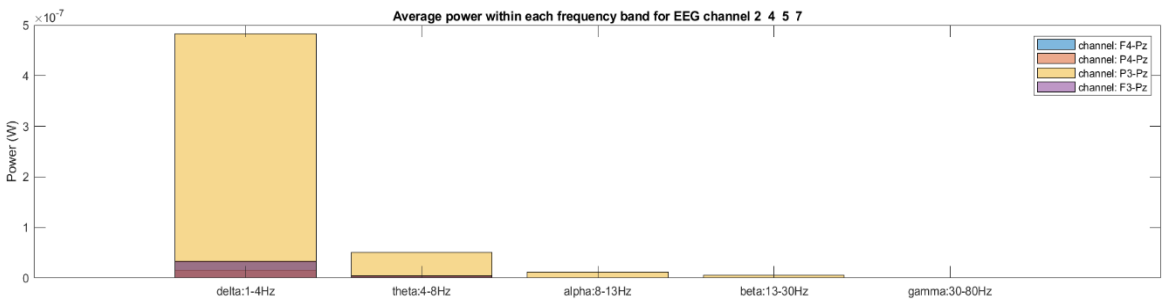


Figure 0.72 P11 Power band

- **Participant 12 (P12)**

During the simulator experiment, participant 12 was navigating on the ideal course, which is the green line, Figure 0.73 shows that Participant 12 passed clear without being involved in a collision. The experiment occurred during the participant's interaction with five events:

Event 1 Baseline: participant 12 was moving around checking the surroundings and he suggested that the participant try to get familiar with the bridge environment and the area around the ship.

Event 2 MV Nowa: when the targets appeared, participant 12 acquired the ship ahead on the radar and then moved to the ECDIS to monitor the targets and back to the radar again. Participant 12 detected MV Nowa visually and tried to acquire it on the radar, but she could not. Therefore, participant 12 communicated with the support team and said “It is a bit difficult to use navigation equipment”, asking for help. In the meantime, MV Nowa communicated with Participant 12 and informed her to maintain course and speed, which was confirmed by Participant 12. This indicated that Participant 12 did not get enough familiarisation with the ship environment and needed more familiarisation time.

Event 3 MV Diamond: after finishing communication with MV Nowa. One of the support teams helped Participant 12 acquire the target but still did not know how to get the information. Therefore, Participant 12 moved to the ECDIS to monitor the targets but did not get to use the ECDIS. After that, participant 12 received a call from MV Dimond informing the participant 12 to maintain course and speed. Participant 12 asked again to repeat and then confirmed the request.

Event 4 Mv Scot Isles: the participant detected MV Scot Isles visually at (14m:20s). Before that Participant 12 still did not know how to use the equipment until one of the support teams explained to her how to use it. However, after acquiring the MV Scot Isles, supported by the support team, Participant 12 changed the steering to manual and altered the course to starboard.

Event 5 Collision Avoidance: Participant 12 altered the course to starboard and called the captain but no one answered. Then she called MV Dimond and informed her attention that she

altered the course to avoid MV Scot Isles and resumed the course after passing clear, which was confirmed by MV Diamond. However, participant 12 altered to starboard and MV Scot Isles passed a stern clear.

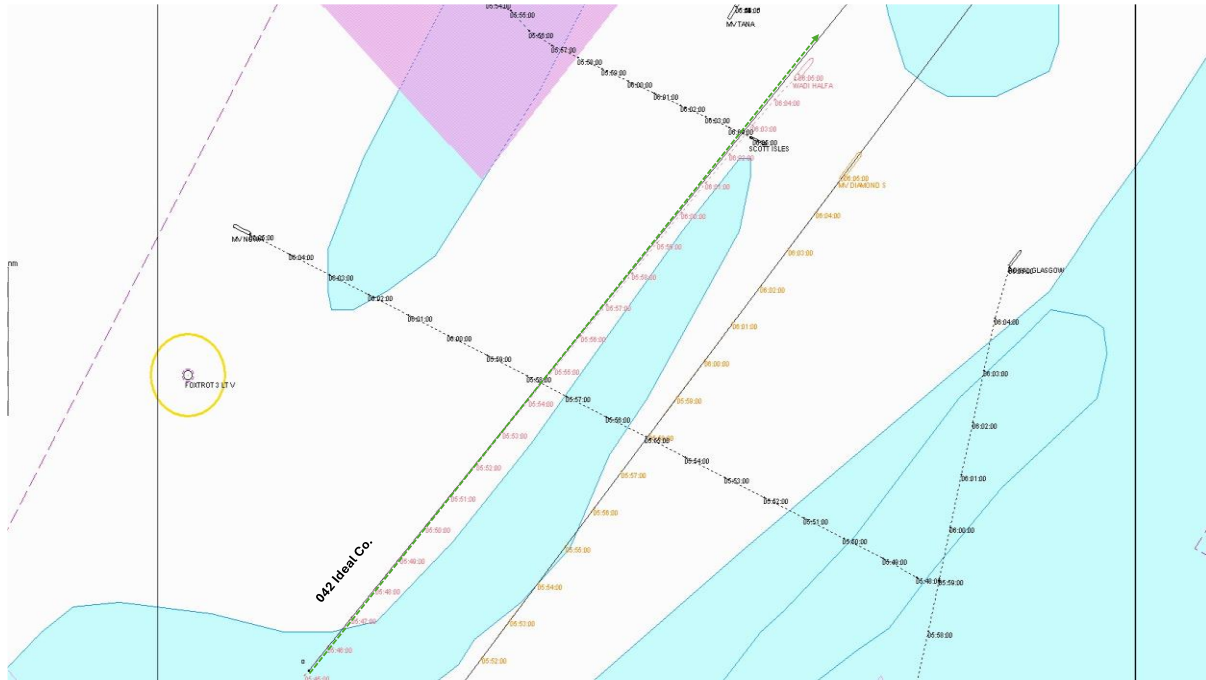


Figure 0.73 P12 Navigation chart

In addition, the heat map provides the participant's visual attention distribution during the ship bridge training simulation in Figure 0.74 , which offers a clear visual focus throughout the events. The red zones indicate the area with high focus, suggesting that the participant concentrated heavily on the radar and rarely used visual observation which indicates that the participant was over-relied on automation. Also, the central navigation display shows the participant was focusing on the Scot Isles approaching a head could at the last moment when it approached. The green regions show less intense focus, indicating that the participant was aware of his surroundings, but he spent less time monitoring these targets.



Figure 0.74 P12 Heat Map

Based on the EEG result and participant's performance metrics illustrated in Table 0.13 and Figure 0.75 Figure 0.75 P 12 EEG result, we can observe how the cognitive demand (MWL, Stress, and attention) differentiation across the different events in the simulator experiments as follows:

Table 0.13 P12 EEG result

Time	Event	Duration	MWL	Stress	Attention
00:00 - 03:04	Baseline	03:04	1.00	0.0000	1.00
05:21 - 06:26	Nowa	01:05	0.00	1.0000	0.00
03:04 - 09:25	Diamond	06:11	0.55	0.0098	0.23
14:18 - 17:36	Scot Isles	03:18	0.81	0.0085	0.10
17:36 - 20:12	Collision Avoidance	02:36	0.62	0.0132	0.30

- **Event 1 Baseline:**

During the baseline, the participant showed a high mental workload while stress level was very low, and attention was high. This suggests that Participant 12 was engaged with high attention because there were no targets, and no immediate risk existed.

- **Event 2 MV Nowa:**

Moving to event 2 MV Nowa, there was a decrease in the MWL, increased stress, and reduced attention. When the scenario started and targets appeared, the participant began to get more

stress dealing with the targets especially when she said, “It is a bit difficult to use navigation equipment”.

- **Event 3 MV Diamond:**

The next event, MV Diamond, shows very low stress with moderate MWL and low attention. Participant 12 was not familiar with the radar and was not aware of the target until she received a call from MV Diamond, indicating that the sudden detection of the MV Diamond and when the communication commenced may have created an increase in MWL and slight increase in the attention for the participant, despite the still no risk of collision.

- **Event 4 MV Scot Isles:**

In the Scot Isles event, the MWL increased during this event with low attention, and this might be due to the fact that Participant 12 still did not know how to use the equipment until one of the support teams explained how to use it. However, after acquiring the MV Scot Isles, supported by the support team. Participant 12 changed the steering to manual and altered the course to starboard.

- **Event 5 Collision Avoidance:**

In the last event, collision avoidance, after taking the action, MWL was still high with moderate attention, and very low stress. This might be because Participant 12 kept communicating with MV Diamond about the risk of collision and taking action at the same time.

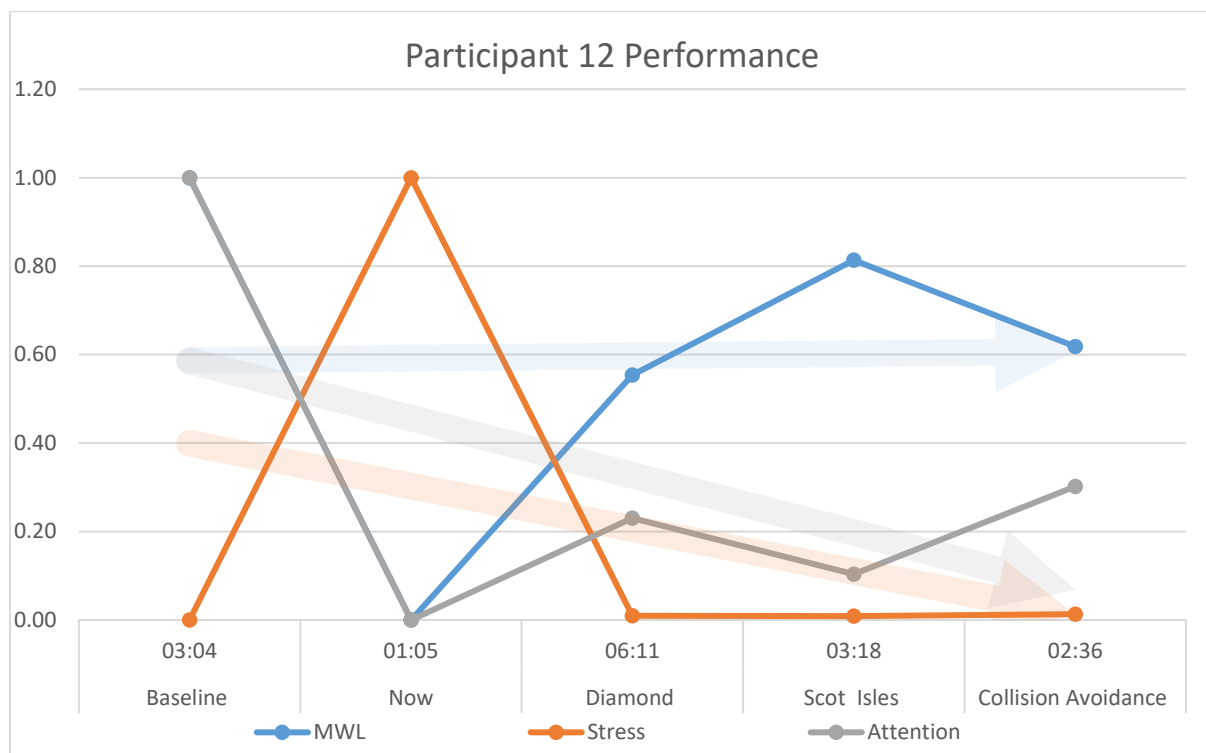


Figure 0.75 P 12 EEG result

The pupil diameters for both eyes show a fluctuation during the events Figure 0.76 . The participant's eye pupil dilation was changed, as shown in Table 0.14 and Figure 0.82 Figure 0.82 for each event as follows:

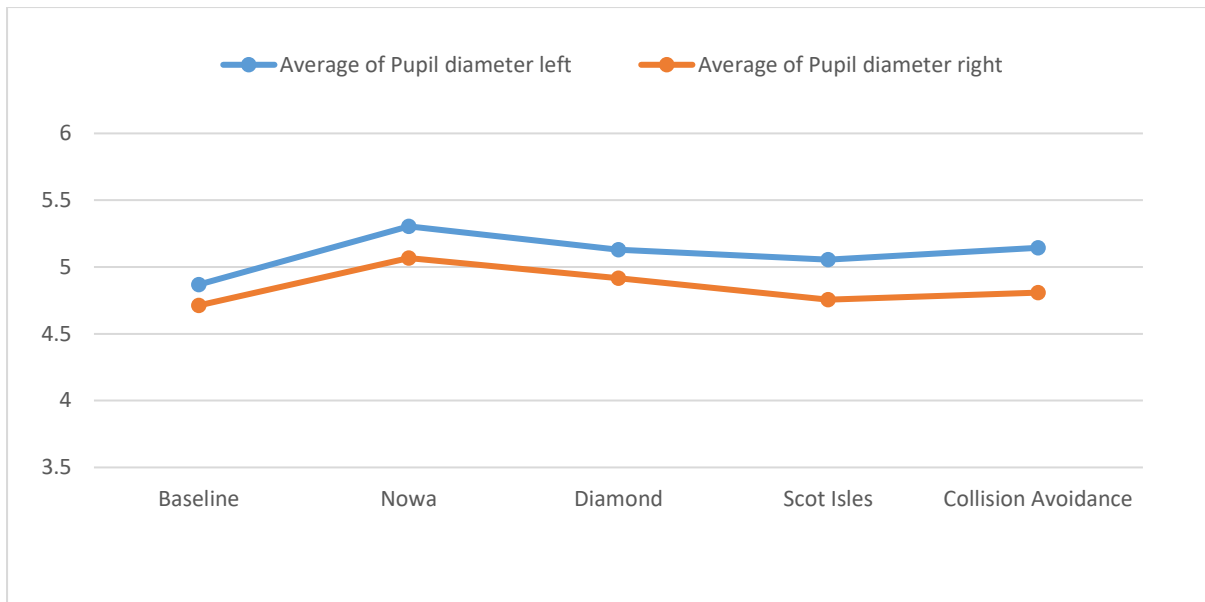


Figure 0.76 P12 Eye-Tracking result

- **Event 1 Baseline:**

During the baseline event, the participant demonstrated average pupils of (4.86) and (4.71) for the left and right eyes, respectively. The participant was not under pressure as there were no external targets to deal with, which should have made her calm and in a low MWL state. The baseline duration is around (21%) of the scenario time, and the participant in the baseline event spent around (40%) of the event time focusing on the radar, (41%) of the event on ECDIS, and around (3%) of the event time she visually scanned the surrounding area to check the situation in the surrounding area. Additionally, little attention was put on the display unit with (9%) and the top display unit with (5%) of the event, indicating initial information check before the targets appeared and indicating that Participant 12 used this time to get familiar with the navigation equipment, Figure 0.77



Figure 0.77 P12 Heat map for baseline

- **Event 2 MV Nowa:**

As the MV Nowa appeared on the radar and was visually detected, the participant's eye pupil diameters increased to (5.30 mm) and (5.07 mm) for the left and right sides, respectively, maybe because of the sudden appearance of the MV Nowa, and Participant 12 was surprised by the situation. In addition, the participant spent around (7%) of the experiment time monitoring the MV Nowa. The participant has shown a strong reliance on radar, with (74%) of the event time, and (19%) of the event time observed visually on the screen. However, Participant 12 did not use the ECDIS, which indicated that he preferred to use the radar as a navigation system to monitor the target Figure 0.78



Figure 0.78 P12 Heat map for MV Nowa

- **Event 3 MV Diamond:**

During this event, pupil dilation decreased slightly further to (5.12 mm) and (4.91 mm), indicating that Participant 12 was getting less cognitive load when the MV diamond appeared. This event took around (32%) of the experiment time. The participant shows that (53%) of event time focused on the radar, indicating less attention on the radar. However, (8%) of the event time, Participant 12 also focused on screens for visualisation. In addition, there was (35%) of the event time focused on the ECDIS because Participant 12 was not familiar with the radar and needed support, which made her use the ECDIS. The display unit took around (2%) of the event time, indicating that Participant 12 was getting the ship information from the display unit and was distributing his attention around the bridge, Figure 0.79



Figure 0.79 P12 Heat map for MV Diamond

- **Event 4 MV Scot Isles:**

During this event, the participant's eye diameter slightly decreased to (5.05 mm) for the left eye and (4.75 mm) for the right, indicating that Participant 12 cognitive load started to reduce after taking some action during MV Diamond. This event took around (22%) of the experiment time. The participant focused approximately (81%) of the event time on the radar during this event to assess the situation with the Scot of Isle. However, participant 12 also checked the situation visually, with (4%) of the event time checking the external environment, (5%) of the event time monitoring the display unit, and (5%) on the ECDIS to support navigational information. This suggests that Participant 12 relied on the radar and then distributed her attention in the ship bridge environment between the navigation equipment and the external observation which indicates he is aware of the situation and trying to improve her situation awareness, Figure 0.80



Figure 0.80 P12 Heat map for MV Scot Isles

- **Event 5 Collision Avoidance:**

The pupil diameter increased slightly to (5.14 mm) on the left and (4.80 mm) on the right, demonstrating little increase in cognitive load when taking action to avoid the risk of collision. The collision avoidance action took around (18%) of the experiment time. The participant distributed his attention more widely across the bridge systems during this event. The participant focused this time less on the radar, with (41%) of the event time while (16%) on the ECDIS, (18%) of the event time on screen for visualisation, and (14%) on the display unit. This means that Participant 12 distributed her attention on the ship bridge environment when she saw the risk of the collision to monitor the target and tried to take imminent action, Figure 0.81



Figure 0.81 P12 Heat map for collision avoidance

Table 0.14 P12 points of focus at different scenario events

Row Labels	Display Unit	ECDIS	Engine	VHF	RADAR	Visualisation	Top Display Unit
Baseline	9%	41%	2%	0%	40%	3%	5%
Nowa	0%	0%	0%	7%	74%	19%	0%
Diamond	2%	35%	0%	0%	53%	8%	1%
Scot Isles	5%	10%	0%	1%	81%	4%	0%
Collision Avoidance	14%	16%	2%	3%	41%	18%	5%

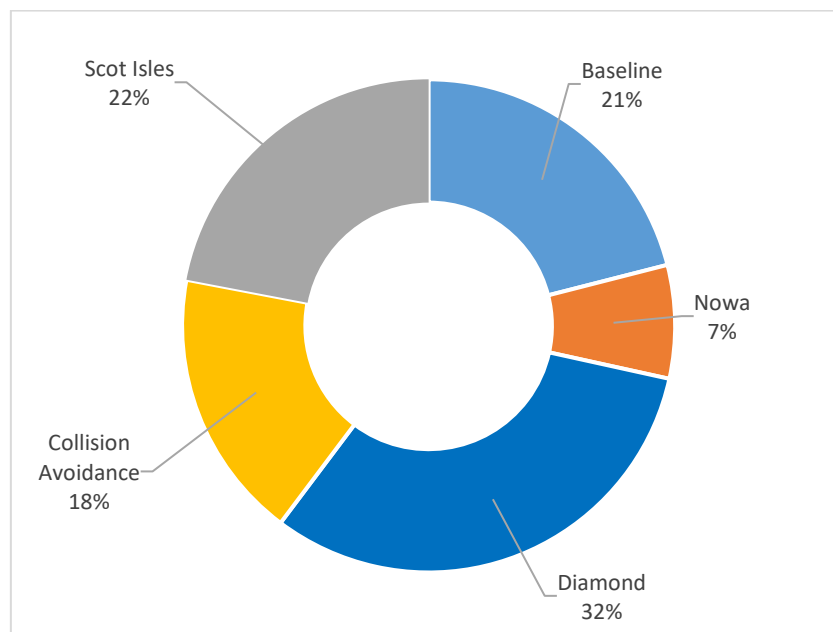


Figure 0.82 P12 Duration time for each event

The combined analysis of EEG and eye tracking data provides a comprehensive view of Participant 12's performance and cognitive demand during the simulator experiment, as shown in the recording. Both results for Participant 12 offer a valuable understanding of how the participant responded to each event and the complexity of the scenario from the baseline to the collision avoidance as shown in Figure 0.83 and Figure 0.84, which demonstrates the brain activity across four channels (F4-PZ, P4-Pz, P3-Pz, and F3-Pz) that illustrate the cognitive demand.

The EEG data reveals cognitive engagement, during the baseline, the EEG signals a low variability, indicating a calm state. However, there was some engagement in all channels in the baseline, but there was low activity as there were no targets, and Participant 12 became familiar with the ship bridge. When the targets appeared, Participant 12 detected MV Diamond on the radar and then MV Nowa which suggests an increase in activity between (10m00s) and (13m20s). After detecting MV Scot Isles and taking action, Participant 12's cognition started to be more stable.

Similarly, the pupil diameter from eye tracking is closely aligned with EEG findings. During the baseline, the pupil diameter was small and stable and increased, indicating that the participant was calm and increased her attention. As the scenario proceeded, Participant 12 detected MV Diamond on the radar, and then MV Nowa and the eye pupil began to fluctuate. During MV Scot Isles and collision avoidance, there is a decrease in the eye pupil, which indicates Participant 12 felt frustrated when she did not know how to use the radar and needed support, and it increased when she started to take action past the clear, suggest increasing in the MWL and attention.

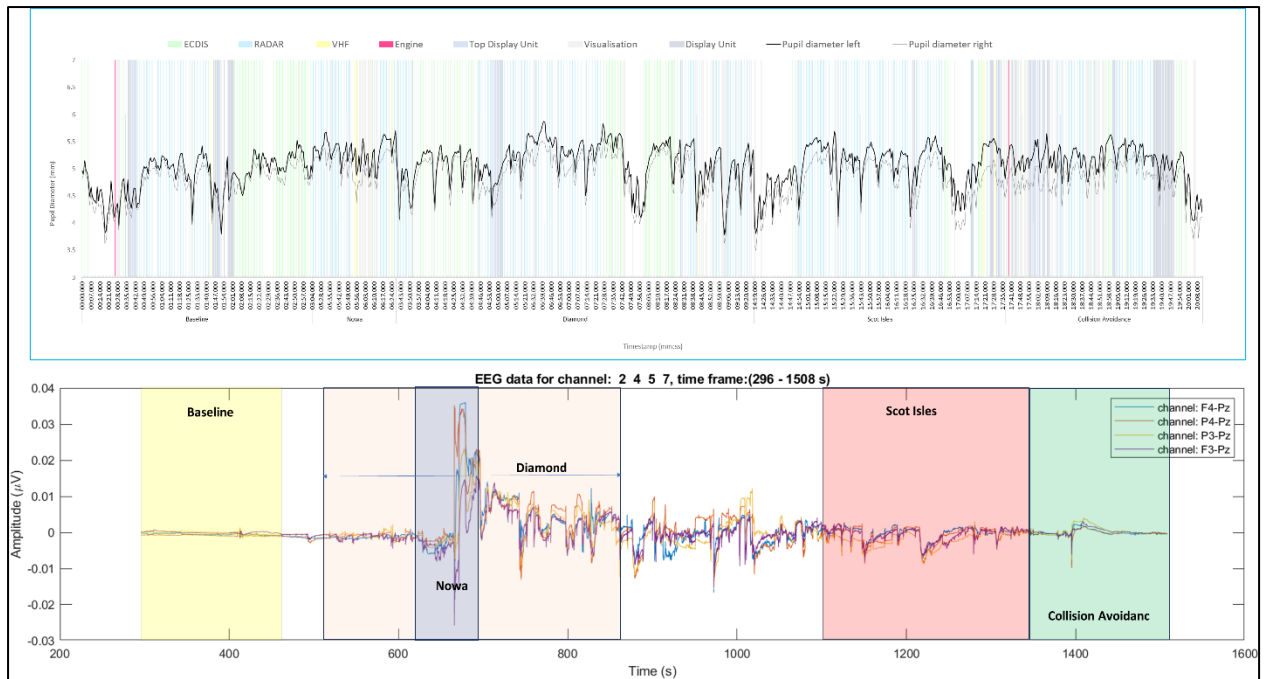


Figure 0.83 P12 EEG and Eye-tracking

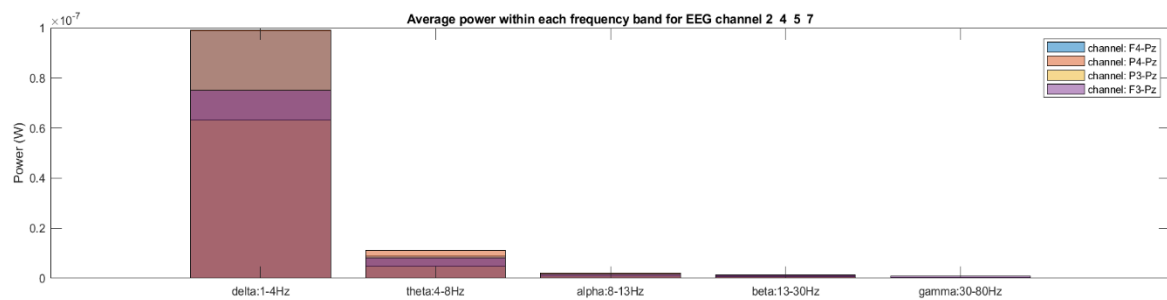


Figure 0.84 P12 Power band

- **Participant 13 (P13)**

During the simulator experiment, participant 13 was navigating on the ideal course, which is the green line, Figure 0.85 shows that Participant 13 passed clear without being involved in a collision. The experiment occurred during the participant's interaction with five events:

Event 1 Baseline: the participant was moving around the bridge environment and asking the support team if he could use the radar now, and they responded after the targets appeared. Then, Participant 13 tries to get familiar with the ship environment.

Event 2 MV Nowa: when the targets appeared, participant 13 moved around and detected MV Nowa visually and kept observing visually the radar and the target until receiving a communication from Mv Nowa informed him to keep course and speed which was confirmed by Participant 13. In the meantime, participant 13 acquired Mv Dimond on the radar.

Event 3 MV Diamond: after the calling finished with MV Now, participant 13 moved to the ECDIS. Participant 13 asked for support teams about how to get MV Nowa information on ECDIS, which indicates that he was not aware of MV Diamond. He kept monitoring MV Nowa visually and on the radar until received a call from MV Diamond requesting him to maintain course and speeds and participate 13 confirmed MV Diamond's request.

Event 4 Mv Scot Isles: participant 13 moved to the ECDIS again to monitor the target. Then he went back to using the radar and acquired MV Scot Isles. After the participant received the information about MV Scot Isles, he tried to communicate with the target, but there was no response. Therefore, participant 13 communicated with MV Diamond and informed her that he would alter to starboard after MV Nowa passed from his stern and to keep clear of him, and MV Diamond confirmed his attention.

Event 5 Collision Avoidance: Participant 13 started to alter the course from autopilot to starboard, then changed it to manual, and kept altering the course. After that, Participant 13 returned the steering to autopilot and monitored the target on ECDIS, radar, and visually until the pass was clear.

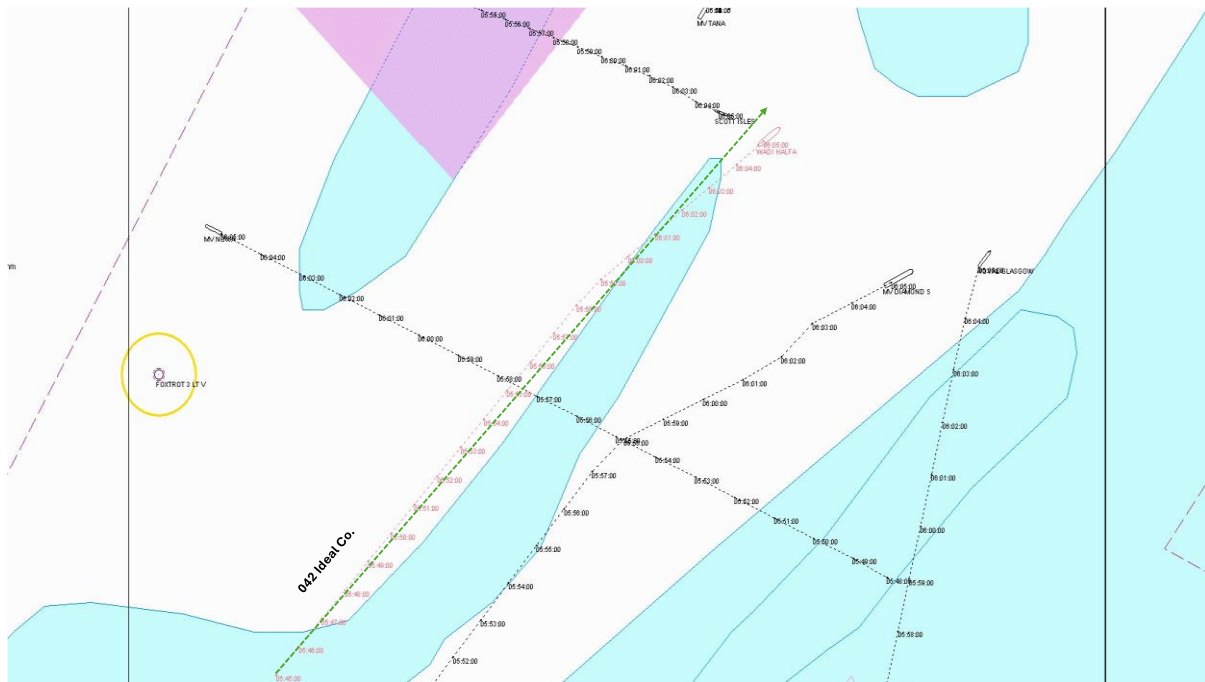


Figure 0.85 P13 Navigation chart

In addition, the heat map provides the participant's visual attention distribution during the ship bridge training simulation in Figure 0.86 Figure 0.86, which offers a clear visual focus throughout the events. The red zones indicate the area with high focus, suggesting that the participant concentrated heavily on the radar more than visual observation, indicating that the participant was over-reliant on automation. Also, the central navigation display shows the participant was focusing on the Scot Isles approaching a head could at the last moment when it approached. The green regions show less intense focus, indicating that the participant was aware of his surroundings, but he spent less time monitoring these targets.



Figure 0.86 P13 Heat map

Based on the EEG result and participant's performance metrics illustrated in Table 0.15 and Figure 0.87, we can observe how the cognitive demand (MWL, Stress, and attention) differentiation across the different events in the simulator experiments as follows:

Table 0.15 P13 EEG result

Time	Event	Duration	MWL	Stress	Attention
00:00 - 03:01	Baseline	03:01	1.00	0.0642	0.65
03:38 - 05:58	Nowa	02:20	0.00	0.1125	1.00
05:58 - 06:52	Diamond	00:50	0.55	0.9989	0.00
09:38 - 10:32	Scot Isles	00:50	0.83	1.0000	0.50
12:32 - 19:29	Collision Avoidance	06:57	0.39	0.0000	0.62

- **Event 1 Baseline:**

During the baseline, the participant showed a high mental workload while stress level was very low, and attention was high. This suggests that the participant was engaged with high attention because there were no targets, and no immediate risk existed. However, the increase in MWL could have been caused by Participant 13 asking if he could use the radar.

- **Event 2 MV Nowa:**

Moving to event 2 MV Nowa, there was a decrease in the MWL and a slight increase in stress and high attention. When the scenario started, and targets appeared, Participant 13 began monitoring the radar and paid more attention.

- **Event 3 MV Diamond:**

The next event, MV Diamond, showed high stress with moderate MWL and no attention. Participant 13 was not aware of the target until he received a second call from MV Diamond. Also, Participant 13 asked about how to get MV Nowa information on the ECDIS, indicating Participant 13 was unfamiliar with the ECDIS, and the sudden detection of the MV Diamond created this MWL and stress despite the still no risk of collision.

- **Event 4 MV Scot Isles:**

In the Scot Isles event, the MWL gets high with moderate stress during this event, which might be due to the detection of the risk of collision and failure in the communication attempts.

- **Event 5 Collision Avoidance:**

In the last event, collision avoidance, after taking action, MWL decreased to moderate, and attention got high with no stress, which reflects that Participant 13 improved his awareness after taking action.

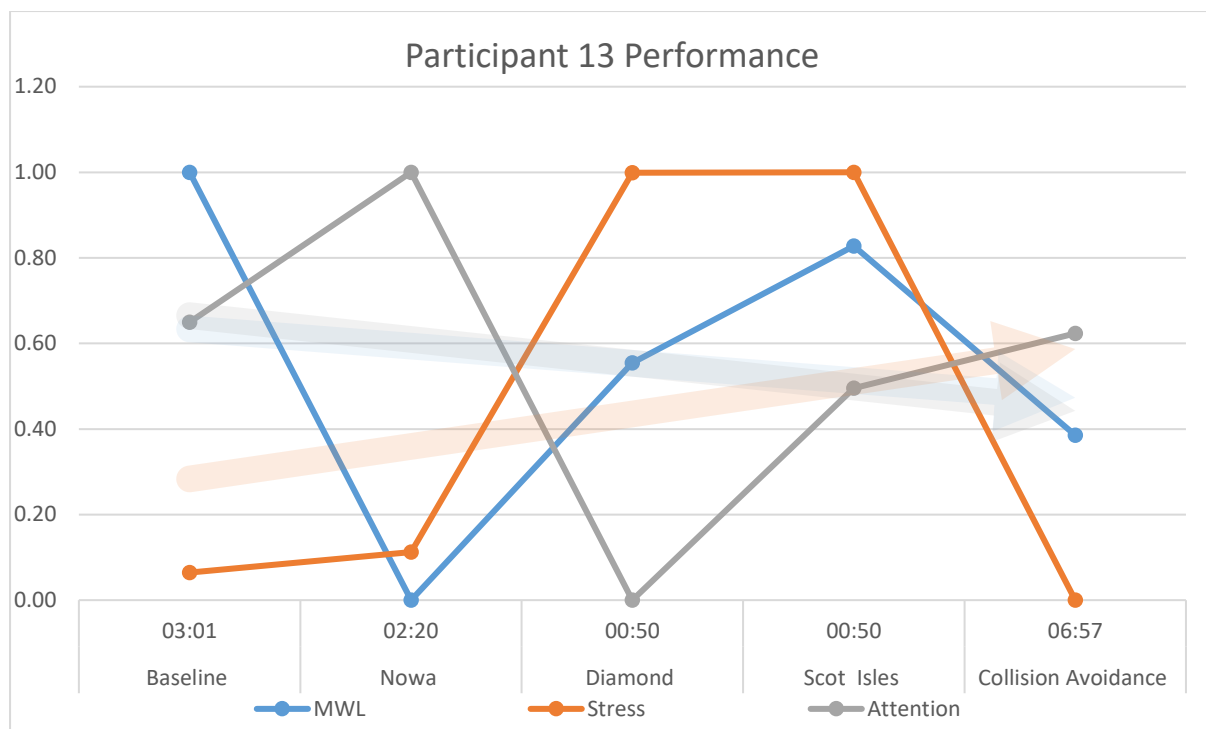


Figure 0.87 P13 EEG result

The pupil diameters for both eyes showed fluctuation during the events. The eye pupil increased slightly and kept increasing until MV Diamond event, then reduced until passed clear, indicating that the MWL was increasing with the situation as presented and decreased when detecting the risk of collision and taking action, Figure 0.88 Figure 0.88. The participant's eye pupil dilation was changed, as shown in Table 0.16 and Figure 0.94 , for each event as follows:

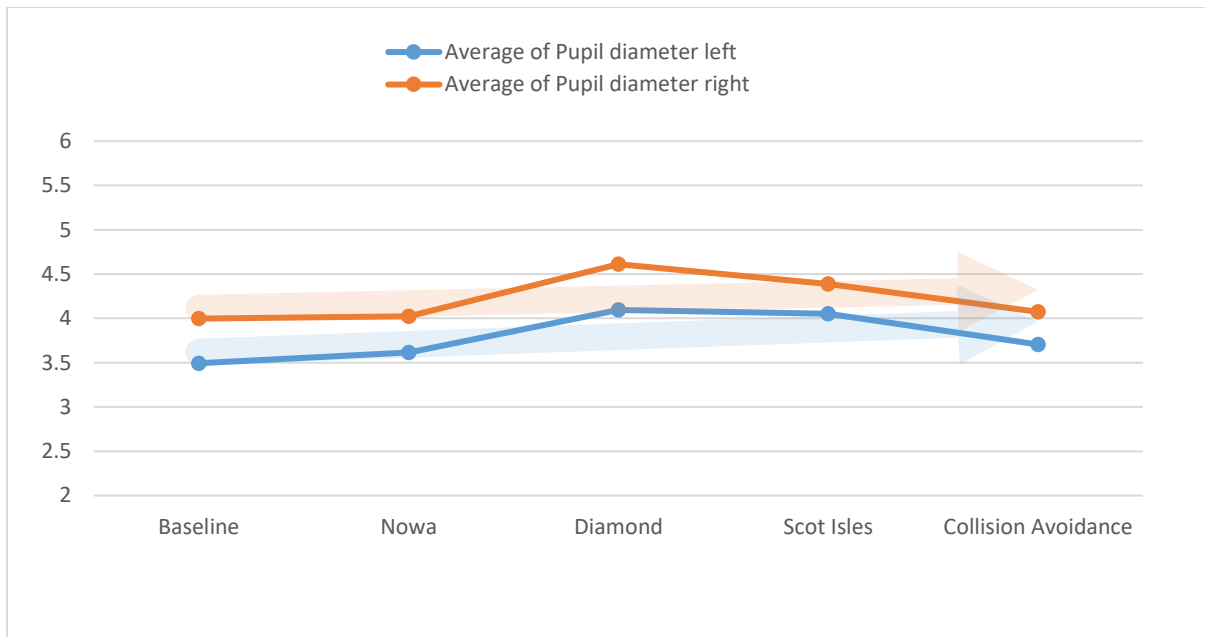


Figure 0.88 P13 Eye-Tracking result

- **Event 1 Baseline:**

During the baseline event, the participant demonstrated the lowest average pupils with (3.49) and (3.99) for the left and right eyes, respectively. The participant was not under pressure as there were no external targets to deal with, which should have made him calm and in a low MWL state. The baseline duration is around (18%) of the scenario time, and the participant in the baseline event spent around (31%) of the event time focusing on the radar, (15%) of the event time on ECDIS, and around (30%) of the event time visually scanned the surrounding area to check the situation in the surrounding area. Additionally, a small amount of attention was put on the display unit, with (19%) of the event indicating an initial information check before the targets appeared and indicates that Participant 13 used this time to get familiar with the navigation equipment. Figure 0.89



Figure 0.89 P13 Heat map for baseline

- **Event 2 MV Nowa:**

As the MV Nowa appeared on the radar and was visually detected, the participant's eye pupil diameters slightly increased to (3.61 mm) and (4.02 mm) for the left and right sides, respectively. In addition, the participant spent around (16%) of the experiment time monitoring the MV Nowa. The participant showed distributed attention when using navigational equipment. On radar, Participant 13's focus was (36%) of the event time and (15%) of the event time on the ECDIS. Participant 13 also increased his visual observation during this event; around (42%) of the event time was observed visually on the screen, which indicates that he relied on visual observation, Figure 0.90



Figure 0.90 P13 Heat map for MV Nowa

- **Event 3 MV Diamond:**

During this event, pupil dilation increased slightly further to (4.09 mm) and (4.61 mm), indicating that Participant 13 was getting more cognitive load when the MV diamond appeared. This event took around (6%) of the experiment time. The participant shows that (4%) of event time focused on the radar, indicating less attention on the radar. However, (86%) of the event time, Participant 10 was focused on ECDIS and (6%) on screens for visualisation. Participant 13 relied on the ECDIS in this event, particularly when he was trying to get information of the target ship, Figure 0.91



Figure 0.91 P13 Heat map for MV Diamond

- **Event 4 MV Scot Isles:**

With this event, the participant's eye diameter slightly decreased to (4.05 mm) for the left eye and (4.38 mm) for the right, indicating that Participant 13 cognitive load started to reduce after taking some action during MV Diamond. This event took around (6%) of the experiment time. The participant focused approximately (63%) of the event time on the radar during this event to assess the situation with the Scot of Isle. However, participant 10 also checked the situation visually with (36%) of the event time checking the external environment, and (1%) of the event on VHF. This suggests that the participant relied on radar and visual observation to monitor the MV Scot Isles to improve his situational awareness, Figure 0.92



Figure 0.92 P13 Heat map for MV Scot Isles

- **Event 5 Collision Avoidance:**

The pupil diameter remained at (3.70 mm) on the left and (4.07 mm) on the right, demonstrating reducing cognitive load when taking action to avoid the risk of collision. The collision avoidance action took around (54%) of the experiment time. During this event, the participant distributed his attention more widely across the bridge systems. The participant focused this time less on the radar, with (36%) of the event time while (26%) on the ECDIS, and (15%) on the event time on the screen for visualisation, and (20%) on the display unit. This means that

Participant 13 distributed his attention on the ship bridge environment when he saw the risk of the collision to monitor the target and tried to take imminent action, Figure 0.93



Figure 0.93 P13 Heat map for collision avoidance

Table 0.16 P13 points of focus at different scenario events

Row Labels	Display Unit	ECDIS	Engine	VHF	RADAR	Visualisation	Top Display Unit
Baseline	19%	15%	3%	1%	31%	30%	1%
Nowa	1%	15%	1%	4%	36%	42%	2%
Diamond	0%	86%	0%	3%	4%	6%	0%
Scot Isles	0%	0%	0%	1%	63%	36%	0%
Collision Avoidance	20%	26%	3%	0%	36%	15%	0%

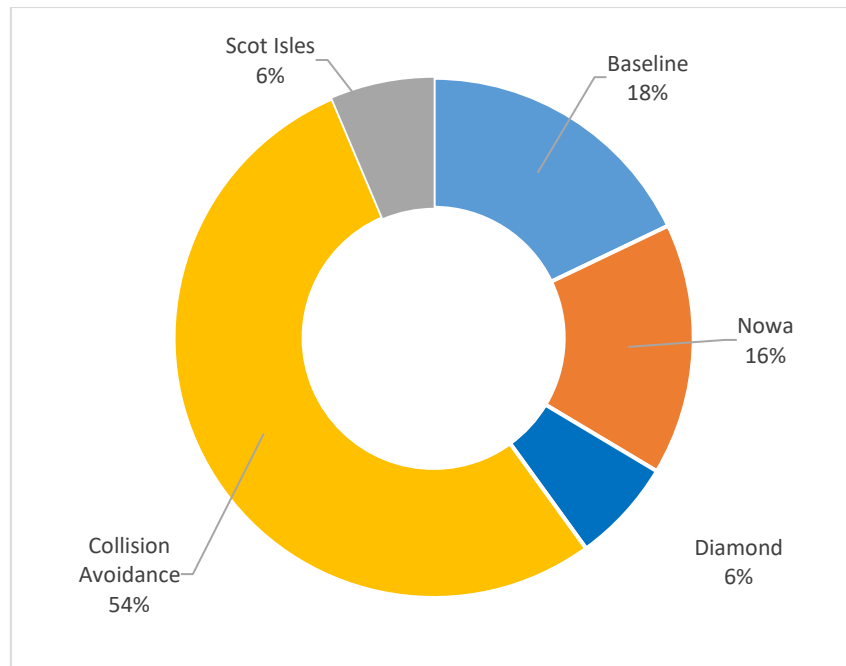


Figure 0.94 P13 duration time for each event

The combined analysis of EEG and eye tracking data provides a comprehensive view of Participant 13's performance and cognitive demand during the simulator experiment, as shown in the recording. Both results for Participant 13 offer a valuable understanding of how Participant 13 responded to each event and the complexity of the scenario from the baseline to the collision avoidance, as shown in Figure 0.95 and Figure 0.96 Figure 0.96, which demonstrates the brain activity across four channels (F4-Pz, P4-Pz, P3-Pz, and F3-Pz) that illustrate the cognitive demand.

The EEG data reveals cognitive engagement, during the baseline, the EEG signals a low variability, indicating a calm state. However, there is engagement in all channels. In the Baseline event, there was stability. I believed this when Participant 13 engaged and used the navigation equipment for familiarisation. During MV Nowa and the progress of the event, there is a visible fluctuation that appears with the signals, which requires cognitive engagement, decision-making, and communication, indicating that Participant 13 got involved and increased her MWL. During MV Dimond, Participant 13 was engaged with tasks and communicated with MV Diamond, which showed remarkable fluctuation when the tasks got complex, lining up with the tasks that involved sensory processing and spatial awareness. In the last event, the signals began to stable.

Similarly, the pupil diameter from eye tracking is closely aligned with EEG findings. During the baseline, the pupil diameter was small and stable and increased, indicating that the participant was calm and increased her attention. As the scenario proceeded to the MV Nowa event, the eye pupil began to fluctuate, reflecting greater cognitive engagement. During the MV Diamond and Scot Isles, the eye pupil showing fluctuated and increased in some points related to Participant 13 starting to get more cognitive load and attention, and this could be a result of the task complexity. During collision avoidance event, there are increases, which indicate an increase in MWL and attention, and then a decrease when the collision approach and the participant felt frustrated.

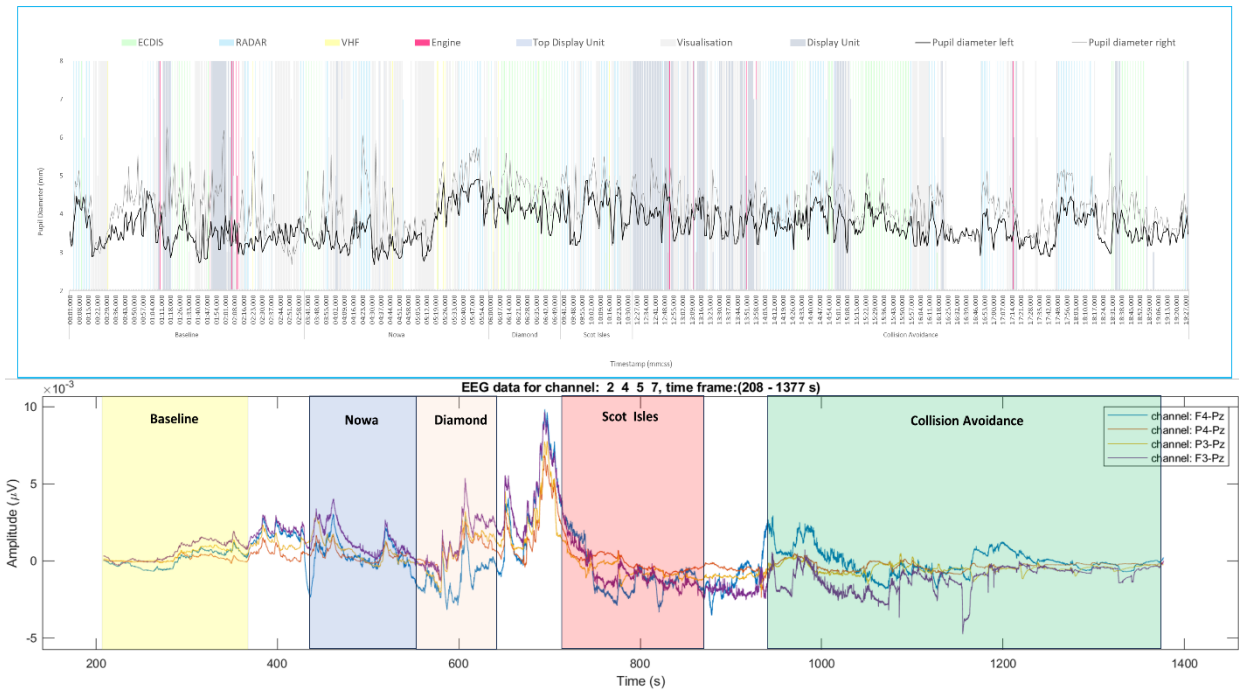


Figure 0.95 P13 EEG and Eye-tracking

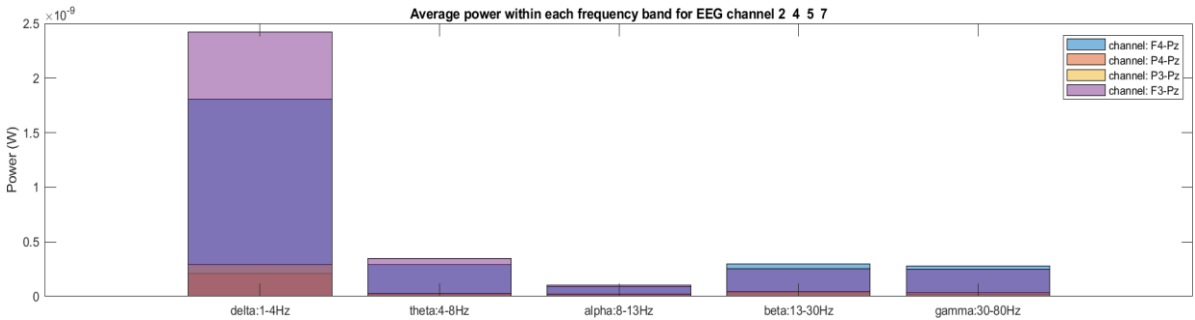


Figure 0.96 P13 Power band

- **Participant 14 (P14)**

During the simulator experiment, participant 14 was navigating around the ideal course, which is the green line, Figure 0.97 shows that Participant 14 passed clear without being involved in a collision. The experiment occurred during the participant's interaction with five events:

Event 1 Baseline: Participant 14 was just standing in the middle of the ship bridge behind the conning display and just looking around the ship environment without moving. This indicates that participant 14 tries to get familiar with the ship environment.

Event 2 MV Nowa: when the targets started to appear, participant 14 moved to the radar observed the ships ahead and acquired MV Nowa. Participant 14 keep monitoring MV Nowa on radar and while monitoring the participant 14 acquired MV Scot Isles on the radar at (04:24s). After that, participant 14 was observing the targets around visually and received a call from MV Nowa instructed him to maintain the course and speed. Participant 14 confirmed the instruction.

Event 3 MV Diamond: participant 14 was not aware of the MV Diamond until received the call from MV diamond. Before that, participant 14 asked the support team about his ship name and communicate MV Nowa again asking about her attention. And then alter the course to port side to increase the CPA with MV Now without check the surrounding area. This indicate that participant 14 was not fully aware about the situation and this impact to the situation awareness.

Event 4 Mv Scot Isles: after the communication with MV Diamond finished, participant 14 back to the radar and observed MV Scot Isles and kept monitoring the Scot Isles. After that, participant 14 was monitor the CAP and TCPA, then moved to the check the area on the starboard side by visualisation panel. Subsequently, participant 14 alter the course to starboard which suggest that participant 14 want to make sure that the area is clear for manoeuvring.

Event 5 Collision Avoidance: after altering the course to starboard, participant 14 kept monitoring the targets visually with radar and ECDIS also until MV Scot Isles passed clear from port side.

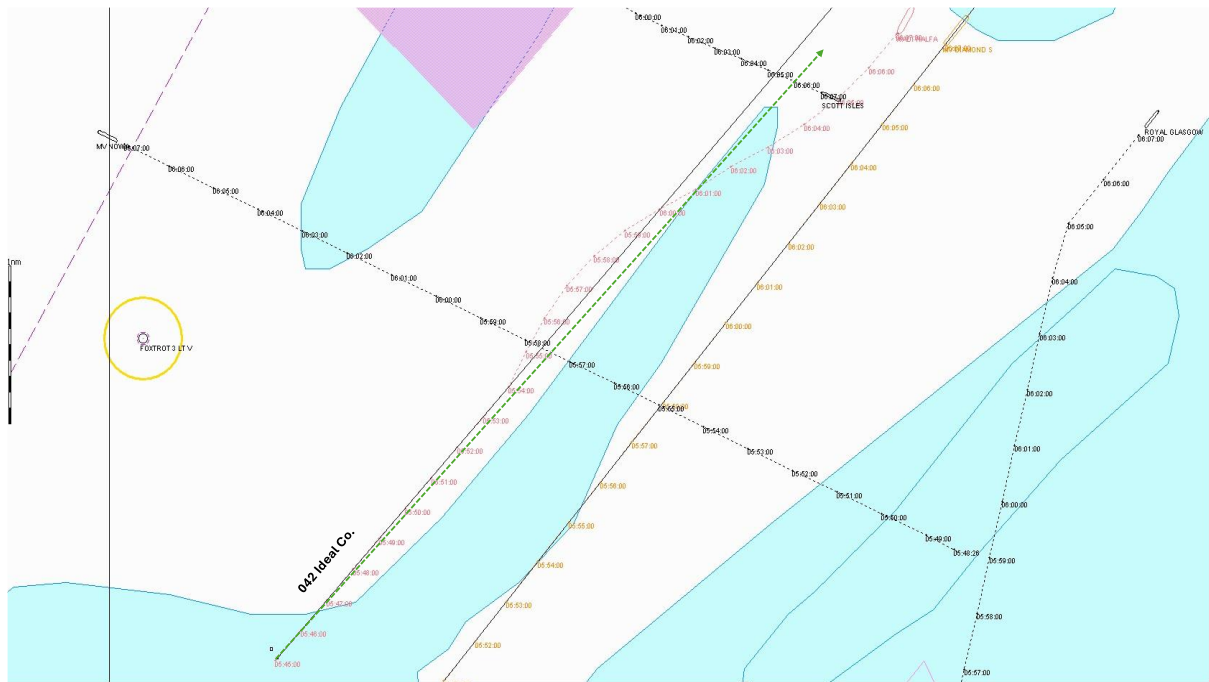


Figure 0.97 P14 Navigation chart

In addition, the heat map provides the participant's visual attention distribution during the ship bridge training simulation in Figure 0.98 , which offers a clear visual focus throughout the events. The red zones indicate the area with high focus, suggesting that the participant concentrated heavily on the radar and rarely used visual observation which indicates that the participant was over-relied on automation. Also, the central navigation display shows the participant was focusing on the Scot Isles approaching a head. The green regions show less intense focus, indicating that the participant was aware of his surroundings, but he spent less time monitoring these targets.



Figure 0.98 P14 Heat map

Based on the EEG result and participant's performance metrics illustrated in Table 0.17 and Figure 0.99 Figure 0.99, we can observe how the cognitive demand (MWL, Stress, and attention) differentiation across the different events in the simulator experiments as follows:

Table 0.17 P14 EEG result

Time	Event	Duration	MWL	Stress	Attention
00:00 - 02:55	Baseline	02:55	1.00	0.0105	0.23
03:20 - 05:52	Nowa	02:32	0.76	0.0103	0.72
07:46 - 08:26	Diamond	01:40	0.33	1.0000	0.00
05:52 - 11:40	Scot Isles	05:48	0.29	0.0396	0.85
11:40 - 20:12	Collision Avoidance	06:32	0.00	0.0000	1.00

- **Event 1 Baseline:**

During the baseline, the participant showed a high mental workload while stress level was very low, and attention was low. This suggests that the participant was engaged with high MWL even though there were no targets, and no immediate risk existed, suggesting that the person could be overwhelmed to deal with all this equipment individually.

- **Event 2 MV Nowa:**

Moving to event 2 MV Nowa, there was a decrease in the MWL but still high and an increase in attention with a high level. This is when the scenario starts and targets appear and monitor the targets on the radar and visually.

- **Event 3 MV Diamond:**

The next event, MV Diamond, showed high stress with moderate MWL and no attention. the participant was not aware of the target until received a call from MV Diamon, indicating that the sudden detection of the MV Diamond and when the communication commenced may have created high stress for the participant, despite the still no risk of collision.

- **Event 4 MV Scot Isles:**

In the Scot Isles event, the stress decreased to moderate during this event with low MWL and high attention, and this might be due to the detection of the risk of collision and checking the surroundings visually to improve the situation awareness before taking action.

- **Event 5 Collision Avoidance:**

In the last event collision avoidance, after taking the action, there was a very low MWL and stress with high attention which reflects that Participant 14 was aware of the situation and passed clearly.

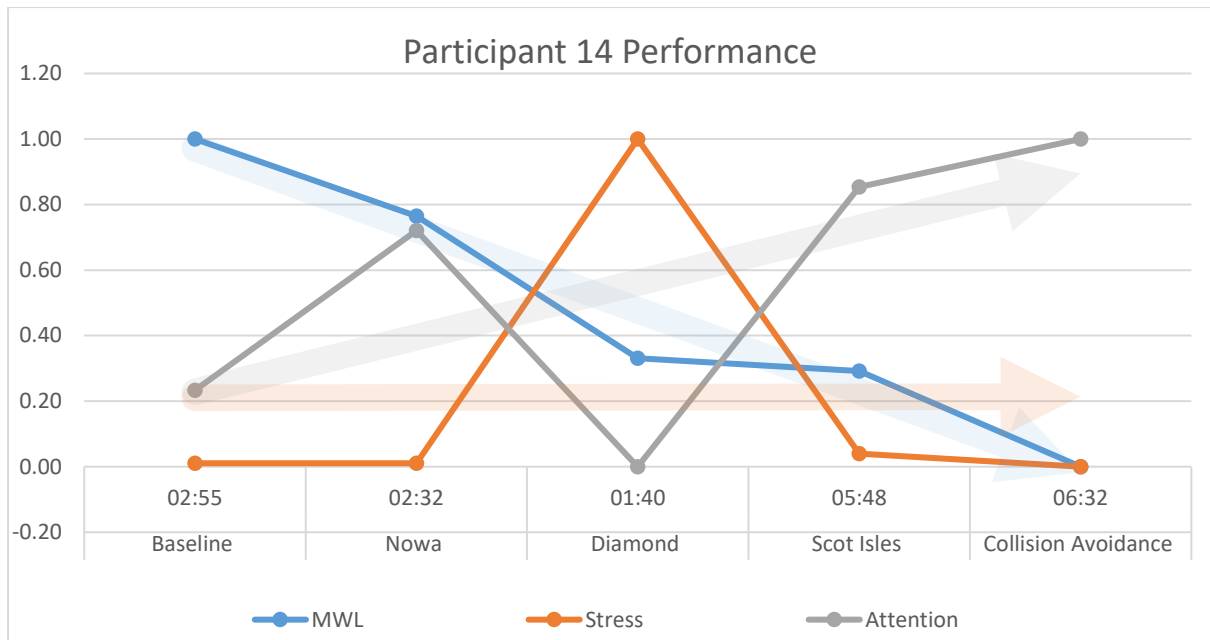


Figure 0.99 P14 EEG result

The pupil diameters for both eyes showed variation during the events. The eye pupil increased until the MV Diamond event and then began to decrease to the collision avoidance event Figure 0.100 Figure 0.100. The participant's eye pupil dilation was changed as shown in Table 0.18 and Figure 0.106 Figure 0.106 for each event as follows:

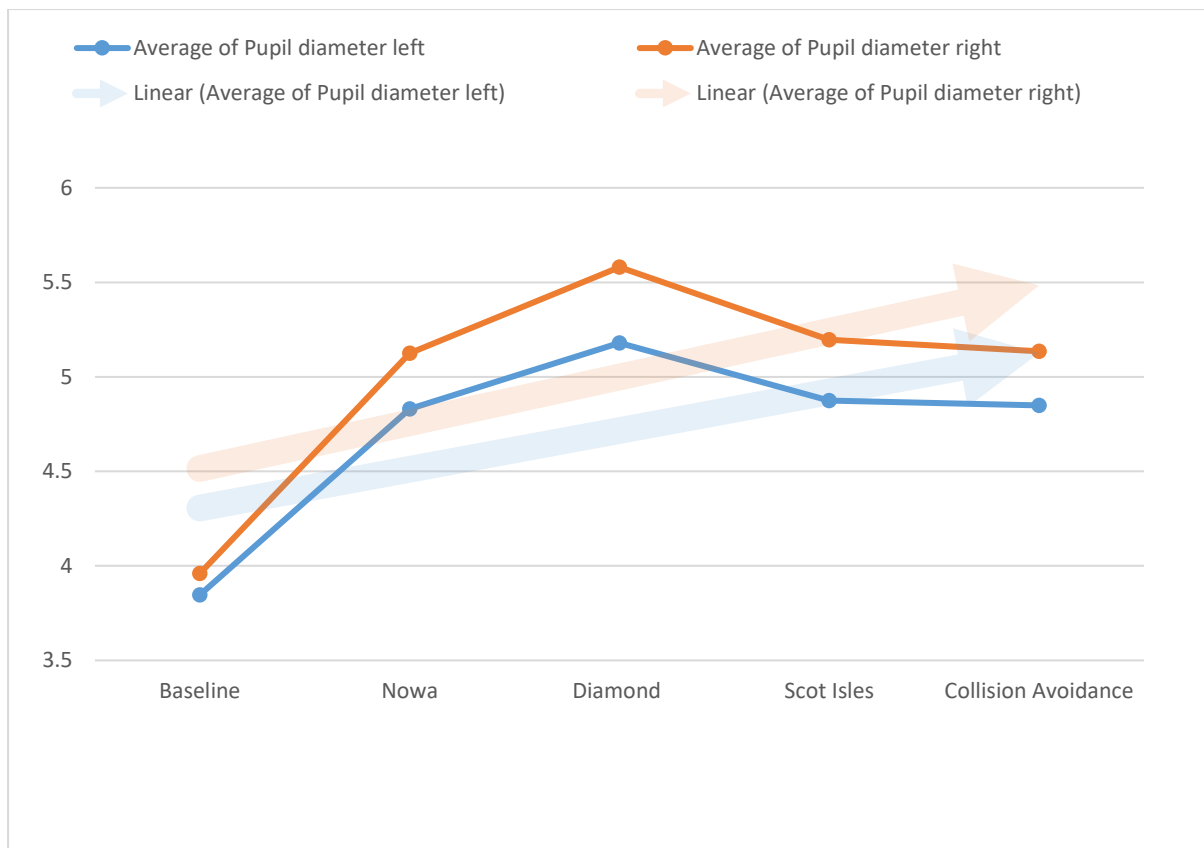


Figure 0.100 P14 Eye-Tracking result

- **Event 1 Baseline:**

During the baseline event, the participant demonstrated the lowest average pupils with (3.84) and (3.95) for the left and right eyes respectively. The participant was not under pressure as there were no external targets to deal with which should made him calm and low MWL state. However, the low of the pupil's eye suggests that Participant 14 gets minimum MWL in addition to attention. The baseline duration is around (14%) of the scenario time, and the participant in the baseline event spent around (8%) of the event time focusing on the radar and (31%) of the event on ECDIS, and around (39%) of the event time visually scanned the surrounding area to check the situation in the surrounding area. Additionally, a small attention was put on the display unit with (18%) of the event indicating initial information check before the targets appeared and indicates that Participant 14 used this time to get familiar with the navigation equipment Figure 0.101



Figure 0.101 P14 Heat map for baseline

- **Event 2 MV Nowa:**

As the MV Nowa appeared on the radar and was visually detected, the participant's eye pupil diameters increased to (4.83 mm) and (5.12 mm) for the left and right sides respectively. This was due to the participant showing an increase in cognitive engagement, maybe because of the sudden appearance of the MV Nowa, and Participant 14 was surprised by the situation. In addition, the participant spent around (13%) of the experiment time monitoring the MV Nowa. The participant has shown a strong reliance on radar, with (88%) of the event time, and (5%) of the event time observed visually on the screen. However, Participant 10 used the ECDIS around (15%) of the event time which indicates that he prefers to use the radar as a navigation system to monitor the target Figure 0.102



Figure 0.102 P14 Heat map for MV Nowa

- **Event 3 MV Diamond:**

During this event, pupil dilation increased slightly further to (5.17 mm) and (4.58 mm), indicating that Participant 14 was getting more cognitive load when the MV diamond appeared, and the scenario get more complex. This event took around (3%) of the experiment time. The participant shows that (80%) of the event time focused on the radar. However, (19%) of the event time Participant 14 also focused on screens for visualization. In addition, there was no attention on the ECDIS. The VHF got the attention of (1%) of the event time, Participant 14 was not aware of MV Diamond until receiving a call from the ship, which indicates the short time duration of this event Figure 0.103



Figure 0.103 P14 Heat map for MV Diamond

- **Event 4 MV Scot Isles:**

With this event, the participant's eye diameter slightly decreased to (4.87 mm) for the left eye and (5.19 mm) for the right, indicating that Participant 14 cognitive load started to reduce after taking some action during MV Diamond. This event took around (26%) of the experiment time. The participant focused approximately (67%) of the event time on the radar during this event to assess the situation with the Scot of Isle. However, participant 14 also checked the situation visually with (14%) of the event time checking the external environment, and (14%) of the event time monitoring the display unit to support navigational information, (4%) of the event time on the ECDIS. This suggests that the participant distributes his attention in the ship bridge environment between the navigation equipment and the external observation which indicates he is aware of the situation which trying to improve her situation awareness Figure 0.104



Figure 0.104 P14 Heat Map for MV Scot Isles

- **Event 5 Collision Avoidance:**

The pupil diameter remained at (4.84 mm) on the left and (5.13 mm) on the right, demonstrating the same cognitive load when taking action to avoid the risk of collision. The collision avoidance action took around (43%) of the experiment time. During this event, the participant distributed his attention more widely across the bridge systems. The participant focused this time less on the radar with (53%) of the event time while (14%) on the ECDIS, and (16%) of the event time on screen for visualization, and (12%) on the display unit. This means that Participant 14 distributed her attention on the ship bridge environment when he saw the risk of the collision to monitor the target and tried to take imminent action Figure 0.105



Figure 0.105 P14 Heat map for collision avoidance

Table 0.18 P14 Points of focus at different scenario events

Row Labels	Display Unit	ECDIS	Engine	VHF	RADAR	Visualisation	Top Display Unit
Baseline	18%	31%	1%	1%	8%	39%	3%
Nowa	3%	1%	0%	3%	88%	5%	0%
Diamond	0%	0%	0%	1%	80%	19%	0%
Scot Isles	14%	4%	1%	0%	67%	14%	0%
Collision Avoidance	12%	14%	4%	0%	53%	16%	0%

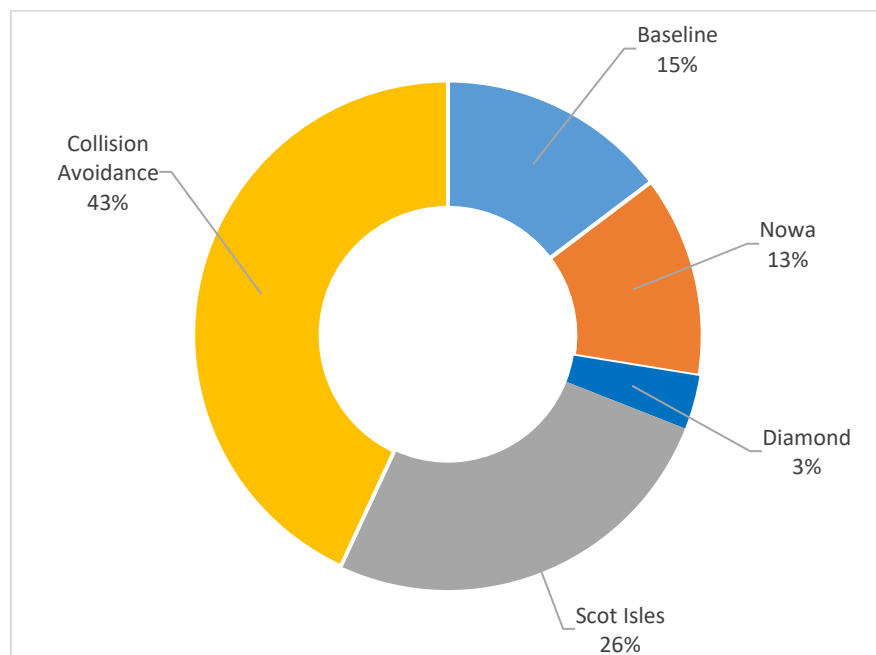


Figure 0.106 P14 duration time for each event

The combined analysis of EEG and Eye tracking data provides a comprehensive view of Participant 14's performance and cognitive demand during the simulator experiment as shown also in the recording. Both results for Participant 14 offer a valuable understanding of how participant respond to each event and the complexity of the scenario from the baseline to the collision avoidance as shown in Figure 0.107 and Figure 0.108Figure 0.108which demonstrates the brain activity across four channels (F4-PZ, P4-Pz, P3-Pz, and F3-Pz) and power band that illustrate the cognitive demand.

The EEG data reveals cognitive engagement, it shows that the signals were stable during baseline with no targets appearing, and MV Now, the signals were more stable. Then, Participant 14 observed MV Scot Isles on the radar and MV Dimond later. During this period, between (05m52s) to (11m:42s) there was high activity with the signals in all lobes. which indicates that Participant 14 involved sensory processing and spatial awareness when the scenario got complex.

Similarly, the pupil diameter from eye tracking is closely aligned with EEG findings. During the baseline, the pupil diameter was small and stable and increased indicating that the participant was in calm and increasing her attention. As the scenario proceeded to the MV Nowa event, the eye pupil began to fluctuate, reflecting greater cognitive engagement. During the MV Diamond and Scot Isles, the eye pupil showing fluctuated and decreased in some points related to Participant 14 starting to be frustrated and this could be a result of the task complexity. During the collision avoidance, there are increases which indicate the increasing of the MWL and attention and then decreasing when the collision approach and participant felt frustrated.

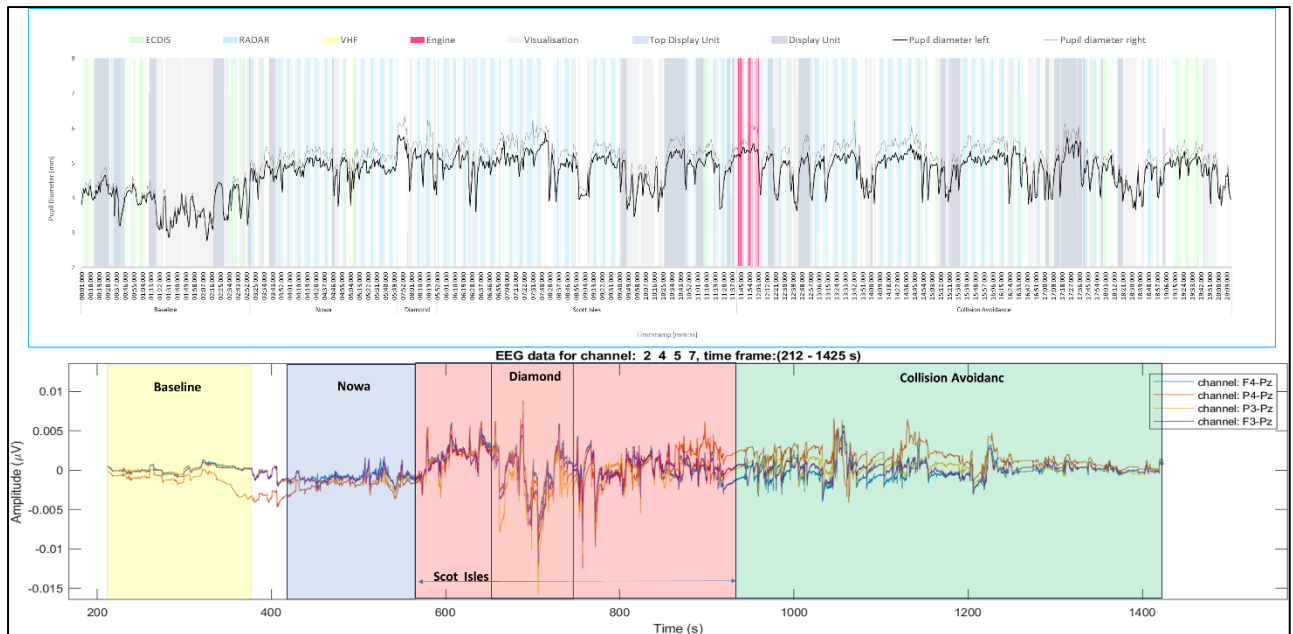


Figure 0.107 P14 EEG and Eye-Tracking

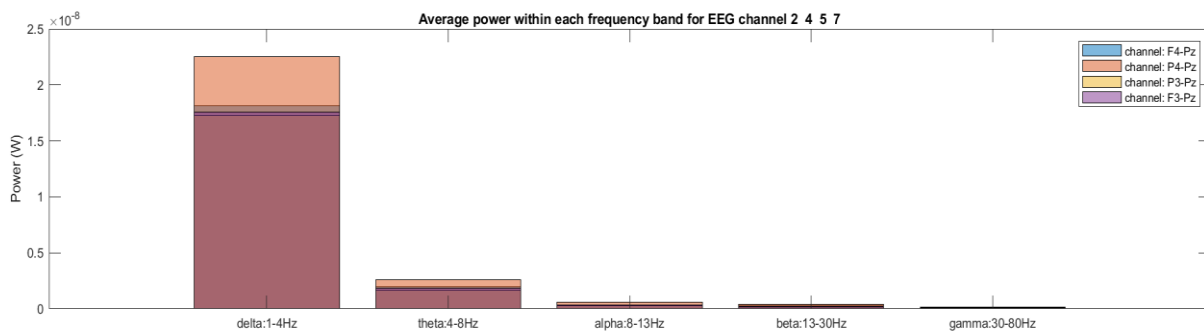


Figure 0.108 P14 Power band

• Participant 15 (P15)

During the simulator experiment, participant 15 was navigating around the ideal course, which is the green line, Figure 0.109 shows that Participant 15 while passing MV Scot Isles clear, participant 15 involved in a collision with MV Dimond. The accident occurred during the participant's interaction with five events:

Event 1 Baseline: the participant 15 was moving around the ship bridge check the ship environment and equipment to get familiar.

Event 2 MV Nowa: the participant immediately acquired MV Nowa and MV Diamond on the radar after the target appeared, then participant 15 monitored the MV Nowa on radar and checked information and directly participant 15 communicated with MV Nowa to explain her attention. After that, MV Nowa communicated with participant 15 to confirm passing from stern and participant 15 should maintain course and speed.

Event 3 MV Diamond: After finishing the communication with MV Nowa, Participant 15 detected MV Scot Isles visually only. Then the participant moved to ECDIS for monitoring the targets. After that, participant 15 back to the radar and acquired MV Scot Isles. Consequently, participant communicated with MV Scot Isles and did not get any answer. All this occurred and still the participant 15 did not aware about the MV Diamond. During participant 15 try to communicate with MV Scot Isles. Participant 15 received call from MV Diamond requesting participant 15 to maintain course and speed to overtake from starboard side. The answer from participant 15 was negative because she will alter the course to starboard side and should MV Diamond keep clear.

Event 4 MV Scot Isles: participant 15 was detected MV Scot Isles during MV Diamond event which indicate that participant 15 has good situation awareness about the surrounding area.

Event 5 Collision Avoidance: after finishing the communication with MV Diamond, participant 15 change the steering to manual and began to alter course to starboard. Participant 15 was monitoring MV Scot Isles visually and on radar and the ship start to be clear with MV Scot Isles. Unfortunately, MV diamond was close to the participant 15 from starboard side which result a collision in the end. This indicate that participant 15 was focused and keep her situation on one side and did not check the surrounding. Even though the answered from her was not agreed with the MV Diamond, participant 15 should keep monitor MV Diamond until keep clear.



Figure 0.109 P15 Navigation chart

In addition, the heat map provides the participant's visual attention distribution during the ship bridge training simulation in Figure 0.110 , which offers a clear visual focus throughout the events. The red zones indicate the area with high focus, suggesting that the participant concentrated heavily on the radar and used visual observation which indicates that the participant was over-relied on automation. Also, the central navigation display shows the participant was focusing on the Scot Isles approaching a head could at the last moment when it approached. The green regions show less intense focus, indicating that the participant was aware of his surroundings, but he spent less time monitoring these targets.



Figure 0.110 P15 Heat map

Based on the EEG result and participant's performance metrics illustrated in , Table 0.19 and Figure 0.111 we can observe how the cognitive demand (MWL, Stress, and attention) differentiation across the different events in the simulator experiments as follows:

Table 0.19 P15 EEG result

Time		Event	Duration	MWL	Stress	Attention
00:00.0	02:35.9	Baseline	02:35.9	0.56	0.0182	0.44
02:53.0	06:31.9	Nowa	03:39.0	0.15	0.0958	0.60
09:34.0	13:34.0	Diamond	04:00.0	0.69	1.0000	0.00
09:18.0	15:03.0	Scot Isles	05:45.0	0.00	0.0584	0.74
15:03.0	19:46.8	Collision Avoidance	04:43.8	1.00	0.0000	1.00

- **Event 1 Baseline:**

During the baseline, the participant showed a moderate mental workload while stress level was very low, and attention was moderate. This suggests that the participant was engaged ship environment, however, there were no targets, and no immediate risk existed.

- **Event 2 MV Nowa:**

Moving to event 2 MV Nowa, there was a decrease in the MWL and a low in stress with high attention. This is when the scenario starts and targets appear participant 15 immediately acquired MV Nowa and MV Diamond on the radar after the target appeared, then Participant 15 monitored the MV Nowa on the radar and checked the information and directly participant 15 communicated with MV Nowa to explain her attention which suggests that Participant 15 manage and maintain her cognitive demand.

- **Event 3 MV Diamond:**

The next event, MV Diamond, shows high MWL and stress with no attention. The participant was not aware of the target until received a call from MV Diamon. In addition, Participant 15 detected MV Scot Isles in this event and also communicated with MV Scot Isles with no response, then received a call from MV Diamond. This indicates that the sudden detection of the MV Diamond and failure in communication with MV Scot Isles may have created high MWL and stress, despite the still no risk of collision.

- **Event 4 MV Scot Isles:**

After failure the communication with MV Scot Isles. Participant 15 attention increased and MWL and stress reduced which indicated that Participant 15 improved his situational awareness and began to take action to avoid collision.

- **Event 5 Collision Avoidance:**

In this event, MWL and attention were high with no stress. Participant 15 was steering the ship manually after the failure of the communication with MV Scot Isles and monitoring MV Scot Isles visually and on the radar. Participant 15 was altering the course to starboard and keep his attention on MV Scot Isles. Unfortunately, Participant 15 collided with MV Diamond on the starboard side. This suggests that Participant 15 was not aware of the surroundings due to her focusing on one target.

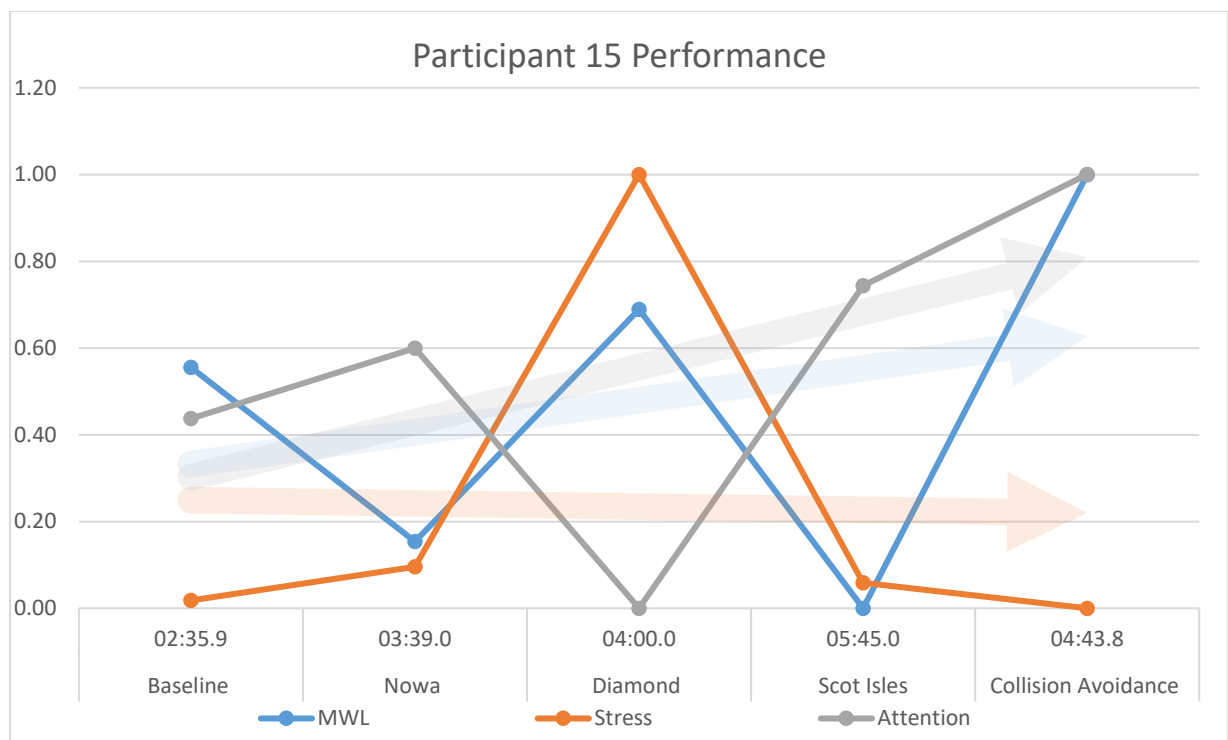


Figure 0.111 P15 EEG result

The pupil diameters for both eyes show a constant increase during the events. During MV Dimond, it was a slight decrease in the eye pupil and then an increase until the collision avoidance event Figure 0.112 . The participant's eye pupil dilation was changed as shown in Table 0.20 Figure 0.118 Figure 0.118 for each event as follows:

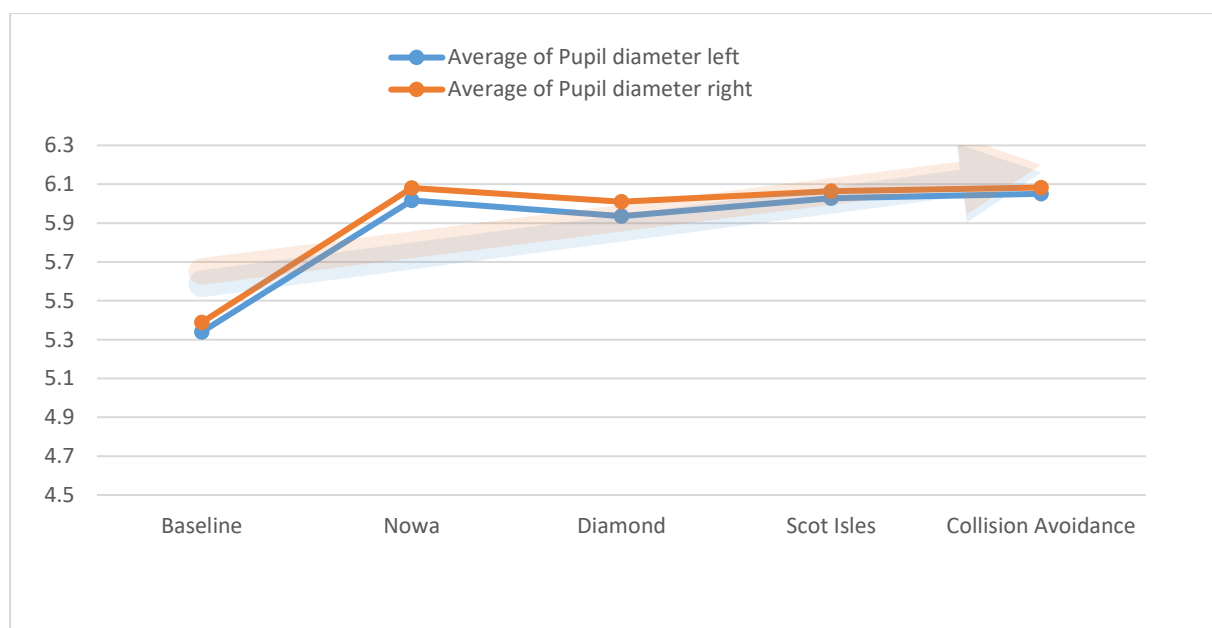


Figure 0.112 P15 Eye-Tracking result

- **Event 1 Baseline:**

During the baseline event, the participant demonstrated the lowest average pupils with (5.33) and (5.38) for the left and right eyes respectively. The participant was not under pressure as there were no external targets to deal with which should made, her calm and low MWL state. However, the low of the pupil's eye suggests that Participant 15 gets minimum MWL in addition to attention. The baseline duration is around (14%) of the scenario time, and the participant in the baseline event spent around (40%) of the event time focusing on the radar and (21%) of the event on ECDIS, and around (14%) of the event time visually scanned the surrounding area to check the situation in the surrounding area. Additionally, a small attention was put on the display unit with (16%) of the event indicating initial information check before the targets appeared and indicates that Participant 10 used this time to get familiar with the navigation equipment Figure 0.113



Figure 0.113 P15 Heat map for baseline

- **Event 2 MV Nowa:**

As the MV Nowa appeared on the radar and was visually detected, the participant's eye pupil diameters increased to (6.01 mm) and (6.08 mm) for the left and right sides respectively. This was due to the participant showing an increase in cognitive engagement, maybe because of the sudden appearance of the MV Nowa, and Participant 15 was surprised by the situation. In

addition, the participant spent around (8%) of the experiment time monitoring the MV Nowa. The participant has shown a strong reliance on radar, with (95%) of the event time, and (3%) of the event time observed visually on the screen. However, Participant 15 did not use the ECDIS which indicates that he prefers to use the radar as a navigation system to monitor the target Figure 0.114



Figure 0.114 P15 Heat map for MV Nowa

- **Event 3 MV Diamond:**

During this event, pupil dilation decreased slightly further to (5.93 mm) and (6.01 mm), indicating that Participant 15 was getting less cognitive load when the MV diamond. This event took around (8%) of the experiment time. The participant shows that (79%) of event time focused on the radar indicating less attention on the radar. However, (7%) of the event time, Participant 10 also focused on screens for visualization. In addition, there was attention on the ECDIS with (11%) of the event time and (2%) on the display unit. The participant was not aware of the MV Dimond until receiving a call which indicated the distribution of the visual attention in this short period Figure 0.115



Figure 0.115 P 15 Heat map for MV Diamond

- **Event 4 MV Scot Isles:**

with this event, the participant's eye diameter slightly increased to (6.02 mm) for the left eye and (6.06 mm) for the right, indicating that Participant 15 cognitive load started to increase during MV Scot Isles. This event took around (13%) of the experiment time. The participant focused approximately (81%) of the event time on the radar during this event to assess the situation with the Scot of Isle. However, participant 10 also checked the situation visually with (6%) of the event time checking the external environment, and (13%) of the event time monitoring the ECDIS to support navigational information. Participant 15 communicated with MV Scot Isles during the MV Diamond event with no response, Participant 15 monitored the MV Scot Isles in both navigational equipment and visually. This suggests that the participant distributes his attention in the ship bridge environment between the navigation equipment and the external observation which indicates he is aware of the situation which trying to improve her situation awareness Figure 0.116 Figure 0.116



Figure 0.116 P15 Heat Map for MV Scot Isles

- **Event 5 Collision Avoidance:**

The pupil diameter slightly increased to (6.05 mm) on the left and (6.08 mm) on the right, demonstrating a bit increase in cognitive load when taking action to avoid the risk of collision. The collision avoidance action took around (57%) of the experiment time. During this event, the participant distributed his attention more widely across the bridge systems. The participant focused this time less on the radar with (57%) of the event time while (5%) on the ECDIS, and (12%) of the event time on screen for visualization, and (14%) on the display unit. This means that Participant 15 distributed her attention to the ship bridge environment when he saw the risk of the collision to monitor the target and tried to take imminent action. Unfortunately, Participant 15 was focused on avoiding MV Scot Isles and did not keep aware of the surroundings which resulted in a collision with MV Diamond Figure 0.117.



Figure 0.117 P15 Heat map for collision avoidance

Table 0.20 P15 points of focus at different scenario events

Row Labels	Display Unit	ECDIS	Engine	VHF	RADAR	Visualisation	Top Display Unit
Baseline	16%	21%	1%	1%	40%	14%	8%
Nowa	1%	0%	0%	1%	95%	3%	0%
Diamond	2%	11%	0%	0%	79%	7%	0%
Scot Isles	0%	13%	0%	0%	81%	6%	0%
Collision Avoidance	14%	5%	0%	0%	57%	12%	12%

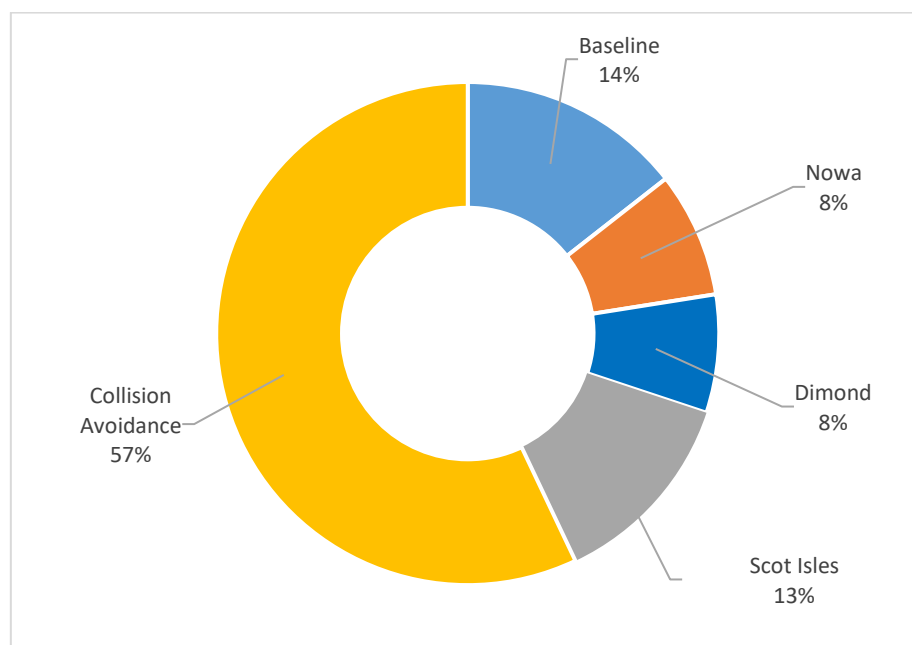


Figure 0.118 P15 duration time for each event

The combined analysis of EEG and Eye tracking data provides a comprehensive view of Participant 15's performance and cognitive demand during the simulator experiment as shown also in the recording. Both results for Participant 15 offer a valuable understanding of how participant respond to each event and the complexity of the scenario from the baseline to the collision avoidance as shown in Figure 0.119 and Figure 0.120 Figure 0.120 and which demonstrates the brain activity across four channels (F4-Pz, P4-Pz, P3-Pz, and F3-Pz) that illustrate the cognitive demand.

The EEG data reveals cognitive engagement, during the baseline, the EEG signals a low variability, indicating a calm state. However, there is some engagement in (F3-Pz), I believed this when Participant 15 engaged and used the navigation equipment for familiarisation. During MV Nowa and the progress of the event, there is a visible fluctuation that appears with the front channel which requires cognitive engagement, decision-making, and communication indicating that Participant 15 got involved and increased her MWL. During MV Dimond and Scot Isles, participant 15 was engaged with tasks and communicated with the targets and she was not stable in her action, which indicates that the parietal lobe channel showed remarkable fluctuation, lining up with the tasks that involved sensory processing and spatial awareness. In the last event, the signals in the begging were fluctuated with the movement of the participant and stable in the end of the event when the ship collided occurred and Participant 15 stopped doing action.

Similarly, the pupil diameter from eye tracking is closely aligned with EEG findings. During the baseline, the pupil diameter was small and stable and increased indicating that the participant was in calm and increasing her attention. As the scenario proceeded to the MV Nowa event, the eye pupil began to fluctuate, reflecting greater cognitive engagement. During the MV Diamond and Scot Isles, the eye pupil showing fluctuated and decreased in some points related to Participant 15 starting to frustrate in some point and this could be a result of the task complexity. During the collision avoidance, there are increased which indicate the increasing of the MWL and attention and then decreasing when the collision approach and participant felt frustrated again.

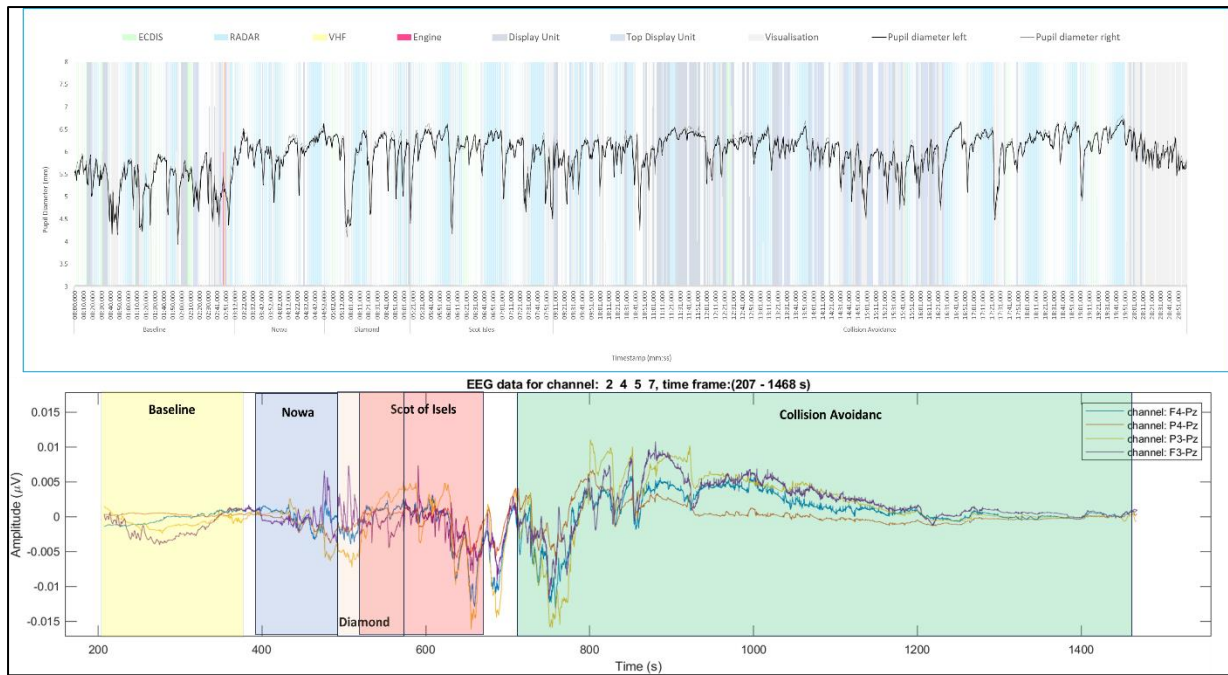


Figure 0.119 P15 EEG and Eye-tracking

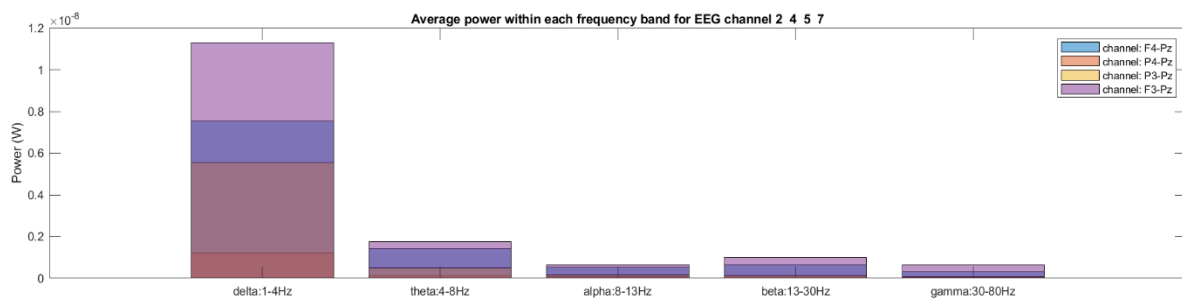


Figure 0.120 P15 Power band

Appendix E: Participants Analysis of the Second Set

- **Participant 3 (P3-L)**

During the simulator experiment, participant 3 was navigating on the ideal course, which is the green line, Figure 0.121 Figure 0.121 it shows that Participant 3 passed clear without being involved in a collision but with near miss. The experiment occurred during the participant's interaction with five events:

Event 1 Baseline: The participant moved around to get familiar with the ship environment.

Event 2 MV Nowa: after the targets appeared, participant 3 acquired MV Nowa immediately. Participant 3 keeps monitoring MV Nowa and checking the information. In the meantime, the lookout informed Participant 3 about the ship on the starboard side which is MV Nowa. Furthermore, the lookout informed Participant 3 about the ships ahead to keep her situation awareness improved. Then Participant 3 received a call from MV Nowa requesting Participant 3 to maintain course and speed which was confirmed by Participant 3. After that, participant 3 informed lookout to keep her eye on MV Nowa and tell her if there was any change.

Event 3 MV Diamond: after finishing communication with MV Nowa, the lookout informed Participant 3 about the ship on the starboard quarter which is MV Dimond. participant 3 then acquired the MV diamond on the radar and used the visualisation panel to observe it visually of male sure about the location of the Diamond. While monitoring MV Dimond on radar, the lookout informed Participant 3 about the ship on the port side in a crossing situation which is MV Scot Isles. Participant 3 acquired the target and then received a call from MV Diamond instructing Participant 3 to maintain course and speed which was confirmed by Participant 3.

Event 4 MV Scot Isles: after terminating the communication with MV Diamond, participant 3 keeps monitoring MV Scot Isles on the radar and ECIDS. After MV Scot Isles became closer, participant 3 tried to communicate more than once time but no answer she got. Then participant 3 asked the lookout how to contact the engine room but she reduced the speed immediately.

Event 5 Collision Avoidance: after reducing speed, participant 3 kept monitoring the target, and MV Scot Isles passed with a near miss from the port side.



Figure 0.121 (P3-L) Navigation Chart

Additionally, the heat map provides the participant's visual attention distribution during the ship bridge training simulation Figure 0.122 . It offers a clear visual focus throughout the events. The red zones indicate the area with high focus. The heat map demonstrates that the participant was focusing on the navigation equipment most of the time



Figure 0.122 (P3-L) Heat Map

Based on the EEG result and Participant 15's performance metrics illustrated in Table 0.21 and Figure 0.123 Figure 0.123 we can observe how the cognitive demand (MWL, Stress, and attention) differentiation across the different events in the simulator training as follows:

Table 0.21 (P3-L) EEG Result

Time		Event	Duration	MWL	Stress	Attention
00:00.0	03:03.9	Baseline	03:03.9	0.12	0.28	0.37
03:34.1	06:04.0	Nowa	02:29.9	0.00	1.00	0.82
06:28.1	08:44.6	Diamond	02:16.5	0.25	0.87	0.35
08:44.6	15:39.8	Scot Isles	06:55.2	1.00	0.00	0.00
15:39.8	21:20.7	Collision Avoidance	05:40.9	0.46	0.04	1.00

- **Event 1 Baseline:**

During the baseline, participant 3 showed low mental workload and stress level with moderate attention. This suggests that the participant was calm because there were not any targets, and no immediate risk existed.

- **Event 2 MV Nowa:**

When the targets began to appear, Participant 3 showed low MWL with high stress and attention. Participant 3 detected the MV Nowa on the RADAR. In the meantime, the lookout informed Participant 3 about the ship on the starboard side which is MV Nowa. Furthermore, the lookout informed Participant 3 about the ships ahead. I believe that all this information increased Participant 3 stress and increased attention to deal with the situation.

- **Event 3 MV Diamond:**

The next event, MV Diamond, remained high stress with low MWL and moderate attention. the lookout informed Participant 3 about the ship on the starboard quarter which is MV Dimond. . While monitoring MV Dimond on radar, the lookout informed Participant 3 about the ship on the port side in a crossing situation which is MV Scot Isles, which kept his stress level high and reduced his attention.

- **Event 4 MV Scot Isles:**

Participant 3 was informed by the lookout about Scot Isles during the MV Diamond event. It shows that Participant 3 had very low MWL and very low attention. However, participant 3 keeps monitoring MV Scot Isles on the radar and ECIDS. After MV Scot Isles became closer, participant 3 tried to communicate more than once time but no answer was received, which suggests the increase in MWL.

- **Event 5 Collision Avoidance:**

Participant 3 showed moderate MWL and high attention with very low stress. After reducing speed, participant 3 kept monitoring the target and improved his attention, and MV Scot Isles passed with a near miss from the port side which suggests that participant 3 reduce his MWL after the risk of collision cleared..

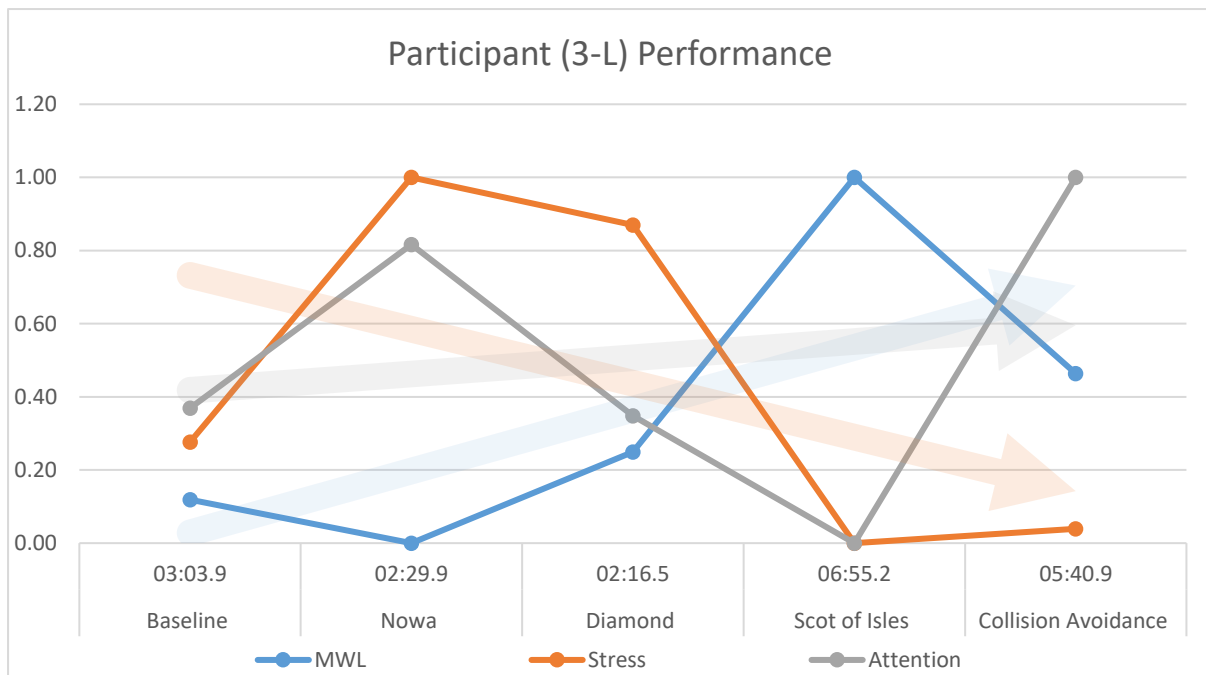


Figure 0.123 (P3-L) EEG Result

Furthermore, pupil diameter for both eyes give a comprehensive view of Participant 3's performance through the events. Participant 3 began with low cognitive demand and started to

increase and reduce after MV Nowa Figure 0.124Figure 0.124. The participant's eye pupil dilation was changed as shown in Table 0.22 and Figure 0.130 for each event as follows:

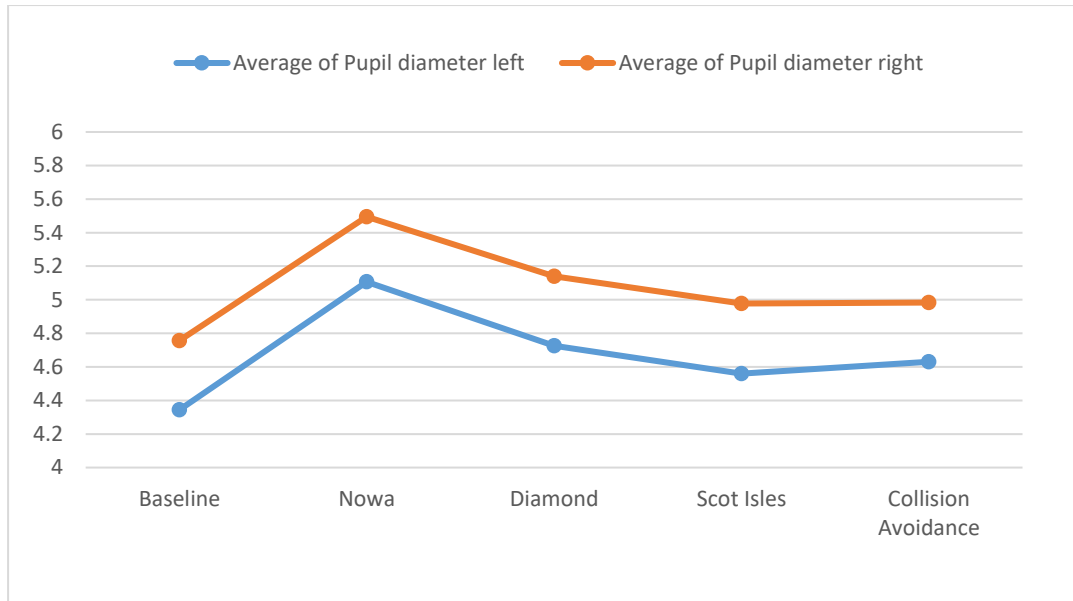


Figure 0.124 (P3-L) Eye-Tracking Result

- **Event 1 Baseline:**

in the baseline, Participant 3 demonstrated a lower pupil diameter of (4.34 mm) on the left side and (4.76 mm) on the right side. Participant 3 shows low cognitive load and a relaxed state in this event as no targets around and no task engagement. However, this event lasts around (15%) of the experiment time. During the event, the participant focused on the radar for around (47%) and (20%) of the event time on the ECDIS, with around (6%) of the time event on scanning the screen for visualisation. In addition, (19%) of the event time was focused on the display unit, and (8%) of the event time on the top display unit. This showed that Participant 3 was familiarising with all navigation equipment and improving his situational awareness with the scanning of the external area Figure 0.125



Figure 0.125 (P3-L) Heat Map for Baseline

- **Event 2 MV Nowa:**

As the MV Nowa appeared on the radar and Participant 3 acquired the target on the radar, the participant's eye pupil diameters increased to (5.10 mm) and (5.49 mm) for the left and right sides respectively. This was due to the participant showing an increase in cognitive engagement, maybe because of the sudden appearance of the MV Nowa, and the lookout informed the participant about the ships in the surroundings. In addition, the participant spent around (12%) of the experiment time monitoring the MV Nowa. The participant has shown a strong reliance on radar, with (70%) of the event time, and (23%) of the event time focusing on the ECDIS. Moreover, (1%) of the event time was observed visually on the screen Figure 0.126



Figure 0.126 (P3-L) Heat Map for MV Nowa

- **Event 3 MV Diamond:**

During this event, pupil dilation decreased slightly further to (4.72 mm) and (5.14 mm), indicating that Participant 3 was getting less cognitive load when the MV diamond appeared, this could be because the lookout information about the location of the target which improved the situation awareness of the Participant 3. This event took around (11%) of the experiment time. The participant shows that (84%) of event time focused on the radar indicating less attention on the radar. However, (2%) of the event time, Participant 3 also focused on screens for visualization. In addition, there was attention on the ECDIS around (14%) of the event time

Figure 0.127



Figure 0.127 (P3-L) Heat map for MV Diamond

- **Event 4 MV Scot Isles:**

with this event, the participant's eye diameter slightly decreased to (4.55 mm) for the left eye and (4.98 mm) for the right, indicating that Participant 3 cognitive load reduced slightly during monitoring MV Scot Isles. This event took around (34%) of the experiment time. The participant focused approximately (87%) of the event time on the radar during this event to assess the situation with the Scot of Isle. However, participant 3 also checked the situation visually with (1%) of the event time checking the external environment, and (11%) of the event time monitoring the ECDIS to support navigational information, and (1%) of the event time using VHF. This suggests that the participant relied on the navigation equipment more than used his visual observation Figure 0.128



Figure 0.128 (P3-L) Heat Map for MV Scot Isles

- **Event 5 Collision Avoidance**

The pupil diameter remained at (4.63 mm) on the left and (4.98 mm) on the right, in this event, Participant 3 almost maintained the same cognitive load when taking action to avoid the risk of collision. The collision avoidance action took around (28%) of the experiment time. During this event, the participant relied on the radar during this event. Participant 3 focused on the radar with (79%) of the event time, and (4%) of the event time on screen for visualization, and (2%) on the display unit. Also, Participant 3 was observing ship information from the top display unit around (14%) of the event time. This means that Participant 3 relied on the radar for monitoring the ship target and relied on the lookout for visual observation and steering Figure 0.129



Figure 0.129 (P3-L) Heat map for collision avoidance

Table 0.22 (P3-L) Points of focus at different scenario events

Row Labels	Display Unit	ECDIS	Engine	VHF	RADAR	Visualisation	Top Display Unit
Baseline	19%	20%	0%	0%	48%	6%	8%
Nowa	4%	23%	0%	2%	70%	1%	0%
Diamond	0%	14%	0%	0%	84%	2%	0%
Scot Isles	0%	11%	0%	1%	87%	1%	0%
Collision Avoidance	2%	0%	0%	1%	79%	4%	14%

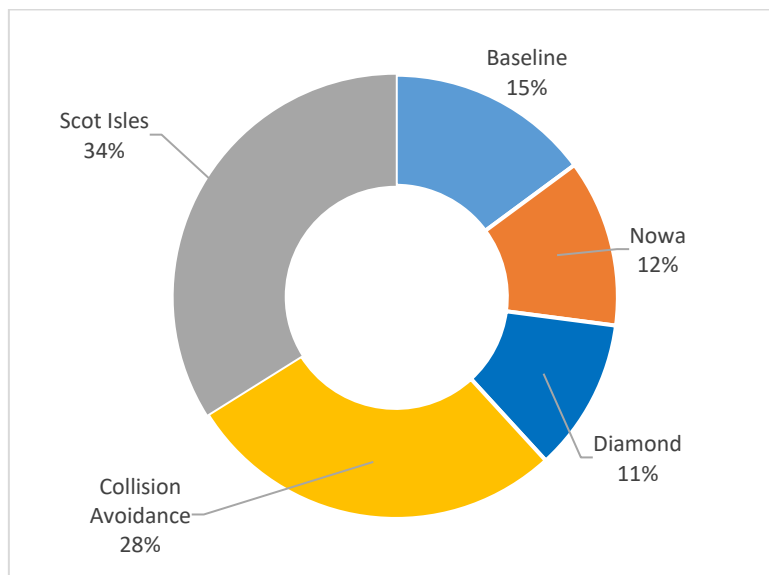


Figure 0.130 (P3-L) Duration time for each event

The Figure 0.131 and Figure 0.132 represent Participant 3 performance through the EEG and Eye-tracking singles which clearly illustrates the cognitive demand through the scenario.

The EEG shows that Participant 3 during the baseline was stable with low cognitive demand. However, when the targets began to appear, a spike appeared after the baseline event around (05m30s) from (F4-Pz) indicating that Participant 3 engaged mentally and stressfully. However, Participant 3 detects the MV Nowa after one minute. The Frontal channel (F3-PZ) showed a significant spike and this could be when the lookout informed Participant 3 about the location which needed a decision from Participant 3. In the MV Scot Isles, Participant 3 showed an engagement activity with due to his monitoring between the radar and the ECDIS, also, Participant 3 tried to communicate with MV Scot Isles but no response which indicated that Participant 3 needed to take a decision as shown a significant spike in (17m30s). During collision avoidance, Participant 3 decided to reduce the speed which indicates the high activity in the frontal channel at (20m10s), and then start to be calm as Participant 3 become clear of the target.

Furthermore, the eye-tracking shows that participant 3 in the baseline had low cognitive demand and maintained his mentality with the task until he became aware of the Scot Isles which indicates a cognitive demand rose. During the scenario, a low eye pupil size appeared in all events, and this could be because Participant 3 had fatigued at some point when the scenario got complex. However, the participant3's cognitive demand maintained during the collision avoidance event calm as Participant 3 became clear of the target.

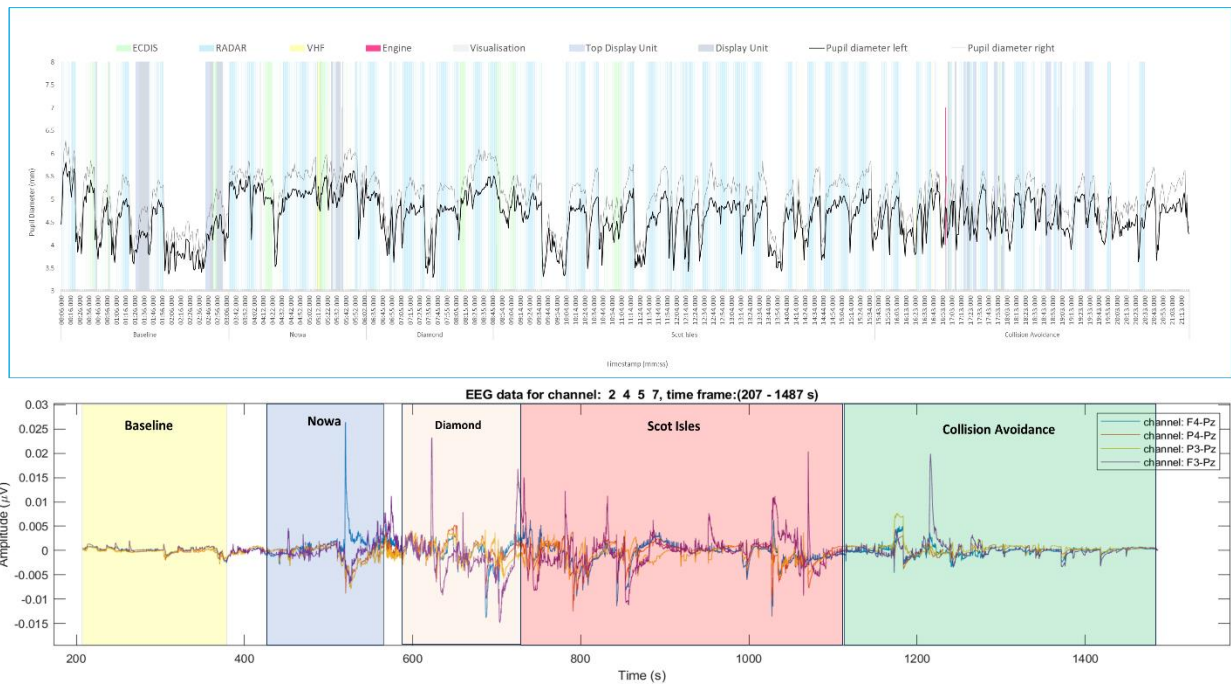


Figure 0.131 (P3-L) EEG and Eye-Tracking

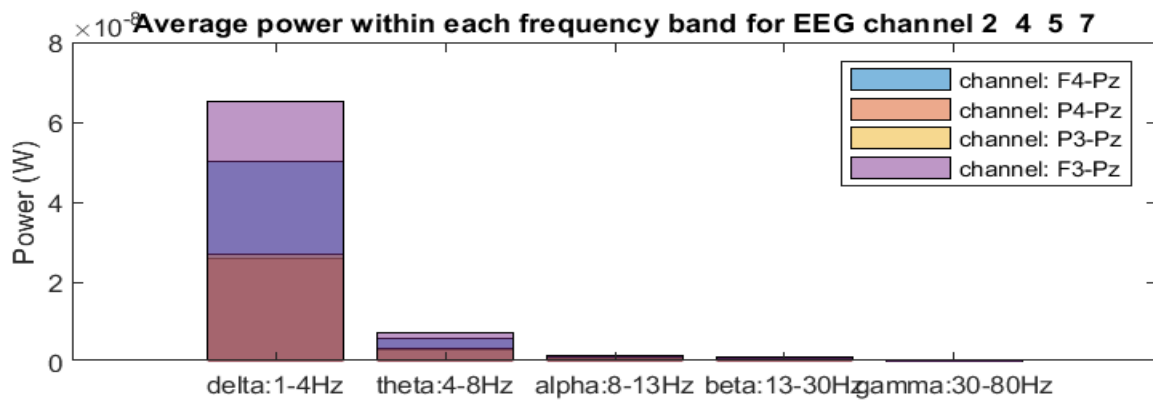


Figure 0.132 (P3-L) Power band

- **Participant 5 (P5-L)**

During the simulator experiment, participant 5 was navigating out of the ideal course. it shows that Participant 5 passed clear without being involved in a collision Figure 0.133. However, participant 5 had ineffective situational awareness. The experiment occurred during the participant's interaction with five events:

Event 1 Baseline: participant 5 stood in the middle of the ship bridge observing around to get familiar with the ship bridge environment

Event 2 MV Nowa: when the targets appeared, participant 5 looked around and the lookout told him that the scenario started which made him aware of the situation. Afterward, participant 5 moved to the radar and observed the ships ahead. Then at (04m:13s), the lookout informed him about MV Nowa and became aware of the crossing situation. Subsequently, participant 5 changed the steering to the manual, told the lookout to steer, and said, “Hard to starboard”. Later, participant 5 received a call from MV Nowa informing him to maintain the course and speed. The answer from Participant 5 was disagreed because the ship already changed the course to starboard. After a few seconds, participant 5 communicates with MV Nowa again. MV Nowa said her location on the starboard side and told to participant 5 please maintain your course and speed. Participant 5 instructed the lookout to make it hard to port and agree with MV Nowa. This suggests that Participant 5 was confused about his decision and still not fully aware of the situation awareness.

Event 3 MV Diamond: participant 5 kept ordering the lookout to keep hard-to-port and also, he was monitoring the radar. Participant 5 acquired MV Diamond on the radar but was not aware of her location because Participant 5 still looking at MV Nowa and ordering the lookout to keep steady on the course (060), then participant 5 received a call from MV Diamond requesting him to maintain the course and speed which was agreed by participant 5.

Event 4 MV Scot Isles: after communication finished with MV Diamond, the lookout informed the participant about MV Diamond's location, Participant 5 was confused between MV Nowa and MV Diamond on the radar, when became aware of the MV Diamond participant 5 ordered the lookout to make hard to port to back to the ideal course. After that, participant 5 monitored the targets on the radar and acquired MV Scot Isles t (13m:32s). participant 5 was to get the information of the MV Scot Isles and communicate to her immediately but no response from MV Scot Isles.

Event 5 Collision Avoidance: After Participant 5 did not get a response from MV Scot Isles, immediately ordered the lookout to make it hard to starboard. Participant 5 kept altering course until become parallel with MV Scot Isles and monitored the target on the radar and visually. During the maneuvering, participant 5 was still not aware of the target's location. Participant 5 communicated with the ship MV Royal Glasgow to inform her to pass by stern which is a target located far away from his ship. Participant 5 did not know what ship that he wanted to contact. Participant 5 passed clear, but his awareness was ineffective.



Figure 0.133 (P5-L) Navigation Chart

Additionally, the heat map provides the participant's visual attention distribution during the ship bridge training simulation Figure 0.135 . It offers a clear visual focus throughout the events. The red zones indicate the area with high focus. The heat map demonstrates that the participant was focusing on the navigation equipment most of the time



Figure 0.134 (P5-L) Heat Map

Table 0.23 (P5-L) EEG result

Time		Event	Duration	MWL	Stress	Attention
00:00.0	03:03.3	Baseline	03:03.3	0.12	0.03	1.00
04:13.7	06:38.4	Nowa	02:24.7	0.00	0.59	0.00
08:14.9	09:34.9	Diamond	01:20.0	0.05	1.00	0.28
13:34.1	14:36.9	Scot Isles	01:02.9	1.00	0.64	0.05
14:44.3	29:00.0	Collision Avoidance	14:15.7	0.11	0.00	0.15

Based on the EEG result and Participant 5's performance metrics illustrated in Table 0.23 and Figure 0.135 we can observe how the cognitive demand (MWL, Stress, and attention) differentiation across the different events in the simulator training as follows:

- **Event 1 Baseline:**

During the baseline, participant 5 showed low mental workload and stress levels while high attention was shown. This suggests that the participant was calm because there were not any targets, and no immediate risk existed.

- **Event 2 MV Nowa:**

When the targets began to appear, Participant 5 detected the MV Now which increased Participant 5's stress to moderate. Participant 5 was not aware when the scenario started and the lookout informed him, immediately Participant 5 noticed the targets around him and ordered

the lookout to steer manually and change to hard starboard, which suggests that Participant 5 got stressed when the targets appeared.

- **Event 3 MV Diamond:**

The next event, MV Diamond, shows significantly high stress with low attention and MWL. In this event, Participant 5 acquired MV Diamond on the radar but was not aware of the target location until the lookout informed him and then receiving the call from MV Diamond. In addition, Participant 5 keeps ordering the lookout to steady at the course (060) and monitoring the MV Nowa which suggests that he is still stressed.

- **Event 4 MV Scot Isles:**

Participant 5 showed in the event a high MWL and stress with low attention. Participant 5 was confused between MV Now and MV Diamond on the radar, when became aware of the MV Diamond Participant 5 ordered the lookout to make it hard to port to back to the ideal course. After that, participant 5 monitored the targets on the radar and acquired MV Scot Isles. In addition, Participant 5 communicated with MV Scot Isles but there was no response. This indicated the increase of the MWL and stress in this event which reduced Participant 5 attention.

- **Event 5 Collision Avoidance:**

MWL, stress, and attention were reduced in this event, this might be because Participant 5 relied on the lookout as support for steering which allowed him to focus and monitor the targets to avoid the collision.

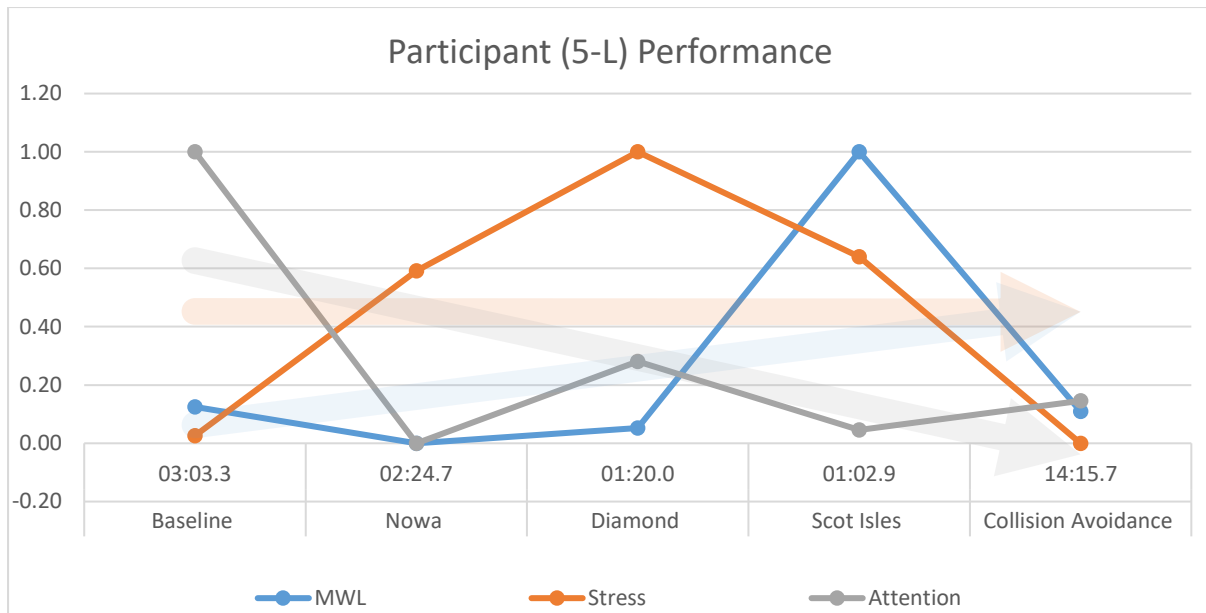


Figure 0.135 (P5-L) EEG result

Furthermore, pupil diameter for both eyes gives a comprehensive view of Participant's 5 performance through the events. Participant 5 began with low cognitive demand and started to increase slightly then during the MV Nowa began to increase until the last event collision avoidance Figure 0.136. Participant 5 eye pupil size and focusing were changed as shown in each event as follows: Table 0.24 and Figure 0.142

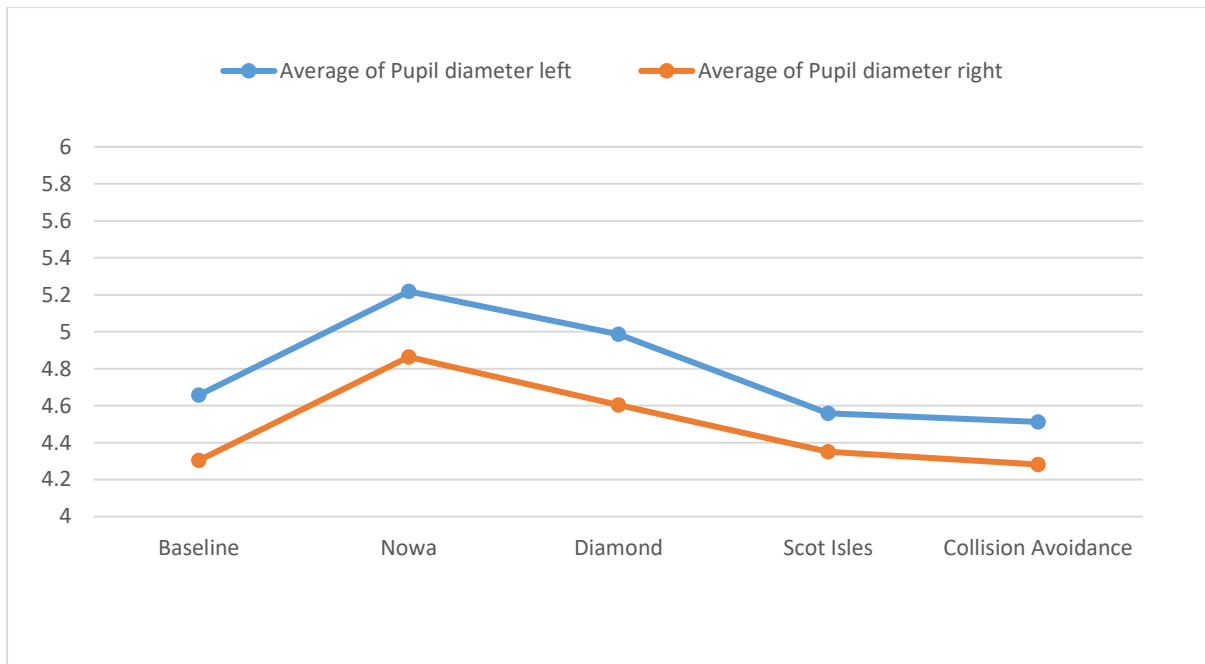


Figure 0.136 (P5-L) Eye-Tracking Result

- **Event 1 Baseline:**

During the baseline event, the participant demonstrated average pupils with (4.66) and (4.31) for the left and right eyes respectively. The participant was not under pressure as there were no external targets to deal with which should made, her calm and low MWL state. The baseline duration is around (14%) of the scenario time, and the participant in the baseline event spent around (36%) of the event time focusing on the radar (27%) of the event on ECDIS, and around (27%) of the event time visually scanned the surrounding area to check the situation in the surrounding area. Additionally, a small attention was put on the display unit with (5%) of the event indicating initial information check before the targets appeared and indicates that Participant 5 used this time to get familiar with the navigation equipment Figure 0.137 Figure 0.137



Figure 0.137 (P5-L) Heat map for Baseline

- **Event 2 MV Nowa:**

As the MV Nowa appeared on the radar and was visually detected, the participant's eye pupil diameters increased to (5.22 mm) and (4.86 mm) for the left and right sides respectively. This was due to the participant showing an increase in cognitive engagement, maybe because of the sudden appearance of the MV Nowa, and Participant 5 was surprised by the situation. In addition, the participant spent around (11%) of the experiment time monitoring the MV Nowa. The participant has shown a strong reliance on radar, with (70%) of the event time, and (5%) of the event time observed visually on the screen. However, Participant 5 monitor the ECDIS around (17%) of the event time, and (7%) on the display unit, which indicates that he prefers to use the radar as a navigation system to monitor the target Figure 0.138



Figure 0.138 (P5-L) Heat map for MV Nowa

- **Event 3 MV Diamond:**

During this event, pupil dilation decreased slightly further to (4.99 mm) and (4.60 mm), indicating that Participant 5 was getting less cognitive load when the MV diamond appeared. This event took around (6%) of the experiment time. The participant shows that (78%) of the event time focused on the radar. However, (2%) of the event time Participant 5 also focused on screens for visualization. In addition, there was no attention on the ECDIS. The display unit got the attention of (20%) of the event time, indicating that Participant 5 relied on the lookout for visual observation which allowed him to monitor the navigation equipment. Figure 0.139



Figure 0.139 (P5-L) Heat map for MV Diamond

- **Event 4 MV Scot Isles:**

with this event, the participant's eye diameter slightly decreased to (4.56 mm) for the left eye and (4.35 mm) for the right, indicating that Participant 5 cognitive load reduced during this event. This event took around (5%) of the experiment time. this event had a short duration because Participant 5 after communication finished with MV Diamond, the lookout informed the participant about MV Diamond's location, Participant 5 was confused between MV Nowa and MV Diamond on the radar when became aware of the MV Diamond Participate 5 ordered the lookout to make hard to port to back to the ideal course. After that, participant 5 monitored the targets on the radar and acquired MV Scot Isles at (13m:32s), then immediately communicated with Scot Isles and did not get any response which made him take action immediately where he spent most of the time in the collision avoidance event. Therefore, it shows that Participant 5 focused most of the time on the radar Figure 0.140



Figure 0.140 (P5-L) Heat map for MV Scot Isles

- **Event 5 Collision Avoidance**

The pupil diameter almost remained at (4.51 mm) on the left and (4.28 mm) on the right, maintaining the same cognitive load when taking action to avoid the risk of collision. The collision avoidance action took around (64%) of the experiment time. During this event, the

participant distributed his attention more widely across navigation systems. The participant focused this time less on the radar with (80%) of the event time while (16%) on the ECDIS, and (2%) of the event time on screen for visualization. This suggests that Participant 5 relied on the lookout for visual observation while he monitored the navigation system Figure 0.141



Figure 0.141 (P5-L) Heat map for collision avoidance

Table 0.24 (P5-L) Points of focus at different scenario events

Row Labels	Display Unit	ECDIS	Engine	VHF	RADAR	Visualisation	Top Display Unit
Baseline	5%	27%	0%	5%	36%	27%	0%
Nowa	7%	17%	1%	0%	70%	5%	0%
Diamond	20%	0%	0%	0%	78%	2%	0%
Scot Isles	0%	0%	0%	0%	100%	0%	0%
Collision Avoidance	0%	16%	0%	2%	80%	2%	0%

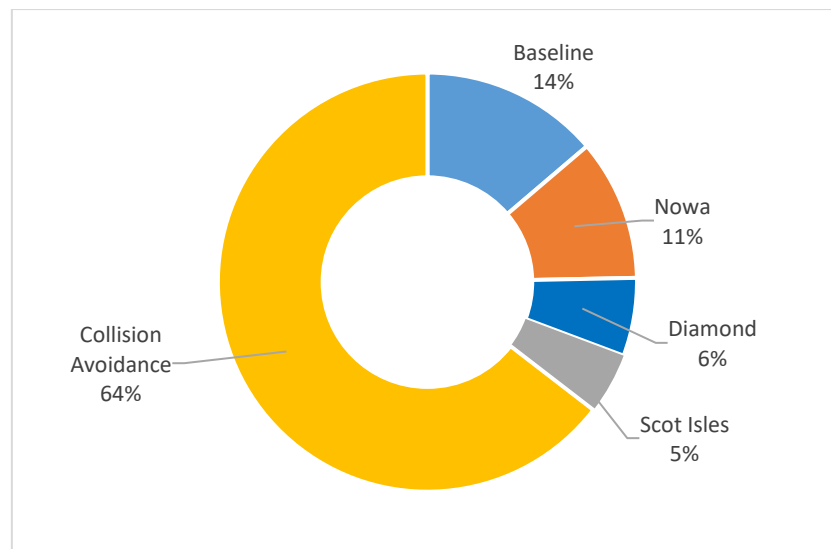


Figure 0.142 (P5-L) Duration time for each event

The Figure 0.143 and Figure 0.144 represent the participant 5 performance through the EEG and Eye-tracking singles which clearly illustrate the cognitive demand through the scenario.

The EEG shows that Participant 5 during the baseline was stable with low cognitive demand. However, when the targets began to appear, The Frontal channel (F4-PZ) was active this might have happened because Participant 5 was making a decision when he changed the steering and ordered the lookout to steer. It shows that between the MV Diamond and MV Scot Isles, a significant activity in the channel which indicated that Participant 5 was mentally high when the lookout informed Participant 5 about the MV Scot Isles and the scenario became more complex, theses fluctuations in the signals occurred due to communication with the lookout and making a decision during the scenario. Participant 5 in the MV Scot Isles event communicated with the target and when he did not get a response immediately Participant 5 took action to avoid the collision. During collision avoidance even, there is some activity in the Frontal and Parietal channels and this is related to communication and decision making which indicates that Participant 5 communicated with the lookout and kept taking decisions to avoid the collision.

Furthermore, the eye-tracking shows that Participant 5 in the baseline had low cognitive demand and maintained his mentality with the task until he became aware of the MV Nowa which indicates a

cognitive demand rose. In the middle of the Scot Isles event, a low eye pupil size appeared, and this might be because Participant 5 relied on the lookout for steering which reduced his cognitive load. However, Participant 5's cognitive demand was maintained during MV Scot Isles and collision avoidance this suggests that the presence of the lookout support maintains the participant's cognitive load.

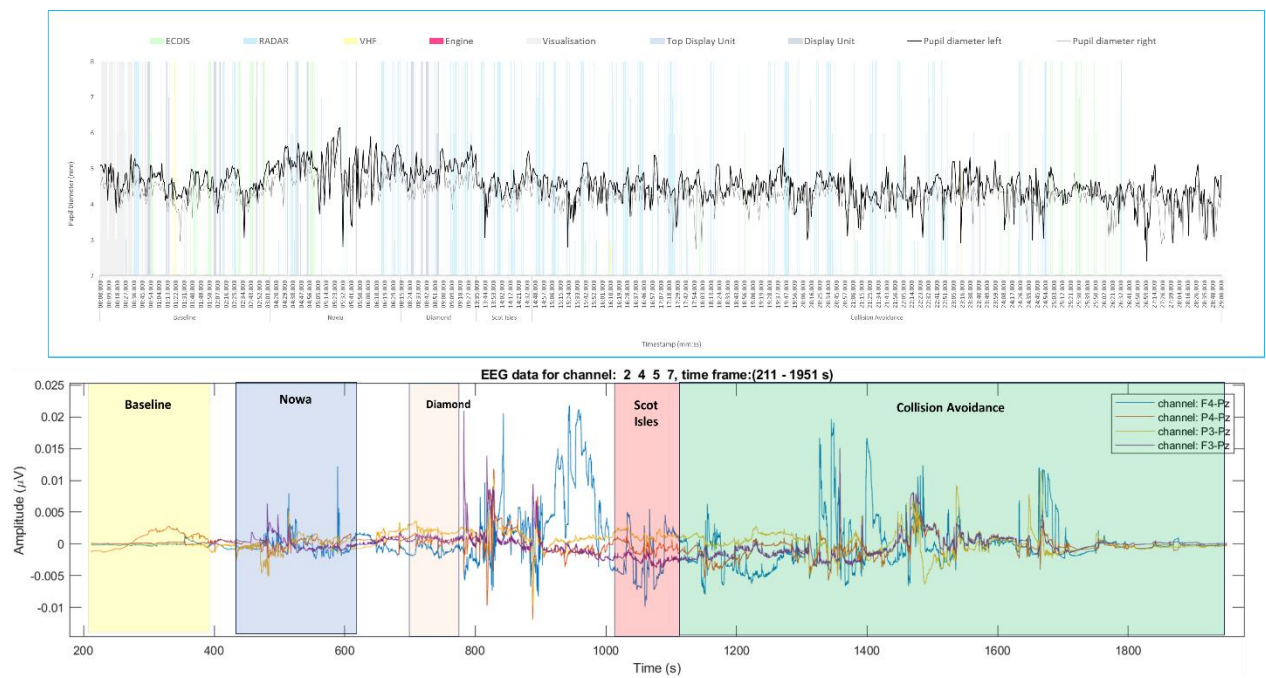


Figure 0.143 (P5-L) EEG and Eye-Tracking

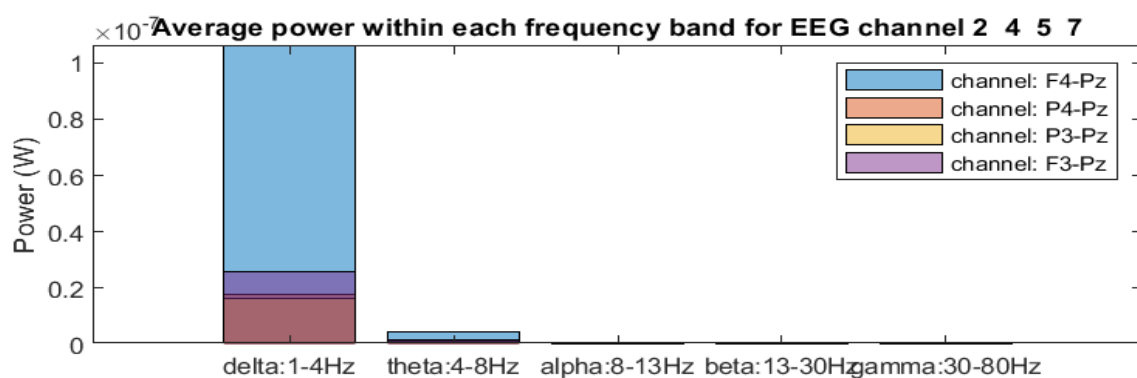


Figure 0.144 (P5-L) Power band

- **Participant 8 (P8-L)**

During the simulator experiment, participant 8 was navigating on the ideal course in first and got out of the course to avoid the collision, which is the green line, Figure 0.145 it shows that Participant 8 passed clear without being involved in a collision but with near miss. The accident occurred during the participant's interaction with five events:

Event 1 Baseline: participant 8 stood in the middle of the ship bridge observing around to get familiar with the ship bridge environment

Event 2 MV Nowa: participant 8 moved to the radar acquired the ships ahead and MV Nowa was on the radar. Then the lookout informed him about the situation. participant 8 was observing and monitoring MV Now on the radar then he received a call from MV Nowa informing him to maintain course and speed which was confirmed by Participant 8.

Event 3 MV Diamond: the lookout informed Participant 8 that there is a ship on the starboard quarter which is MV Diamond. Participant 8 acquired the target on the radar, in the meantime, participant 8 acquired MV Scot Isles, in addition to that, the lookout informed him about the ship on the port side which is MV Scot Isles. Then, participant 8 moved to look at the screen for visualization to observe it visually which improved his situational awareness. Later, participant 8 received a communication from Mv Diamond to inform him to maintain course and speed which was confirmed by Participant 8.

Event 4 MV Scot Isles: participant 8 back to the radar to monitor the targets. He ordered the lookout to take the steer and change it to manual. Then, participant 8 communicated with the engine room and asked that the RPM drop. The engine room informed him that they would check and reply to him later. In the meantime, participant 8 observed MV Scot Isles on the radar and visually. Then, participant 8 communicated with Scot Isles, and no response was found.

Event 5 Collision Avoidance: participant 8 moved to check the port side visually and then ordered the lookout to make the port side and steady on (060). After that, participant 8 kept monitoring MV Scot Isles on the radar and visually. Also, participant 8 looks around the

surroundings region visually to ensure that the area is clear for manouvering which is effective situational awareness until pass clear.

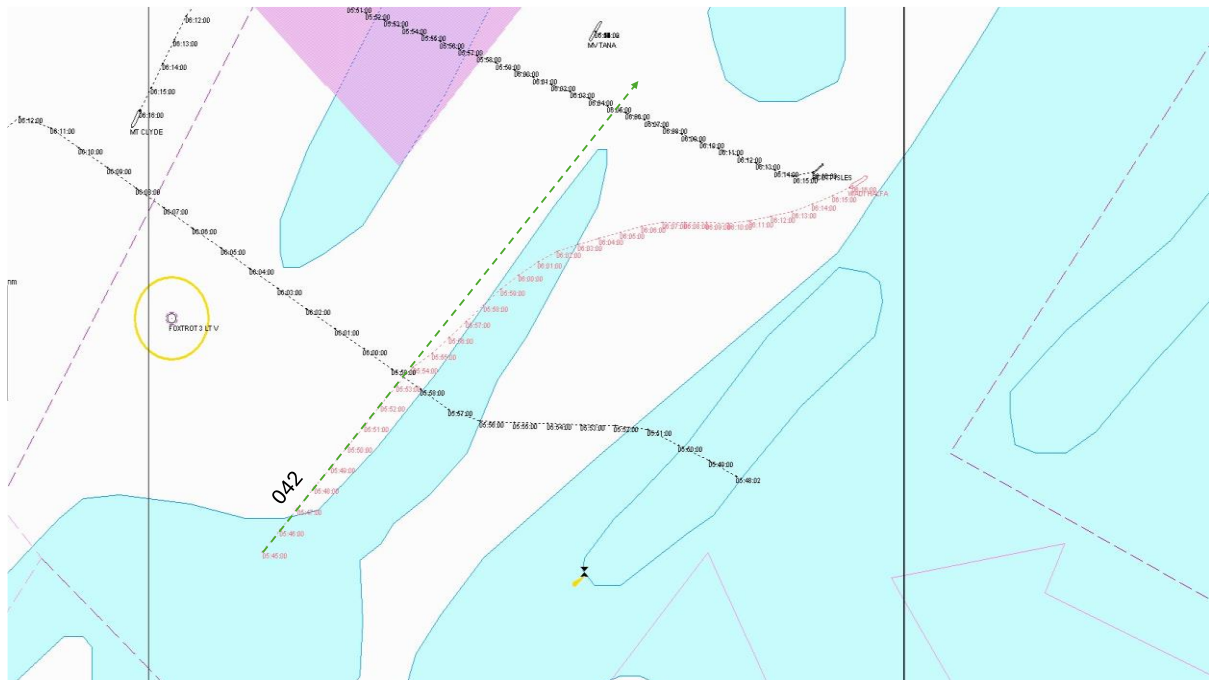


Figure 0.145 (P8-L) Navigation chart

Additionally, the heat map provides the participant's visual attention distribution during the ship bridge training simulation Figure 0.146 provide a clear visual focus throughout the events. The red zones indicate the area with high focus. The heat map demonstrates that the participant was focusing on the navigation equipment most of the time.



Figure 0.146 (P8-L) Heat Map

Table 0.25 (P8-L) EEG Result

Time		Event	Time Period	MWL	Stress	Attention
00:00.0	03:07.6	Baseline	03:07.6	1.00	0.14	0.02
03:47.2	05:51.9	Nowa	02:04.6	0.23	0.05	0.17
06:16.6	06:41.7	Diamond	00:25.1	0.17	0.80	1.00
09:07.5	11:18.8	Scot Isles	02:11.3	0.22	1.00	0.00
13:21.3	27:58.3	Collision Avoidance	14:37.0	0.00	0.00	0.03

Based on the EEG result and participant 8's performance metrics illustrated in Table 0.25 and Figure 0.147 we can observe how the cognitive demand (MWL, Stress, and attention) differentiation across the different events in the simulator training as follows:

- **Event 1 Baseline:**

During the baseline, participant 8 showed low high workload and low-stress levels while very low attention was shown. This is possible because the participant was calm because there were not any targets, no immediate risk existed, and Participant 8 familiarized himself with the setup.

- **Event 2 MV Nowa:**

Participant 8 in the MV Now reduced MWL to low and very low stress. However, the attention increased but was still low. This reflects that Participant 8 engaged with the task with no risk

and attention increased because the participant monitored the situation and responded to communication from MV Now.

- **Event 3 MV Diamond:**

The next event, MV Diamond, shows significantly high stress and attention with low MWL. This suggests that Participant 8 was not aware of the MV Diamond and when the lookout alerted him, participant 8 got stressed and increased his attention to resolve the situation

- **Event 4 MV Scot Isles:**

Participant 8 was informed by the lookout about Scot Isles. It shows that Participant 8 had low MWL with very low attention and high stress. This indicates that Participant 8 was managing the situation but the lack of communication with MV Scot Isles contributed to his stress. The overlying on the radar and the presence of the lookout could have reduced his attention to the situation.

- **Event 5 Collision Avoidance:**

In this event, Participant 8 had very low MWL, stress, and attention. this could be reflected that Participant 8 was frustrated and exhausted after the complex situation and try to manage his situation awareness after becoming clear of the risk of the collision.

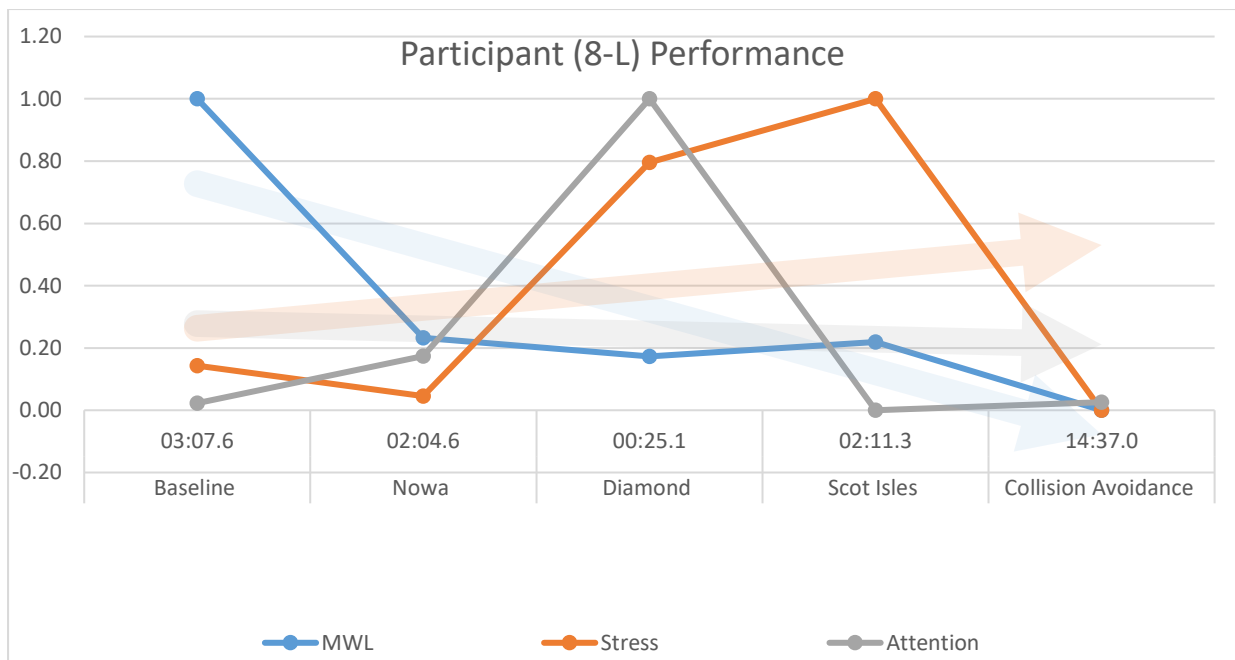


Figure 0.147 (P8-L) EEG result

Furthermore, pupil diameter for both eyes give a comprehensive view of Participant 8's performance through the events. Participant 8 began with low cognitive demand and started to increase slightly then with the scenario complexity Figure 0.148. Participant 8 eye pupil size and focusing were changed as shown in each event as follows: Table 0.26 and Figure 0.154

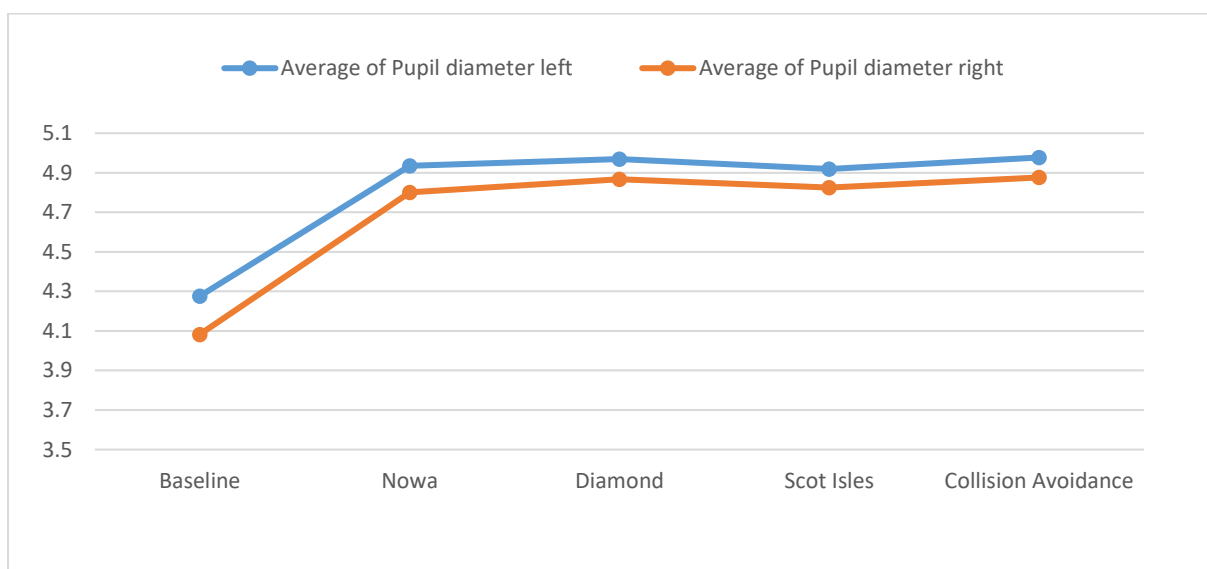


Figure 0.148 (P8-L) Eye-Tracking Result

- **Event 1 Baseline:**

During the baseline event, the participant demonstrated the lowest average pupils with (4.28) and (4.08) for the left and right eyes respectively. The participant was not under pressure as there were no external targets to deal with which should made, her calm and low MWL state. However, the baseline duration is around (12%) of the scenario time, and the participant in the baseline event spent around (11%) of the event time focusing on the radar and (21%) of the event on ECDIS, and around (38%) of the event time visually scanned the surrounding area to check the situation in the surrounding area. Additionally, little attention was put on the display unit with (6%) and (23%) on the top display unit of the event time indicating initial information check before the targets appeared and indicating that Participant 8 used this time to get familiar with the ship environment as no risk of collision exists Figure 0.149



Figure 0.149 (P8-L) Heat map for baseline

- **Event 2 MV Nowa:**

As the MV Nowa appeared on the radar and was visually detected, the Participant's 8 eye pupil diameters increased to (4.93 mm) and (4.80 mm) for the left and right sides respectively. This might be because of the sudden appearance of the MV Nowa, and Participant 8 was surprised by the situation. In addition, the participant spent around (8%) of the experiment time

monitoring the MV Nowa. The participant has shown a strong reliance on the radar with (91%) of the event time, and (4%) of the event time observed in the ECDIS. However, little attention was on the display unit with (1%) and (2%) on the VHF when communicating, which indicates that Participant 8 prefers to use the radar as a navigation system to monitor the target and little visual observation to ensure the appearance of the target Figure 0.150



Figure 0.150 (P8-L) Heat map for MV Nowa

- **Event 3 MV Diamond:**

During this event, pupil dilation maintained and increased slightly further to (4.96 mm) and (4.86 mm), indicating that Participant 8 managed his cognitive load when the MV diamond appeared. This event took around (11%) of the experiment time. The participant shows that (94%) of the event time focused on the radar. However, (6%) of the event time, Participant 10 used the engine indicating that Participant 8 did some action to manage his situation awareness when the scenario become more critical Figure 0.151



Figure 0.151 (P8-L) Heat map for MV Diamond

- **Event 4 MV Scot Isles:**

Still, with this event, the participant's eye diameter maintained and slightly decreased to (4.92 mm) for the left eye and (4.83 mm) for the right, indicating that Participant 8 maintained his cognitive load. This event took around (12%) of the experiment time. The participant focused approximately (73%) of the event time on the radar during this event to assess the situation with the Scot of Isle. However, participant 10 also checked the situation visually with (2%) of the event time checking the external environment, and (3%) of the event time monitoring the display unit to support navigational information, and (19%) of the event time still observing the top display unit. This suggests that Participant 8 distributes his attention in the ship bridge environment between the navigation equipment to improve his situation awareness while relying on the lookout for external observation Figure 0.152



Figure 0.152 (P8-L) Heat map for MV Scot Isles

- **Event 5 Collision Avoidance**

The pupil diameter was maintained with a slight increase to (4.97 mm) on the left and (4.87 mm) on the right, demonstrating the same cognitive load when taking action to avoid the risk of collision. The collision avoidance action took around (57%) of the experiment time. During this event, the participant distributed his attention more widely across the bridge systems. The participant focused on the radar for (76%) of the event time while (13%) of the event time on ECDIS, (2%) of the event time on screen for visualization, and (1%) on the display unit with (8%) of the event time on the top display unit. This means that Participant 8 distributed his attention to the ship navigation equipment when he saw the risk of the collision to monitor the target and relied on the lookout for steering and external observation Figure 0.153



Figure 0.153 (P8-L) Heat map for collision avoidance

Table 0.26 (P8-L) Points of focus at different scenario events

Row Labels	Display Unit	ECDIS	Engine	VHF	RADAR	Visualisation	Top Display Unit
Baseline	6%	21%	0%	1%	11%	38%	23%
Nowa	1%	4%	2%	2%	91%	0%	0%
Diamond	0%	0%	6%	0%	94%	0%	0%
Scot Isles	3%	0%	1%	1%	73%	2%	19%
Collision Avoidance	1%	13%	0%	1%	76%	2%	8%

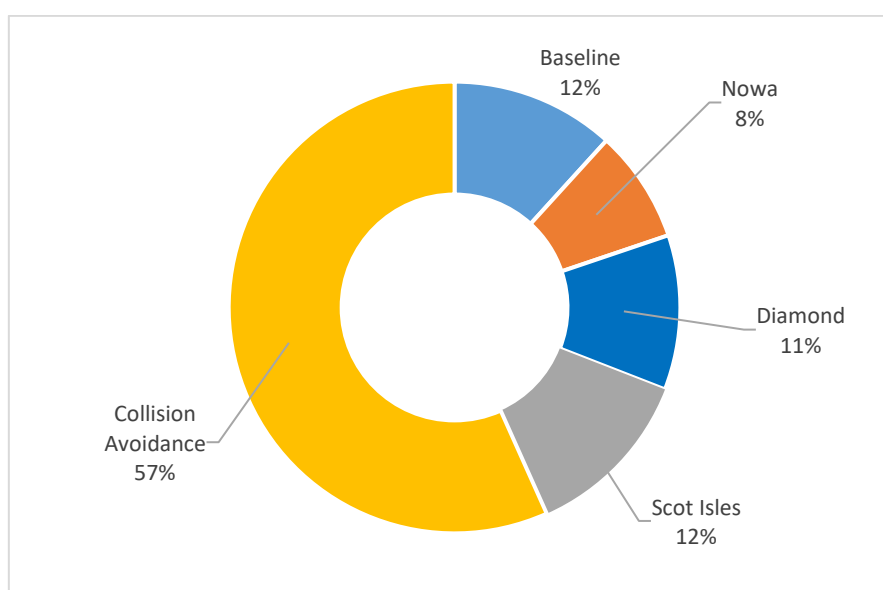


Figure 0.154 (P8-L) Duration time for each event

The Figure 0.155 and Figure 0.156 represent the participant 8 performance through the EEG and Eye-tracking singles which clearly illustrate the cognitive demand through the scenario.

The EEG shows that Participant 8 during the baseline was stable with low cognitive demand. However, when the targets began to appear, Participant 8 detected the MV Nowa with slight fluctuation present indicating that Participant 8 engaged mentally and stressfully. During MV Diamond and MV Scot Isles, Participant 8 likely had a significant cognitive challenge as the participant resolved an unexpected situation. During collision avoidance, amplitude variation increases, reflecting the cognitive effort required, and this is associated with different actions that occur by the participant.

Furthermore, the eye-tracking shows that Participant 8 in the baseline had low cognitive demand, and when he became aware of the MV Nowa the cognitive demand and attention rose. During MV Nowa, Participant 8 maintained his mentality with task complexity until collision avoidance. During the collision avoidance, it shows there is some decrease which indicates that Participant 8 felt frustrated in some point due to the critical scenario.

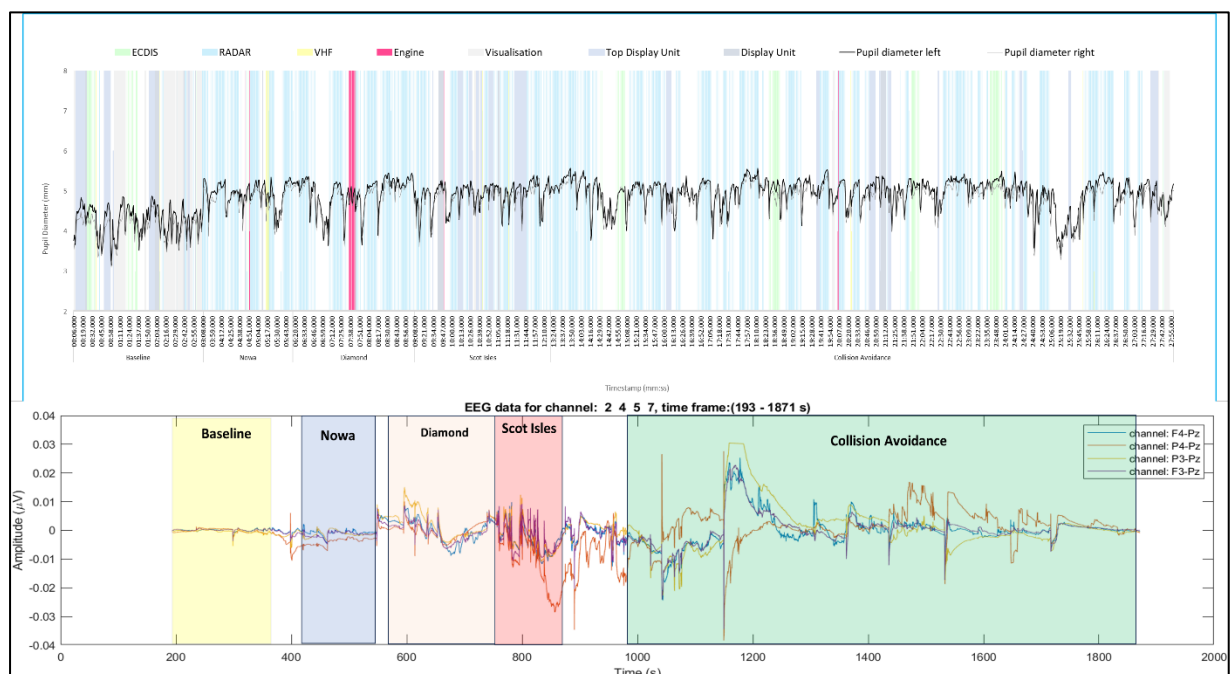


Figure 0.155 (P8-L) EEG and Eye-Tracking

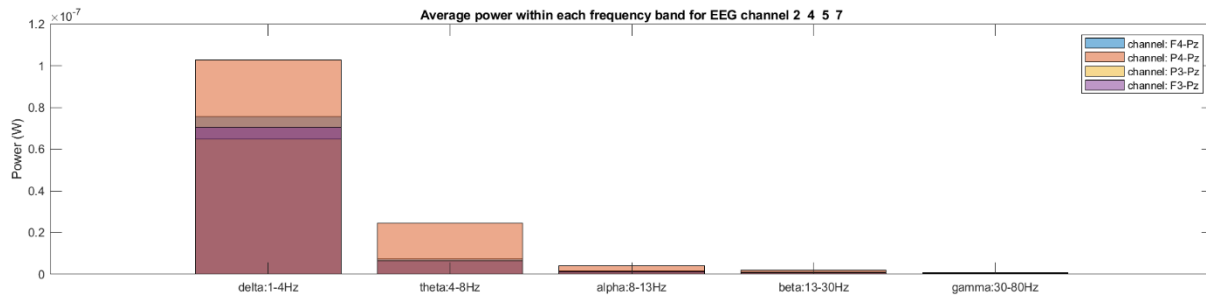


Figure 0.156 (P8-L) Power band

- **Participant 10 (P10-L)**

During the simulator experiment, participant 10 was navigating out of the ideal course Figure 0.157 It shows that Participant 10 passed clear without being involved in a collision but with a near miss. The experiment occurred during the participant's interaction with five events:

Event 1 Baseline: participant 10 was moving around the ship bridge checking the navigation equipment. Participant 10 was trying to get familiar with the ship environment.

Event 2 MV Nowa: Participant 10 moved to the radar to monitor the targets, and then Participant 10 detected MV Nowa visually. Participant 10 then acquired MV Nowa on the radar to get the information. After that, the lookout informed him about the situation with MV Nowa. While monitoring MV Now on the radar, participant 10 acquired MV Diamond on the radar. Later, participant 10 moved to look at the surroundings and confirmed visually the location of the MV Nowa and MV Dimond which is effective situation awareness by Participant 10. After that, participant 10 received a communication from MV Nowa confirming to maintain the course and speed and MV Nowa will pass from the stern.

Event 3 MV Diamond: the lookout informed Participant 10 about the MV Diamond location. However, participant 10 already acquired the target and was monitoring the MV Dimond. In the meantime, the lookout informed Participant 10 about the Mv Scot Isles that will [ass from the port side. The participant then acquired the target on the radar and got the information. Then, participant 10 received a communication from MV Dimond informing Participant 10 that

the ship would overtake from the starboard side. The answer was confirmed and Participant 10 informed MV Diamond that she altered to the starboard slightly to avoid traffic.

Event 4 MV Scot Isles: participant 10 was monitoring the situation visually and on the radar and kept moving around in the ship bridge. Participant 10 was observing MV Scot Isles visually and then on the radar. When the MV Scot Isles became closer, participant 10 communicated to the engine room that she would start to slow down

Event 5 Collision Avoidance: participant 10 instructed the lookout to take the steering and change it to manual. Then participant 10 started to reduce the speed and keep monitoring the target visually until passed clear from ahead.

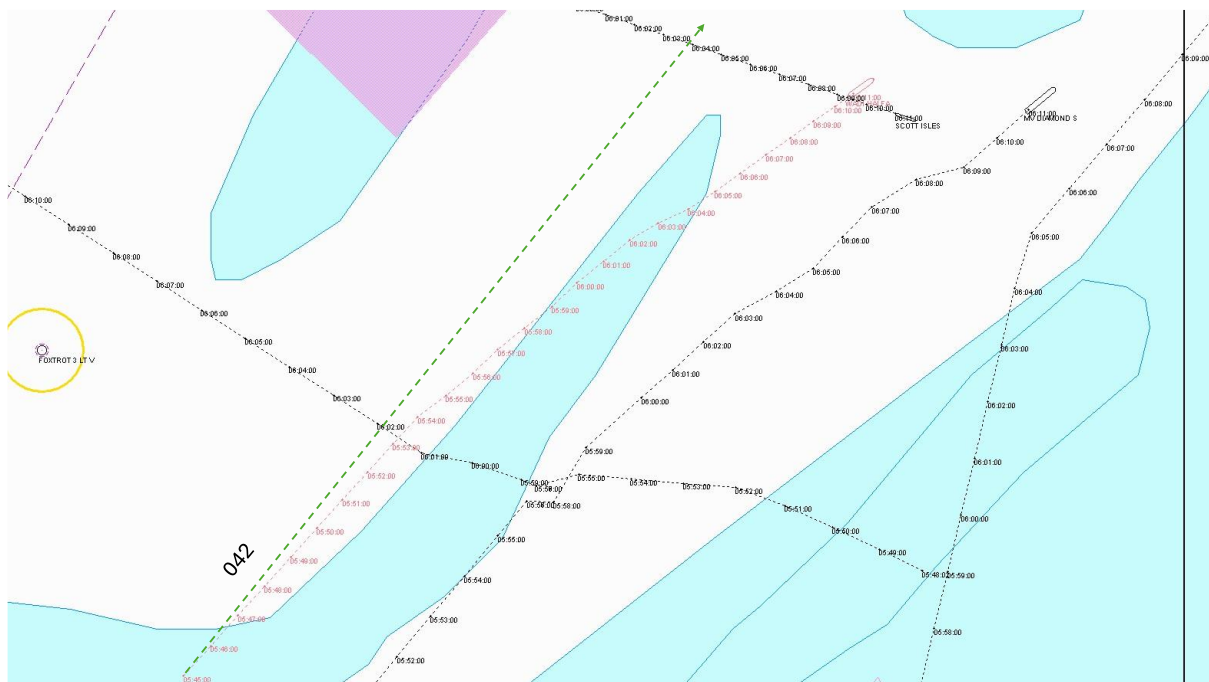


Figure 0.157 (P10-L) Navigation chart

Additionally, the heat map provides the participant's visual attention distribution during the ship bridge training simulation Figure 0.158 shows a clear visual focus throughout the events. The red zones

indicate the area with high focus. The heat map demonstrates that the participant focused on the navigation equipment most of the time with little attention to the external observation.



Figure 0.158 (P10-L) Heat map

Table 0.27 (P10-L) EEG result

Time		Event	Duration	MWL	Stress	Attention
00:00.0	03:05.1	Baseline	03:05.1	0.00	1.00	1.00
03:38.0	05:47.2	Nowa	02:09.2	0.08	0.76	0.85
05:47.2	08:57.5	Diamond	03:10.3	1.00	0.33	0.00
08:57.5	18:59.9	Scot Isles	10:02.4	0.22	0.00	0.38
19:23.1	24:51.6	Collision Avoidance	05:28.5	0.53	0.05	0.17

Based on the EEG result and Participant 10's performance metrics illustrated in Table 0.27 and Figure 0.159 we can observe how the cognitive demand (MWL, Stress, and attention) differentiation across the different events in the simulator training as follows:

- **Event 1 Baseline:**

During the baseline, Participant 10 showed a very low mental workload and high-stress level with high attention. This suggests that Participant 10 moved around the ship bridge to check the equipment and surroundings, and the high stress could be because of initial anxiety or pressure to perform.

- **Event 2 MV Nowa:**

In the MV Now event, MWL remained minimal, and street level with attention level remained high too, indicating Participant 10 maintained his MWL and the street remained high might be because of the appearance of the targets and the need for monitoring to keep an effective situational awareness which keeps his attention high.

- **Event 3 MV Diamond:**

The next event, MV Diamond, shows significantly high MWL with moderate stress and very low attention. Participant 10 experienced high MWL possibly due to the complexity of monitoring multiple targets and responding to communication, which reduced his stress. The attention dropped might be due to cognitive overload or reliance on the radar rather than visual monitoring where there is a lookout present for external observation.

- **Event 4 MV Scot Isles:**

Participant 10 experienced low MWL, very low stress, and moderate attention. Participant 10 monitored MV Scot Isles visually and on the radar, communicated with the engine to slow down, and maintained situational awareness, this showed that Participant 10 managed his MWL and stress to improve his attention.

- **Event 5 Collision Avoidance:**

During the collision avoidance event, Participant 10 experienced moderate MWL, very low stress, and low attention. Participant 10 instructed the lookout to take manual control, reduce speed, and monitor the target visually. This suggests that Participant 10 managed his MWL and stress which improved his situational awareness with confident decision-making.

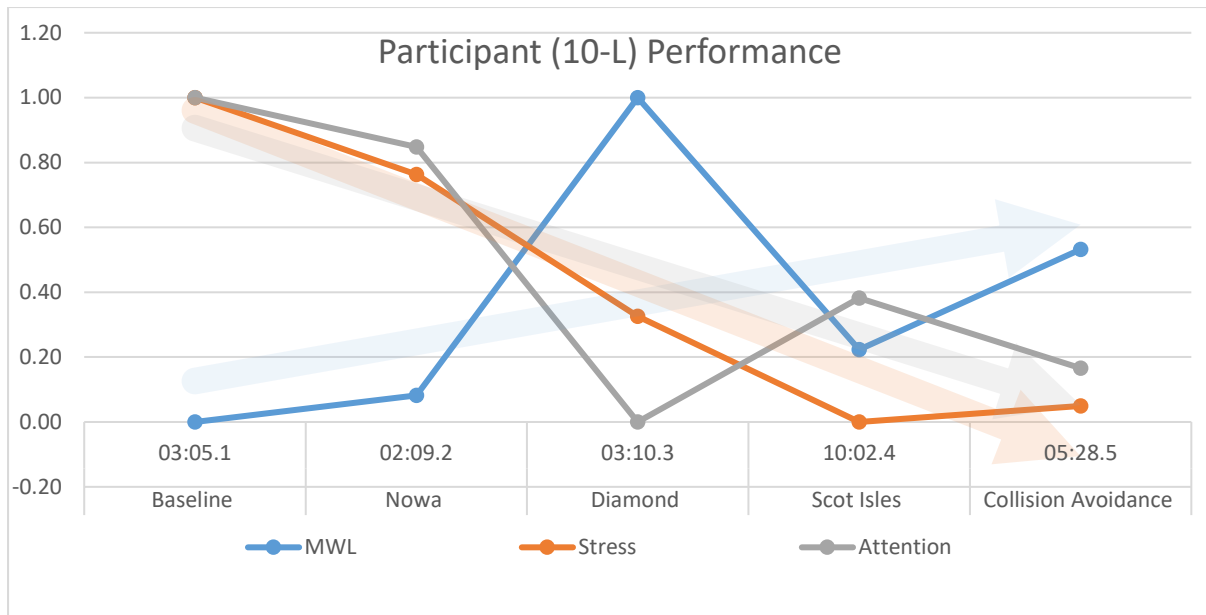


Figure 0.159 (P10-L) EEG result

Furthermore, pupil diameter for both eyes give a comprehensive view of Participant 10's performance through the events. Participant 10 began with low cognitive demand and increased slightly during the MV Nowa then decreased to MV Diamond and maintained to the collision avoidance Figure 0.160. The participant 10 eye pupil size and focusing were changed as shown in each event as follows Table 0.30 and Figure 0.166

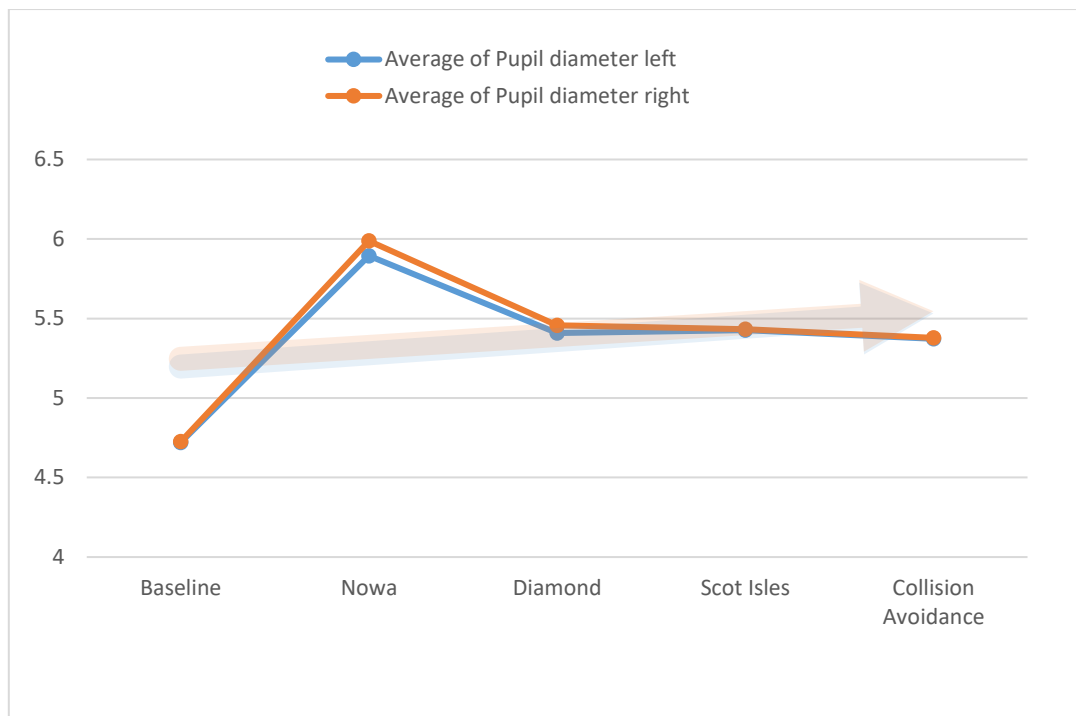


Figure 0.160 (P10-L) Eye-Tracking Result

- **Event 1 Baseline:**

During the baseline event, the participant demonstrated the lowest average pupils with (4.72) and (4.73) for the left and right eyes respectively. The participant was not under pressure as there were no external targets to deal with which should made him calm and low MWL state. The baseline duration is around (13%) of the scenario time, and the participant in the baseline event spent around (20%) of the event time focusing on the radar and (22%) of the event on ECDIS, and around (38%) of the event time visually scanned the surrounding area to check the situation in the surrounding area. Additionally, little attention was put on the display unit with (9%) and (10%) of the time event on the top display unit indicating that Participant 10 used this time to get familiar with the navigation equipment and moved around to improve situational awareness Figure 0.161



Figure 0.161 (P10-L) Heat map for baseline

- **Event 2 MV Nowa:**

As the MV Nowa appeared on the radar and was visually detected, the participant's eye pupil diameters increased to (5.89 mm) and (5.98 mm) for the left and right sides respectively. This was due to the participant showing an increase in cognitive engagement, maybe because of the sudden appearance of the MV Nowa, and Participant 10 was surprised by the situation. In addition, the participant spent around (9%) of the experiment time monitoring the MV Nowa. The participant has shown a strong reliance on the radar with (99%) of the event time, and (1%) of the event time on the VHF for communication. However, Participant 10 did not use the ECDIS and just little attention to on-screen visualisation which indicates that he prefers to use the radar as a navigation system to monitor the target Figure 0.162



Figure 0.162 (P10-L) Heat map for MV Nowa

- **Event 3 MV Diamond:**

During this event, pupil dilation decreased slightly further to (5.41 mm) and (5.46 mm), indicating that Participant 10 was getting less cognitive load when the MV diamond appeared. This event took around (13%) of the experiment time. The participant shows that (90%) of the event time focused on the radar indicating less attention on the radar. However, (2%) of the event time Participant 10 also focused on the ECDIS. In addition, there was. In addition, the Engine got the attention of (7%) of the event time because of the use of the engine when the scenario got complex. (1%) of the event time on VHF responding to the communication. This indicates that Participant 10 used the speed and getting the ship information from the display unit and was distributing his attention around the bridge when the scenario became more critical which improved his situational awareness Figure 0.163



Figure 0.163 (P10-L) Heat map for MV Diamond

- **Event 4 MV Scot Isles:**

with this event, the participant's eye diameter almost sustained at (5.43 mm) for the left eye and (5.43 mm) for the right, indicating that Participant 10 maintained his cognitive load and attention. This event took around (42%) of the experiment time. The participant focused approximately (84%) of the event time on the radar during this event to assess the situation with the Scot of Isle. However, participant 10 also checked the situation visually with (1%) of the event time checking the external environment, and (1%) of the event time monitoring the display unit to support navigational information, and (9%) of the event time still observing the engine for speed, and (2%) of the event time on top display unit. This suggests that the participant distributes his attention in the ship bridge environment between the navigation equipment and the external observation which indicates he is aware of the situation and trying to improve his situation awareness to avoid the collision by using the engine Figure 0.164



Figure 0.164 (P10-L) Heat map for MV Scot Isles

- **Event 5 Collision Avoidance**

The pupil diameter reduced slightly and almost maintained at (5.37 mm) on the left and (5.38 mm) on the right, demonstrating the same cognitive load when taking action to avoid the risk of collision. The collision avoidance action took around (23%) of the experiment time. During this event, the participant distributed his attention more widely across the bridge systems. The participant focused this time less on the radar with (66%) of the event time while (5%) on the ECDIS, and (10%) of the event time on screen for visualization, and (19%) on the top display unit. This means that Participant 10 distributed his attention on the ship bridge environment when he saw the risk of the collision to monitor the target and was confident for making-decision Figure 0.165



Figure 0.165 (P10-L) Heat map for collision avoidance

Table 0.28 (P10-L) Points of focus at different scenario events

Row Labels	Display Unit	ECDIS	Engine	VHF	RADAR	Visualisation	Top Display Unit
Baseline	9%	22%	1%	0%	20%	38%	10%
Nowa	0%	0%	0%	1%	99%	0%	0%
Diamond	0%	2%	7%	1%	90%	0%	0%
Scot Isles	1%	2%	9%	0%	84%	1%	2%
Collision Avoidance	0%	5%	0%	0%	66%	10%	19%

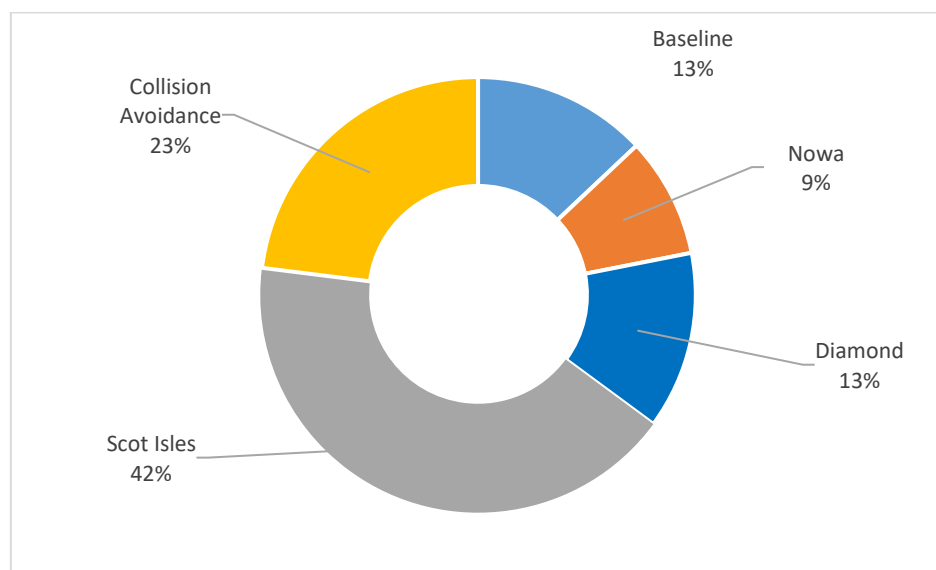


Figure 0.166 (P10-L) Duration time for each event

The Figure 0.167 and Figure 0.168 represent the participant 10 performance through the EEG and Eye-tracking singles which clearly illustrate the cognitive demand through the scenario.

The EEG shows that Participant 10 during the baseline had stable amplitude reflected by low cognitive processing, consistent with the participant's calm state while familiarizing with the environment. However, participant 10 during the MV Nowa showed gradual increases in the amplitude suggesting growing cognitive engagement as the participant monitors targets and responds to the MV Now communication. MV Diamond event, pronounced spikes in the frontal channels indicated high cognitive demand as the scenario becomes more critical with monitoring multiple targets. During the Scot Isles and collision avoidance, a fluctuation appeared in the (F3-Pz) which related to the decision-making suggesting that Participant10 cognitive engagement by keeping instructing the lookout until becomes clear where is a stable amplitude showing at the end of the scenario.

Furthermore, the eye-tracking shows that Participant 10 in the baseline had low cognitive demand and increased with the appearance of the MV Nowa suggestion increasing in the cognitive demand and attention. with MV Diamond and MV Scot Isles, variation of the eye pupil size appeared, and some points showed decreasing and this could be because the participant 10 started to feel fatigued with monitoring multiple targets. However, Participant10's cognitive demand was maintained during collision avoidance which suggests an effective distribution of Participant 10 situation awareness.

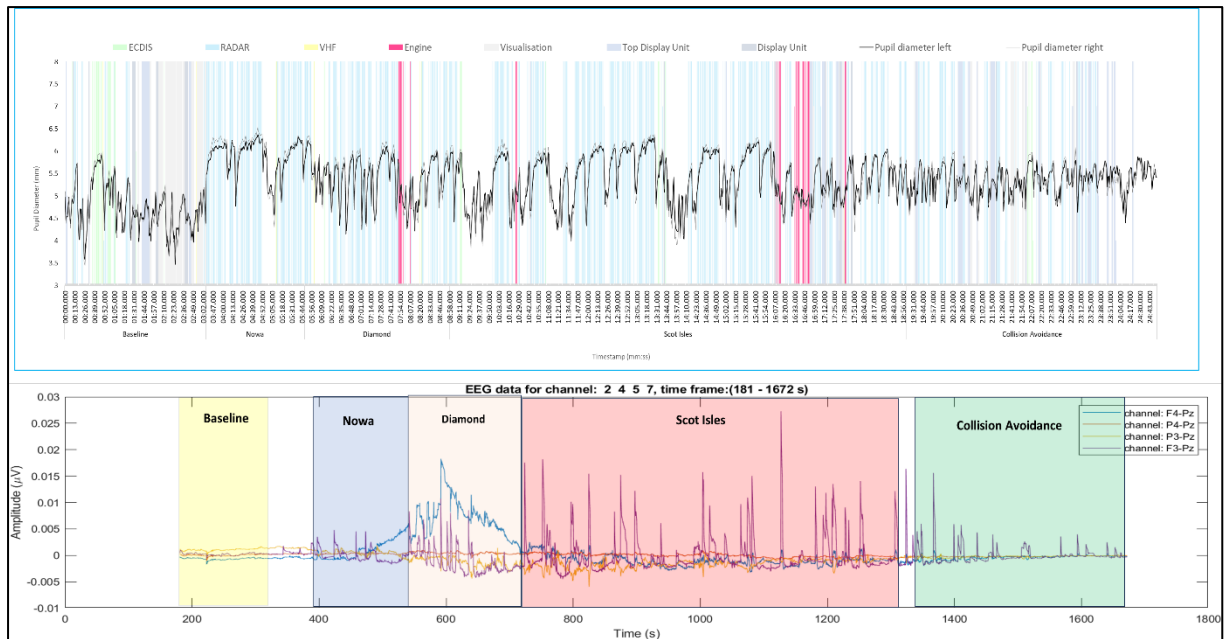


Figure 0.167 (P10-L) EEG and Eye-Tracking

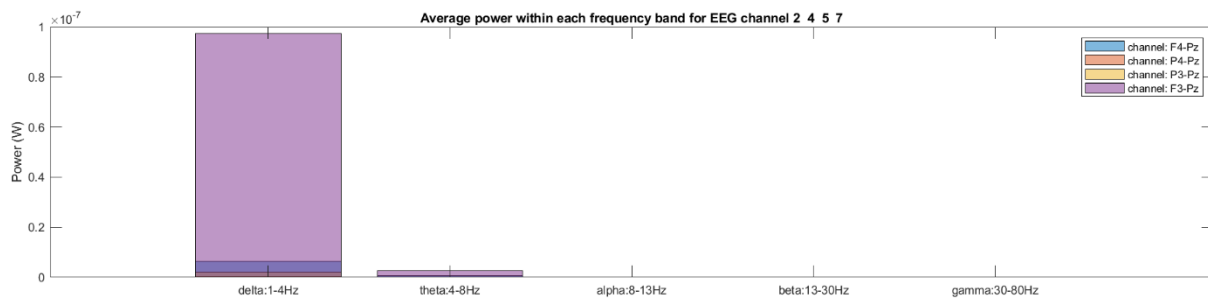


Figure 0.168 (P10-L) Power Band

- **Participant 11 (P11-L)**

During the simulator experiment, participant 11 was navigating out of the ideal course Figure 0.169 shows that Participant 11 passed clear without being involved in a collision. The experiment occurred during the participant's interaction with five events:

Event 1 Baseline: the participant 11 was moving around using the navigation equipment and checking the surrounding area which indicates that Participant 11 wants to get more familiar with the ship bridge environment.

Event 2 MV Nowa: Participant 11 moved to the radar to monitor the targets, and then Participant 10 acquired MV Nowa on the radar to get the information. After that, the lookout informed her about the situation with MV Nowa. While Participant 11 monitored Mv on the radar, she acquired MV Scot Isles to monitor. After that, participant 11 received communication from Mv Nowa and informed her to maintain the course and speed which was confirmed by Participant 11.

Event 3 MV Diamond and Event 4 MV Scot Isles: Participant 11 was not aware of MV Dimond until the lookout informed her. Then participant 11 acquired the target on the radar to get the information. While Participant 11 monitored MV Dimond on the radar, the lookout informed her about the target crossing from the port side which is MV Scot Isles. Participant 11 checked again the information of the MV Scot Isles and then received a call from Mv Diamond requesting her to maintain the course and speed and overtake from the starboard side and both agreed. After terminating the communication with MV Diamond. Participant 11 is back to monitor MV Scot Isles. After observing the information on the radar. Participant 11 communicated with Mv Scot Isles twice but there was no answer found. Therefore, participant 11 communicated with the Dover Coast Guard to explain the situation and her attention that she would alter course to the starboard and reduce speed.

Event 5 Collision Avoidance: participant 11 started to alter the course and reduced the speed by herself, then she communicated with MV Scot Isles a third time but also there was no response. Therefore, participant 11 kept reducing speed to stop the engine and alter the course to starboard. While doing the maneuvering, participant 11 was monitoring the situation visually and on the radar until MV Scot Isles passed clear.

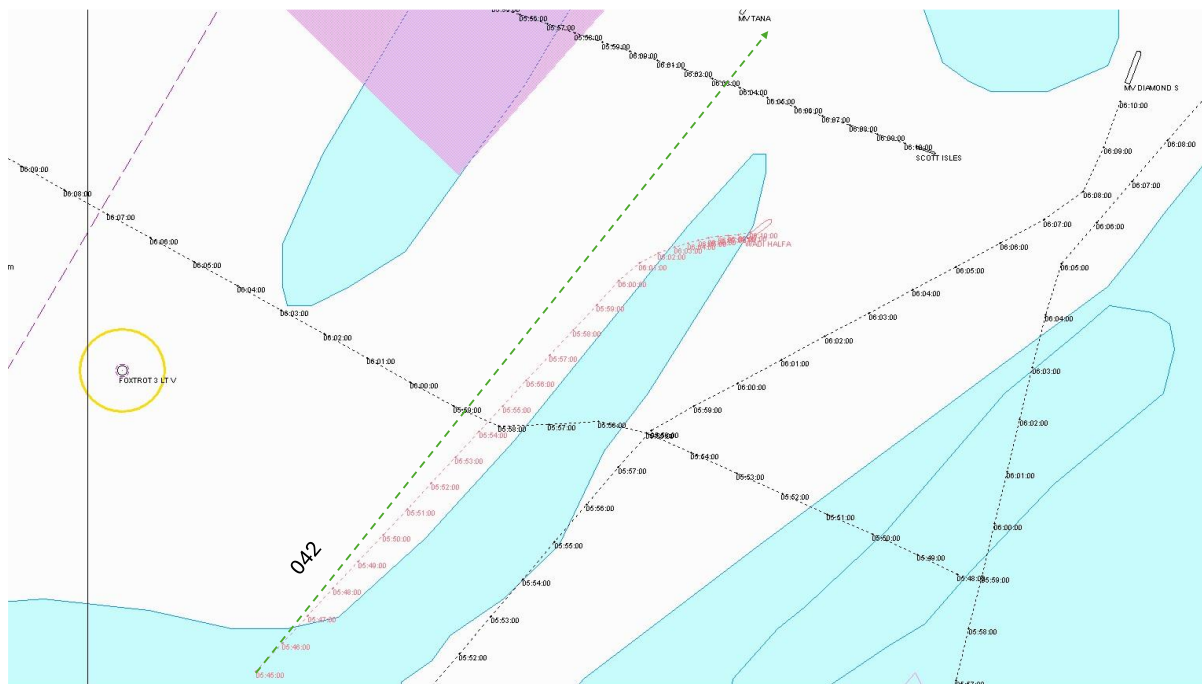


Figure 0.169 (P11-L) Navigation chart

Additionally, the heat map provides the participant's visual attention distribution during the ship bridge training simulation. Figure 0.170 offers a clear visual focus throughout the events. The red zones indicate the area with high focus. The heat map demonstrates that the participant focused on the radar heavily and paid little attention to other equipment.



Figure 0.170 (P11-L) Heat Map

Table 0.29 (P11-L) EEG result

Time		Event	Duration	MWL	Stress	Attention
00:00.0	03:04.7	Baseline	03:04.7	1.00	0.39	0.00
04:01.5	06:16.6	Nowa	02:15.0	0.46	1.00	1.00
06:40.6	09:49.3	Diamond+Scot Isles	03:08.7	0.57	0.48	0.79
14:04.0	25:49.2	Collision Avoidance	11:45.2	0.00	0.00	0.79

Based on the EEG result and participant 11's performance metrics illustrated in Table 0.29 and Figure 0.171 we can observe how the cognitive demand (MWL, Stress, and attention) differentiation across the different events in the simulator training as follows:

- **Event 1 Baseline:**

During the baseline, Participant 11 showed a high mental workload and moderate stress level while no attention was shown. This could be reflected in the unfamiliarity with the ship environment and Participant 11 attempts to adapt to the new environment which likely reduced his attention.

- **Event 2 MV Nowa:**

When the targets began to appear, Participant 11 detected the MV Now which increased Participant 11's attention to high and reduced the MWL to moderate and high stress. This suggests that Participant 11 engaged cognitively. Participant 11 experienced high stress might be due to the appearance of multiple targets and the need to process communication which increased his attention to managing the situation.

- **Event 3 and Event 4 MV Diamond and MV Scot Isles:**

Participant 11 was monitoring both targets at the same time after the lookout informed Participant 11 about the location of both ships. This indicated that Participant 11 had moderated MWL and stress and tried to manage multiple targets and respond to the communication. Moreover, Participant 11 maintained high attention while managing the situation

- **Event 5 Collision Avoidance:**

During the Scot Isles event, Participant 11 experienced very low MWL and stress while maintaining attention at a high level. Participant 11 managed his cognitive demand and kept his attention at a high level as he communicated with the Dover Coast Guard, taking immediate action like altering course and reducing speed which improved his situational awareness and effectively avoided a collision.

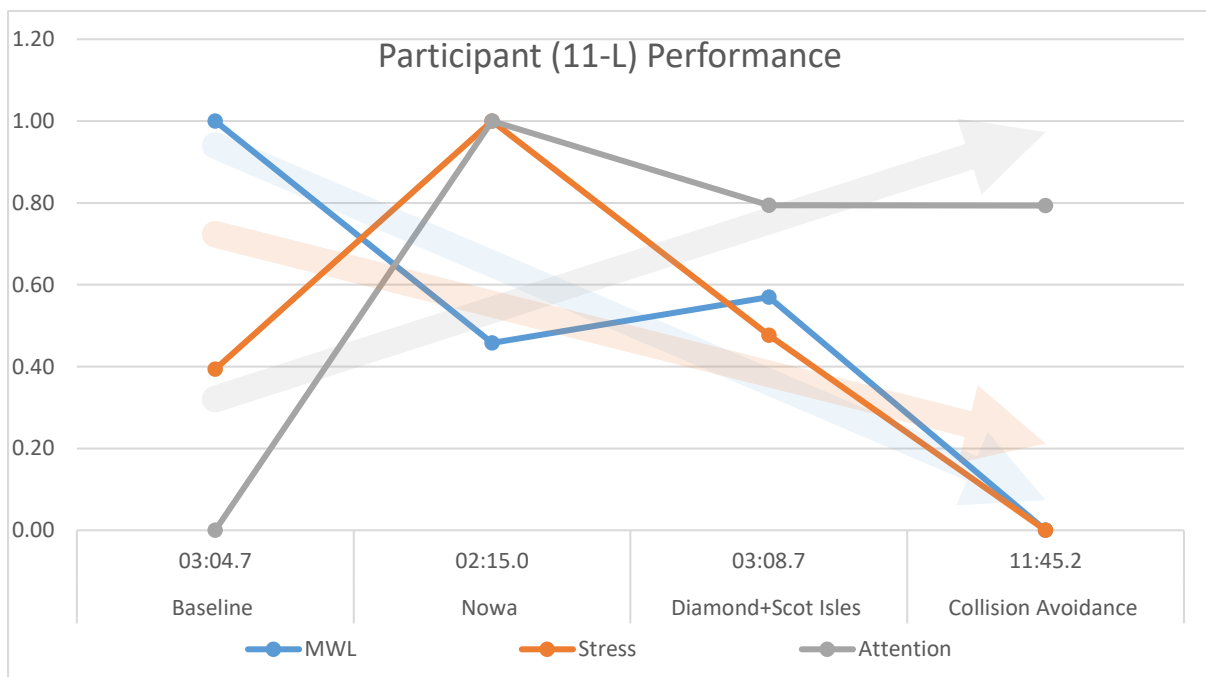


Figure 0.171 (P11-L) EEG result

Furthermore, pupil diameter for both eyes give a comprehensive view of Participant 11's performance through the events. Participant 11 began with low cognitive demand and started to increase slightly then during collision avoidance began to reduce as the ship became clear of the collision Figure 0.172. Participant 11's pupil size and focusing were changed as shown in each event as follows Table 0.30 and Figure 0.177

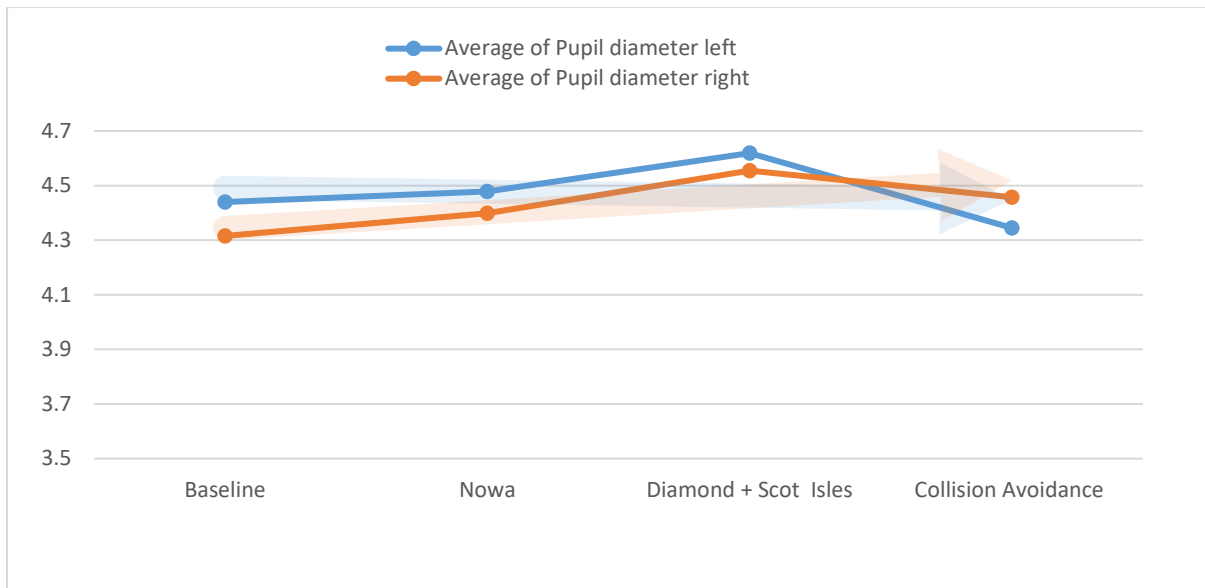


Figure 0.172 Eye-Tracking result

- **Event 1 Baseline:**

During the baseline event, the participant demonstrated the lowest average pupils with (4.44) and (4.32) for the left and right eyes respectively. The participant was not under pressure as there were no external targets to deal with which should made him calm and low MWL state. . The baseline duration is around (15%) of the scenario time, and the participant in the baseline event spent around (69%) of the event time focusing on the radar and (4%) of the event on ECDIS, and around (8%) of the event time visually scanned the surrounding area to check the situation in the surrounding area. Additionally, a small attention was put on the display unit with (18%) of the event indicating initial information check before the targets appeared and indicates that Participant 11 used this time to get familiar with the navigation equipment, particularly the radar Figure 0.173



Figure 0.173 (P11-L) Heat map for baseline

- **Event 2 MV Nowa:**

As the MV Nowa appeared on the radar and was visually detected, the participant's eye pupil diameters increased slightly to (4.48 mm) and (4.40 mm) for the left and right sides respectively. This was due to the participant showing an increase in cognitive engagement, maybe because of the sudden appearance of the MV Nowa, and Participant 11 was surprised by the situation. In addition, the participant spent around (11%) of the experiment time monitoring the MV Nowa. The participant has shown a strong reliance on radar, with (97%) of the event time, and (2%) of the event time observed visually on the screen. However, Participant 11 did not use the ECDIS which indicates that he prefers to use the radar as a navigation system to monitor the target Figure 0.174



Figure 0.174 (P11-L) Heat map for MV Nowa

- **Event 3 MV Diamond and Event 4 MV Scot Isles:**

During this event, pupil dilation increased further to (4.62 mm) and (4.55 mm), indicating that Participant 11 was getting more cognitive load as Participant 11 monitored both ships. This event took around (16%) of the experiment time. The participant shows that (98%) of event time focused on the radar indicating overlying attention on the radar. However, (2%) of the event time Participant 10 also focused on screens for visualization, and this could be during the communication and observing the targets Figure 0.175.



Figure 0.175 (P11-L) Heat map for MV Diamond and MV Scot Isles

- **Event 5 Collision Avoidance**

The pupil diameter reduced to (4.35 mm) on the left and (4.45 mm) on the right, demonstrating less cognitive load after taking action to avoid the risk of collision which indicates an effective situational awareness of the participant. The collision avoidance action took around (58%) of the experiment time which is more than half of the experiment. This suggests that Participant 11 took early action to avoid the collision. During this event, the participant distributed his attention more widely across the bridge systems. The participant focused this time less on the radar with (63%) of the event time while no attention was detected on the ECDIS, and (5%) of the event time on the screen for visualization, and (30%) on the display unit. This means that Participant 11 distributed his attention on the ship bridge environment. However, Participant 11 relied more on the radar for monitoring and was using his observation to improve situational awareness in addition to the lookout support Figure 0.176.



Figure 0.176 (P11-L) Heat map for collision avoidance

Table 0.30 (P11-L) Points of focus at different scenario events

Row Labels	Display Unit	ECDIS	Engine	VHF	RADAR	Visualisation	Top Display Unit
Baseline	18%	4%	1%	1%	69%	8%	0%
Nowa	1%	0%	0%	0%	97%	2%	0%
Diamond + Scot Isles	0%	0%	0%	0%	98%	2%	0%
Collision Avoidance	30%	0%	1%	0%	63%	5%	0%

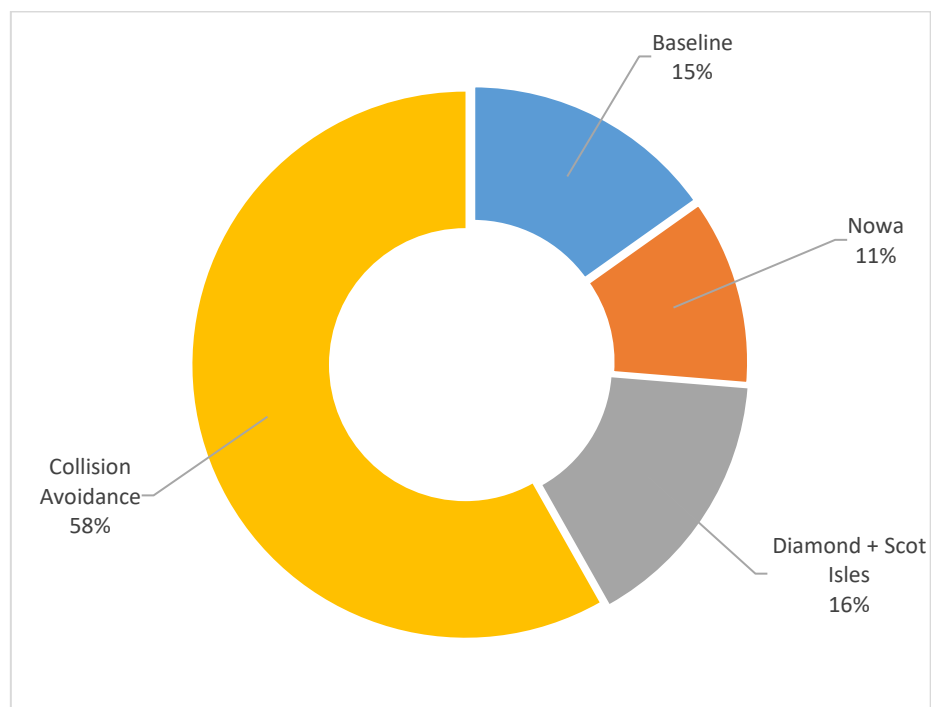


Figure 0.177 (P11-L) Duration time for each event

The Figure 0.178 and Figure 0.179 represent the participant 11 performance through the EEG and Eye-tracking singles which clearly illustrate the cognitive demand through the scenario.

In the baseline, EEG amplitude remained stable reflecting minimal cognitive activity as no targets appeared and no risk of collision, the participant used this event to get familiar with the ship environment. During MV Nowa, Participant 11 showed a significant spike, and this aligns with growing cognitive demand as Participant 11 made a decision and responding the communication with MV Nowa. In the MV Diamond and MV Scot Isles events, Participant 11 amplitude increased as the cognitive workload increased while handling multiple targets and communicating with external targets. The variation between MV Diamond and MV Scot Isles events, and the Collision avoidance events is when Participant 11 communicates with the Dover Coast Guard explaining the situation and his attention. Therefore, during the collision avoidance event, after a high cognitive load while taking action, sustained and stable fluctuation indicates Participant 11 active decision-making improved his cognitive and awareness.

Furthermore, the eye-tracking shows that Participant 11 in the baseline tried to maintain his cognitive load demand and maintained his mentality with the task until targets began to appear which indicates a cognitive demand rose. In the middle of the MV Diamond and Scot Isles event, a low eye pupil size appeared, and this could be because the participant 11 started to feel fatigued. However, participant11's cognitive demand increased again in the collision avoidance and also decreased at some point with the complexity of the task which also indicated fatigue, however, Participant 11 illustrated sustained cognitive demand in the end utile passes clearly.

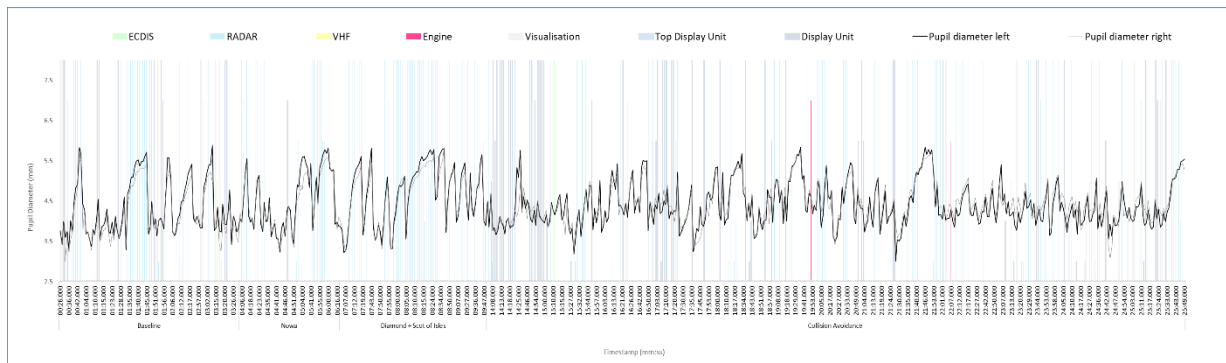


Figure 0.178 (P11-L) EEG and Eye-Tracking

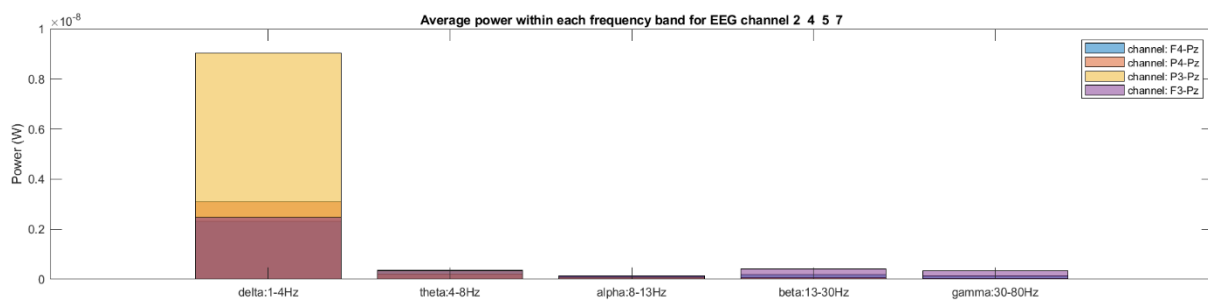


Figure 0.179 (P11-L) Power band

- **Participant 14 (P14-L)**

During the simulator experiment, participant 14 was navigating on starboard of the ideal course. Figure 0.180 shows that Participant 14 passed clear without being involved in a collision. The experiment occurred during the participant's interaction with five events:

Event 1 Baseline: Participant 14 was moving around using the navigation equipment and checking the surrounding area which indicates that Participant 14 wants to get more familiar with the ship bridge environment.

Event 2 MV Nowa: when the targets appeared, participant 14 moved to the radar observing the targets. participant 14 acquired the targets on ahead and then acquired MV Nowa. After that, the lookout informed him about the situation with MV Nowa. Then, participant 14 kept monitoring MV Nowa visually, on the ECDIS, and radar until received a contact from MV Nowa required him to maintain the course and speed. Participant 14 in the first mentioned that he could not hear the voice, then the lookout told him that the call is for us and then participant 14 replay and confirmed the manoeuvring. Which indicate that the participant 14 felt stress in the beginning.

Event 3 MV Diamond: after communication done with MV Dimond, the lookout informed participant 14 about the target on starboard quarter which is MV Diamond. The participant mentioned that first want to check the speed of the first target, and he acquired MV diamond on the radar. In the meant time, the look out informed participant 14 about the target on the port side which is MV Scot Isles. Participant 14 confirmed that he saw it and back to monitor the MV Dimond until received call from MV Dimond instructed him to maintain the course and speed.

Event 4 MV Scot Isles: after finishing communication with MV diamond. Participant 14 informed the lookout to observe the targets ahead and if there is any change the lookout should inform participant 14. After that, participant 14 moved to the radar and acquired MV Scot Isles. Participant 14 keep monitoring and getting the information of Mv Scot Isles. Then, he starts to communicate at (10m:49s) with MV Scot Isles but there was no response. Then participant 14 kept monitor Mv Scot Isles visually and on the radar and made another communication at (15m:04s) and also there was no response. After that, participant 14 explained to the lookout his attention that he will reduce speed and alter course to the port. Subsequent, participant 14 ordered the lookout to take the steering and change it to manual.

Event 5 Collision Avoidance: participant 14 reduced the speed and give the instruction to the lookout to alter the course to port side and steady (038). When the target become closer,

participant 14 ordered the lookout hard to port. Then, the target passed clear and the participant 14 order the lookout to alter to starboard to back to main course.

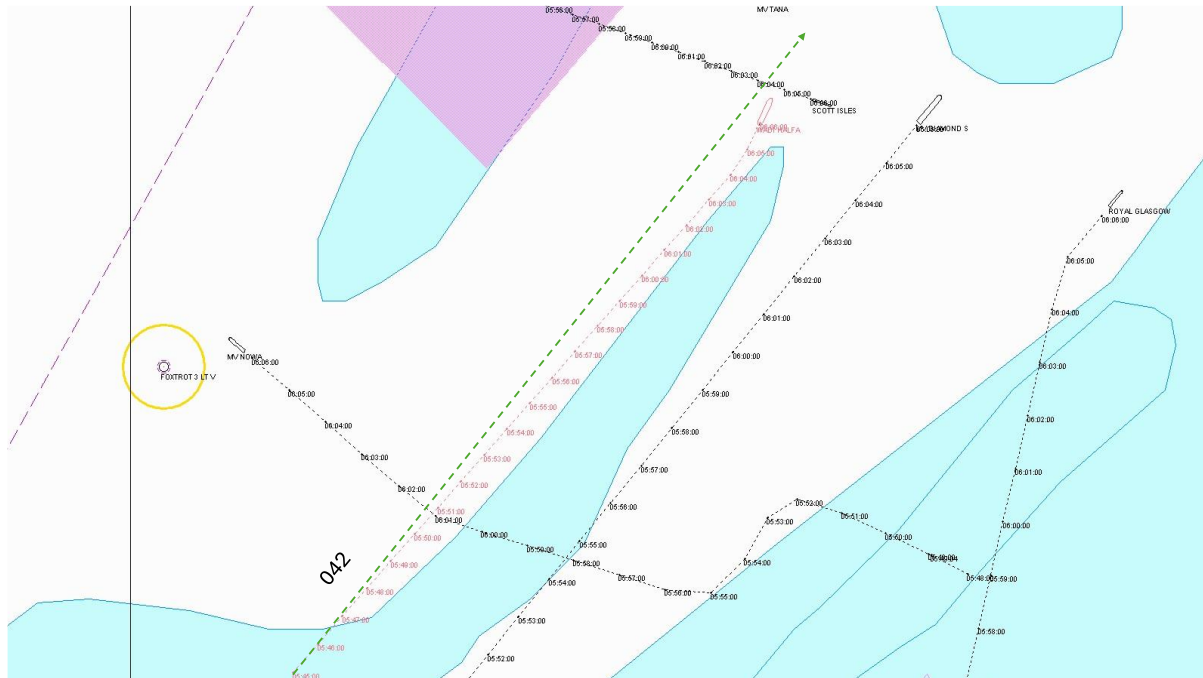


Figure 0.180 (P14-L) Navigation chart

Additionally, the heat map provides the participant's visual attention distribution during the ship bridge training simulation. Figure 0.181 offers a clear visual focus throughout the events. The red zones indicate the area with high focus. The heat map demonstrates that the participant was not focusing on the navigation equipment most of the time. the participant relied on his visualisation. Even though the participant has an assistant as a lookout, the participant did not concentrate on the navigation equipment. In addition, the red area indicates the participant was focusing on Scot Isles while approaching but unfortunately got into collision because of the late action.



Figure 0.181 (P14-L) Heat map

Table 0.31 (P14-L) EEG result

Time		Event	Duration	MWL	Stress	Attention
00:00.0	03:03.2	Baseline	03:03.2	0.00	0.46	1.00
03:36.4	06:18.5	Nowa	02:42.2	0.56	0.35	0.58
07:01.5	08:56.5	Diamond	01:55.0	0.43	0.83	0.50
08:56.5	15:09.0	Scot Isles	06:12.6	1.00	0.00	0.64
18:16.2	21:22.4	Collision Avoidance	03:06.2	0.14	1.00	0.00

Based on the EEG result and Participant 14's performance metrics illustrated in Table 0.31 and Figure 0.182 we can observe how the cognitive demand (MWL, Stress, and attention) differentiation across the different events in the simulator training as follows:

- **Event 1 Baseline:**

During the baseline, participant 14 showed a very low mental workload and moderate stress level while high attention was shown. This suggests that the participant was calm because there were not any targets, and no immediate risk existed.

- **Event 2 MV Nowa:**

When the targets began to appear, participant 14 detected the MV Now which increased Participant 14's MWL and stress to moderate and reduced the attention level to moderate also. This suggests that when the targets began to appear, Participant 14 tried to maintain his

creativity and make a balance utilizing the target visually and on the navigation equipment especially after the lookout informed him about the location of the target.

- **Event 3 MV Diamond:**

The next event, MV Diamond, shows high stress with moderate MWL and attention. In this event, the lookout informed Participant 11 about the location of the target. However, Participant 14 checked the speed first and then acquired the target on the radar. After that, the lookout informed the participant about the other ship's location which is MV Scot Isles, then Participant received a call from MV Diamond. This indicated that Participant 11's stress increased due to multiple target monitoring and responding communication.

- **Event 4 MV Scot Isles:**

Participant 14 was informed by the lookout about Scot Isles. It shows that Participant 14 experienced high MWL and attention with reduced stress to a minimum. This could be due to the communication challenge with the MV Scot Isles and Participant 14 need to monitor the target and make a decision.

- **Event 5 Collision Avoidance:**

Participant 14 reduced speed, altered course, and gave instructions to the lookout. This effective action indicates that Participant 11 got more stress which reduced his MWL and attention which suggests that Participant 14 was overreliance on automation or the lookout.

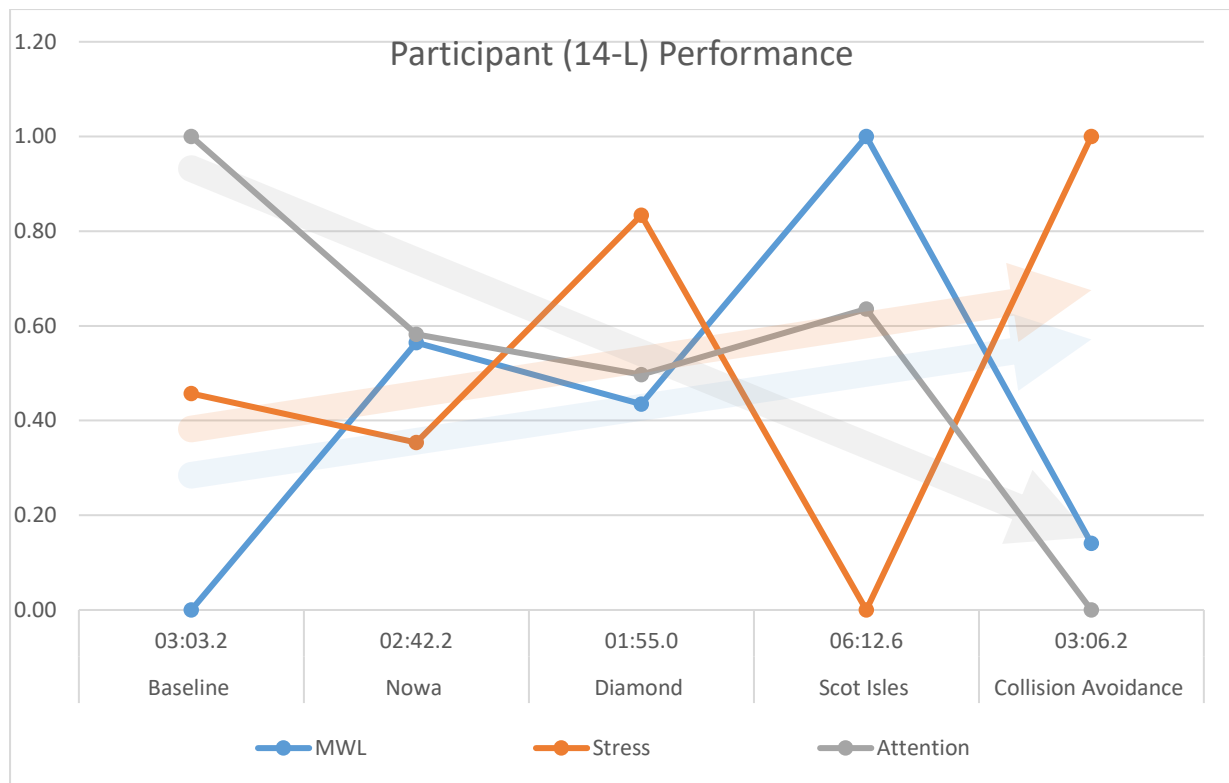


Figure 0.182 (P14-L) EEG result

Furthermore, pupil diameter for both eyes give a comprehensive view of Participant 14's performance through the events. Participant 14 began with low cognitive demand and started to increase slightly then during the MV Nowa began to decrease until the collision avoidance . Figure 0.183. The participant 14 eye pupil size and focusing were changed as shown in each event as follows Table 0.32 and Figure 0.189

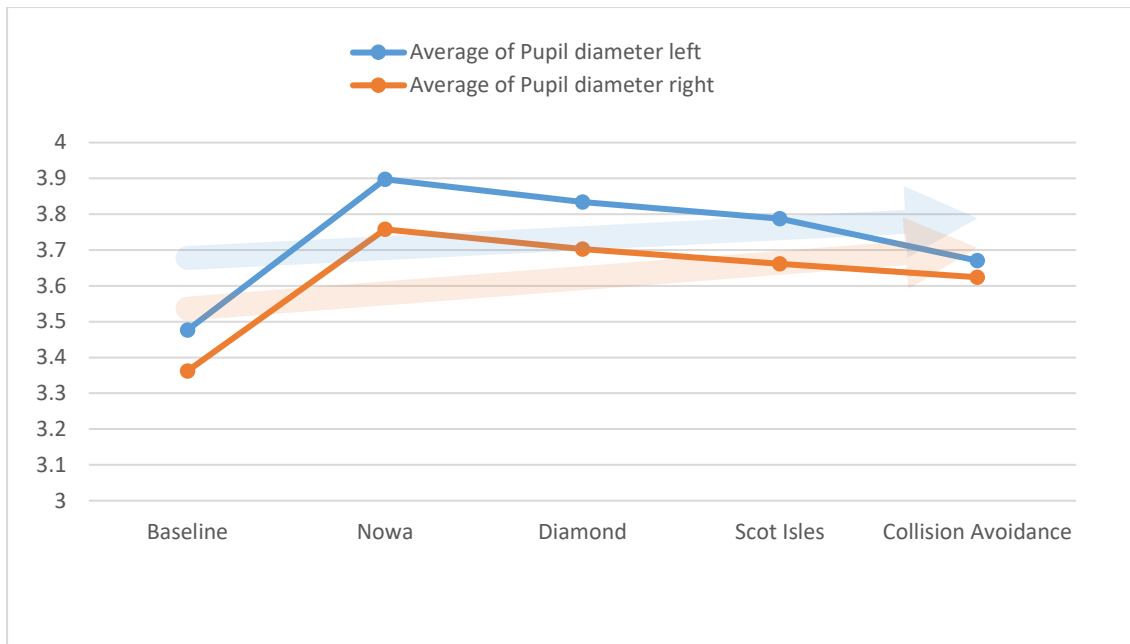


Figure 0.183 (P14-L) Eye-Tracking result

- **Event 1 Baseline:**

During the baseline event, the participant demonstrated the lowest average pupils with (3.48) and (3.36) for the left and right eyes respectively. The participant was not under pressure as there were no external targets to deal with which should made him calm and low MWL state. The baseline duration is around (18%) of the scenario time, and the participant in the baseline event spent around (30%) of the event time focusing on the radar and (28%) of the event on ECDIS, and around (10%) of the event time visually scanned the surrounding area to check the situation in the surrounding area. Additionally, a small attention was put on the display unit with (7%) and (21%) of the event time on the top display unit indicating initial information check before the targets appeared and indicates that Participant 14 used this time to get familiar with the navigation equipment Figure 0.184



Figure 0.184 (P14-L) Heat map for baseline

- **Event 2 MV Nowa:**

As the MV Nowa appeared on the radar and was visually detected, the participant's eye pupil diameters increased to (3.90mm) and (3.76 mm) for the left and right sides respectively. This was due to the participant showing an increase in cognitive engagement, maybe because of the sudden appearance of the MV Nowa, and Participant 14 was surprised by the situation. In addition, the participant spent around (16%) of the experiment time monitoring the MV Nowa. The participant has shown a strong reliance on radar, with (62%) of the event time, and (7%) of the event time observed visually on the screen. However, Participant 14 used the ECDIS around (14%) of the event time. in addition, Participant 14 used the VHF around (14%) as in the first call the participant mentioned that he did not hear the voice appropriately. Participant 14 showed that he distributed his situation awareness around the ship bridge Figure 0.185



Figure 0.185 (P14-L) Heat map for MV Nowa

- **Event 3 MV Diamond:**

During this event, pupil dilation decreased slightly to (3.83 mm) and (3.70 mm), indicating that Participant 14 began to reduce cognitive load when observing MV Diamond. This event took around (11%) of the experiment time. The participant shows that (78%) of event time focused on the radar indicating more attention on the radar. However, (10%) of the event time Participant 10 also focused on screens for visualization, and this was caused when the MV Diamond communicated with Participant 14. Participant 10 tried to observe visually to ensure the location of the MV Diamond for situation awareness. In addition, there was attention on the ECDIS around (7%). The VHF (23%) of the event time, indicated that Participant 14 preferred to use the radar more than the ECDIS and improved his situational awareness and decision-making by ensuring the appearance of the targets visually Figure 0.186.



Figure 0.186 (P14-L) Heat map for MV Diamond

- **Event 4 MV Scot Isles:**

With this event, the participant's eye diameter slightly decreased to (3.79 mm) for the left eye and (3.66 mm) for the right, indicating that Participant 14 cognitive reduced after taking some action during MV Diamond. This event took around (37%) of the experiment time. The participant focused approximately (78%) of the event time on the radar during this event to assess the situation with the Scot of Isle. However, participant 14 also checked the situation visually with (11%) of the event time checking the external environment, and (2%) of the event time monitoring the display unit to support navigational information and (9%) of the event time still observing the ECDIS. This suggests that the participant distributes his attention in the ship bridge environment between the navigation equipment and the external observation which indicates he is aware of the situation which trying to improve his situation awareness Figure 0.187



Figure 0.187 (P14-L) Heat map for MV Scot Isles

- **Event 5 Collision Avoidance**

The pupil diameter slightly decreased to (3.67 mm) on the left and (3.62 mm) on the right, demonstrating that Participant 14 maintained his cognitive load when taking action to avoid the risk of collision. The collision avoidance action took around (18%) of the experiment time. During this event, the participant distributed his attention more widely across the bridge systems. The participant focused this time less on the radar with (32%) of the event time while (27%) on the ECDIS, and (10%) of the event time on screen for visualization, and (10%) on the display unit with (20%) on the top display unit. This means that Participant 14 distributed his attention on the ship bridge environment when he saw the risk of the collision to monitor the target and tried to take imminent action while he keep the lookout for steering Figure 0.188



Figure 0.188 (P14-L) Heat map for collision avoidance

Table 0.32 (P14-L) Points of focus at different scenario events

Row Labels	Display Unit	ECDIS	Engine	VHF	RADAR	Visualisation	Top Display Unit
Baseline	7%	28%	2%	3%	30%	10%	21%
Nowa	1%	14%	0%	13%	62%	7%	1%
Diamond	0%	7%	0%	5%	78%	10%	0%
Scot Isles	2%	9%	0%	1%	78%	11%	0%
Collision Avoidance	10%	27%	1%	0%	32%	10%	20%

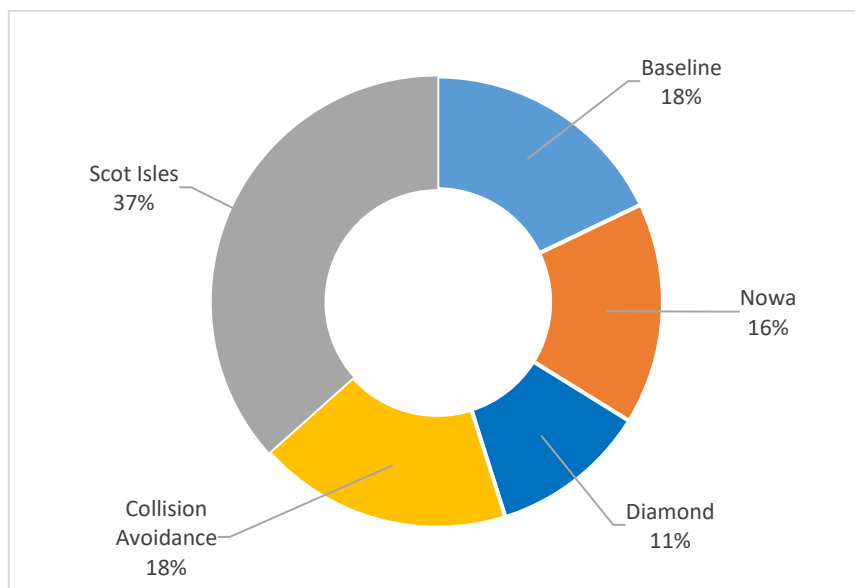


Figure 0.189 (P14-L) Duration time for each event

The Figure 0.190 and Figure 0.191 represent the participant 15 performance through the EEG and Eye-tracking singles which clearly illustrate the cognitive demand through the scenario.

The EEG shows that Participant 14 during the baseline was stable with low cognitive demand. However, when the targets began to appear, a signal variation appeared as the participant monitored targets and communicated MV Nowa. However, all channels were active during MV Diamond because Participant 14 was speaking with the lookout and showed a bit of stress when the lookout inform him about the location of the MV Diamond and MV Scot Isles in addition to responding to communication with MV Diamond. During the Scot Isles, significant fluctuations in amplitude particularly (P3-Pz) due to the failure communication, and Participant 14 was speaking with the lookout about his attention. Moreover, (P3-Pz) was active during the collision avoidance due to reducing speed and instruction given by the participant to the lookout.

Furthermore, the eye-tracking shows that Participant 14 in the baseline had low cognitive demand and maintained his mentality with the task until he became aware of MV Nowa indicating a cognitive demand rose as Participant 14 engaged with the scenario. In the MV Diamond event, a low eye pupil size appeared, and this could be because Participant 14 started to feel fatigued when the scenario became critical. However, Participant 14 maintained his cognitive capacity during MV Scot Isles and collision avoidance, and he took effective action to improve his situational awareness.

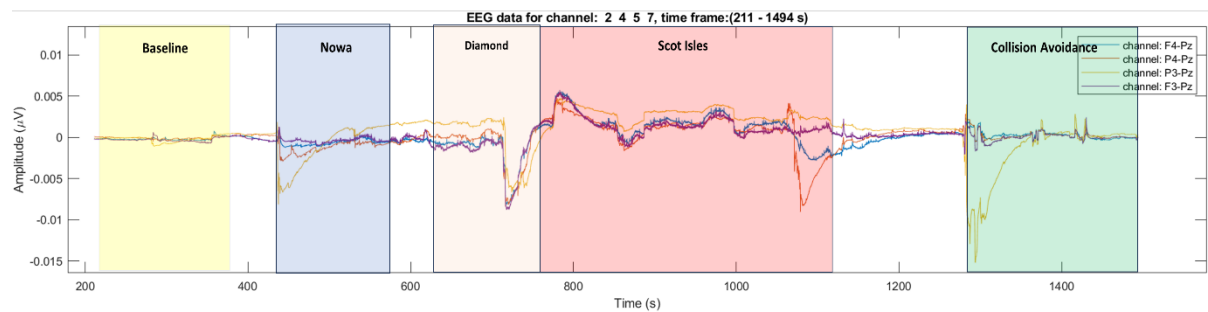
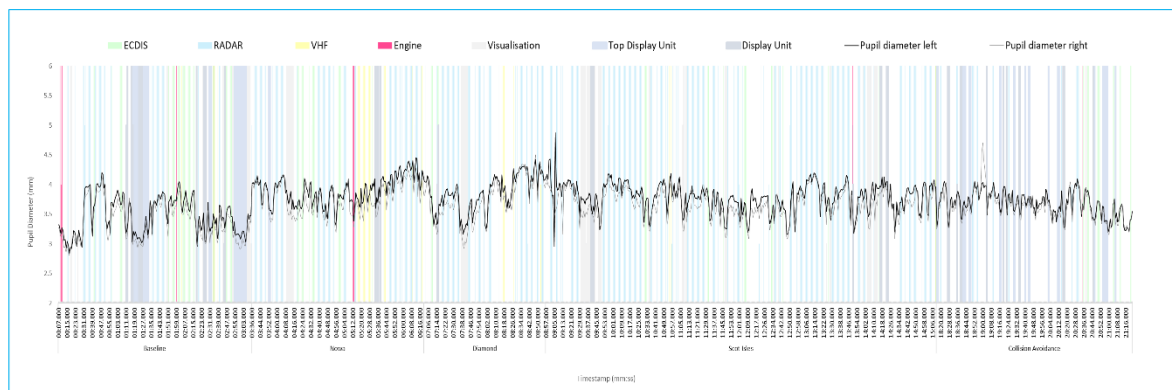


Figure 0.190 (P14-L) EEG and Eye-Tracking

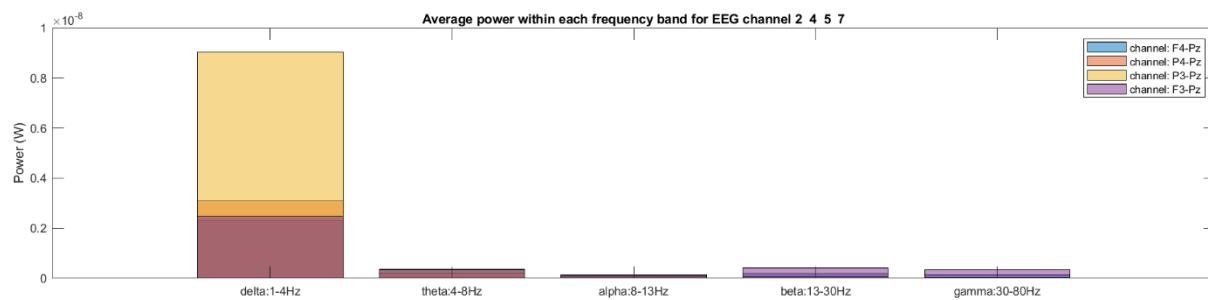


Figure 0.191 (P14-L) Power band

- **Participant 17 (P17-L)**

During the simulator experiment, participant 17 was navigating on the ideal course Figure 0.192. it shows that Participant 17 passed clear without being involved in a collision. The experiment occurred during the participant's interaction with five events:

Event 1 Baseline: Participant 17 was moving around observing the navigation equipment and checking the surrounding area which indicates that Participant 17 wants to get more familiar with the ship bridge environment.

Event 2 MV Nowa: when the targets appeared, participant 17 moved to the radar observing the targets. participant 14 acquired MV Nowa the targets on ahead and then acquired the targets ahead of him. Then, participant 17 moved to port side of the bridge to ensure of the MV Nowa location visually. After that, the lookout informed him about the situation with MV Nowa. Therefore, participant 17 instructed the lookout to take the steering and change it to manual and give her order to steer to (088).while participant 17 monitor MV Nowa on the radar, he acquired MV Dimond and observe the information of her. Later, participant 17 received call from MV Nowa requesting him to maintain the course and speed. During the communication, participant 17 informed the lookout to steady and keep the course on (035), then he confirms with MV Nowa about the manoeuvring.

Event 3 MV Diamond: after communication has done with MV Nowa. Participant still gives orders to the lookout to steer on the course. After that. Participant 17 was checking the surrounding area to confirm the location of the targets similar to what he observed on the radar. The participant 17 spoke loudly about the situation with each target. In the meantime, the lookout informed him about the ship crossing from the port which is Mv Scot Isles. The participant's response was the ship should give us away and we keep observing her. This indicate that the participant had effective situational awareness. Later, participant 17 received a call from MV Dimond instructed him to maintain the course and the speed. Participant 17 agreed and informed MV Dimond that there is a ship crossing from port side just keep clear.

Event 4 MV Scot Isles: after communication with MV Diamond terminated, participant 17 was speaking loudly with the look about each situation. He explained how each situation would be cleared to the lookout. This indicate that the participant keeps his situation awareness effective. After that. Participant 17 keeps monitoring Mv Scot Isles on the radar and visually. While observing, the participant called the master to inform him about the ship not under command a head to keep him updated. Later, participant 17 was monitored MV Scot Isles and requested the lookout to alter the course to (025) which is to the port side.

Event 5 Collision Avoidance: participant 17 kept altering to the port side until MV Scot Isles passed ahead. Participant 17 in this experiment had an effective situation awareness, the participant verified himself by observing the target on the radar and confirming it visually. Then he explained the situation and what he should do to keep clear speaking loudly to himself.

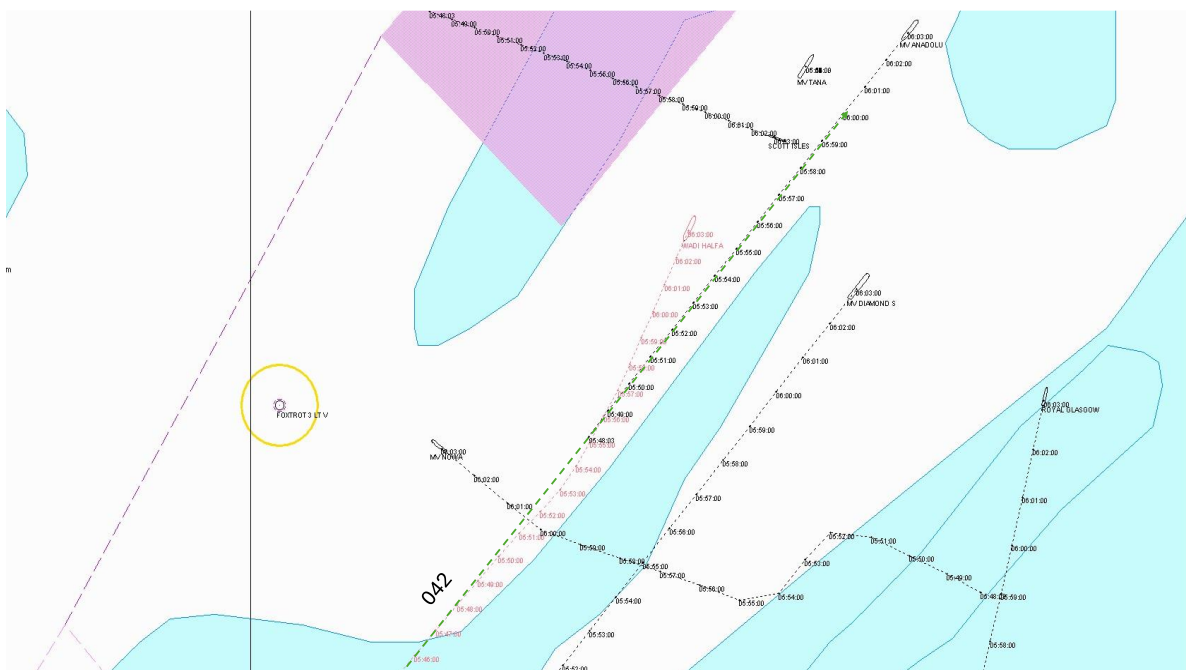


Figure 0.192 (P17-L) Navigation chart

Additionally, the heat map provides the participant's visual attention distribution during the ship bridge training simulation Figure 0.193. It offers a clear visual focus throughout the events. The red zones indicate the area with high focus. The heat map demonstrates that the participant was focusing on the

radar and screen visualisation most of the time, which suggests that Participant 17 effectively improved his situational awareness.



Figure 0.193 (P17-L) Heat Map

Table 0.33 (P17-L) EEG result

Time		Event	Duration	MWL	Stress	Attention
00:00.0	03:01.2	Baseline	03:01.2	0.00	0.07	0.29
03:24.4	05:49.8	Nowa	02:25.3	1.00	0.22	0.00
05:49.8	07:16.4	Diamond	01:26.6	0.14	1.00	1.00
08:58.5	11:22.4	Scot Isles	02:23.9	0.73	0.25	0.22
11:22.4	17:42.6	Collision Avoidance	06:20.2	0.03	0.00	0.31

Based on the EEG result and Participant 17's performance metrics illustrated in Table 0.33 and Figure 0.194 we can observe how the cognitive demand (MWL, Stress, and attention) differentiation across the different events in the simulator training as follows:

- **Event 1 Baseline:**

During the baseline, participant 17 showed low mental workload and stress levels while no low attention was shown also. This suggests that the participant was calm because there were not any targets, and no immediate risk existed. However, participant 17 had low attention might be because of inefficient observation.

- **Event 2 MV Nowa:**

When the targets began to appear, Participant 17 detected the MV Now which increased Participant 17's MWL to high as he managed multiple tasks, including monitoring and communication. Despite the cognitive workload, stress remained manageable, and attention was minimal indicating Participant 17 relied on the radar and lookout instructions.

- **Event 3 MV Diamond:**

The next event, MV Diamond, shows significantly high stress with high attention and low MWL. In this event, Participant 17 was informed about the MV Diamond by the lookout. After that, Participant 17 observed the target visually speaking loudly about his action and instructing the lookout which suggests the increasing of stress and the increasing of the attention indicated ensuring the situational awareness. In the meantime, the lookout informed Participant 17 about the MV Scot Isles. During monitoring MV Diamond and MV Scot Isles, Participant 17 tried to manage his stress and reduce it to moderate but he kept his attention high ensuring the situational awareness with manageable MWL.

- **Event 4 MV Scot Isles:**

Participant 17 was informed by the lookout about Scot Isles. It shows that Participant 17 experienced high MWL and low attention with low stress. Participant 17 was speaking loudly and communicating with the captain to inform him about the situation but there was no response which suggests the increasing of MWL, and attention reduced possibly due to cognitive fatigue or overreliance on lookout support.

- **Event 5 Collision Avoidance:**

In the collision avoidance event, low MWL and stress experienced by Participant 17 and increasing attention to moderate suggested that Participant 17 managed the situational awareness after taking efficient action to keep clear from the target.

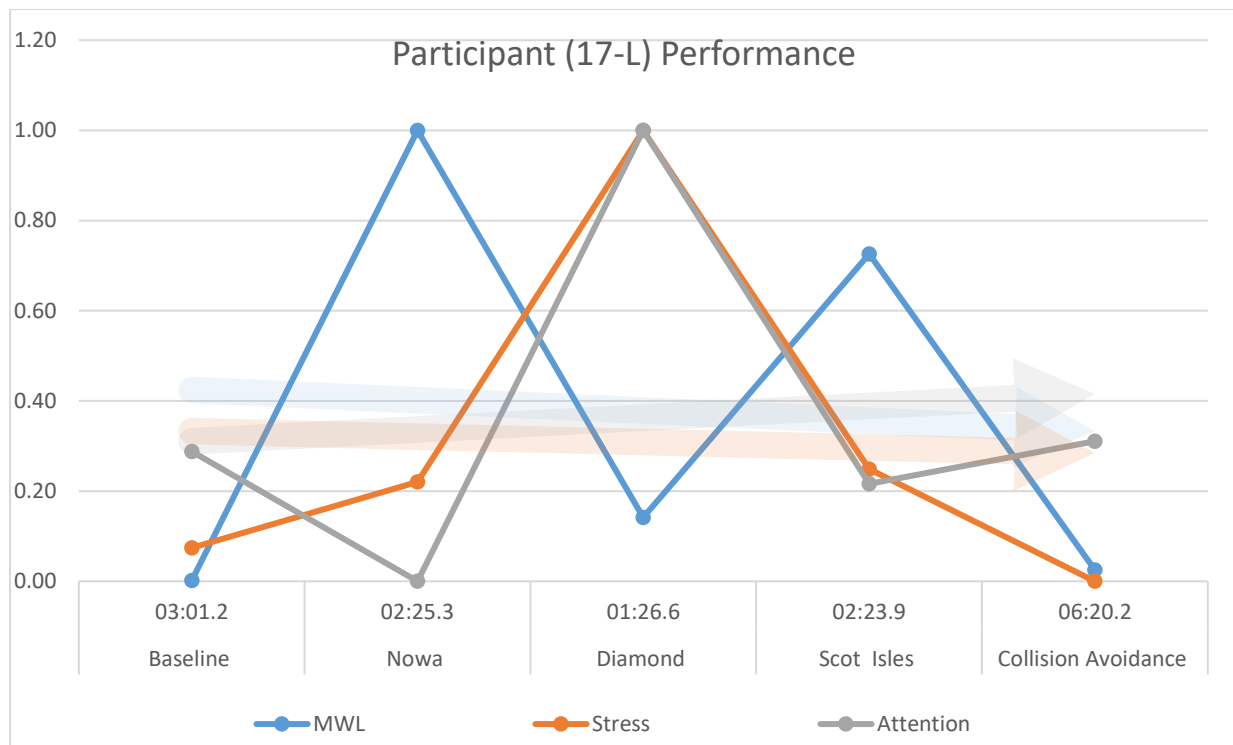


Figure 0.194 (P17-L) EEG result

Furthermore, pupil diameter for both eyes give a comprehensive view of Participant 17's performance through the events. Participant 17 began with low cognitive demand and started to increase slightly to MV Nowa and then began to decrease and manageable to the collision avoidance event Figure 0.195. Participant 17's pupil size and focusing were changed as shown in each event as follows Table 0.34 and Figure 0.201

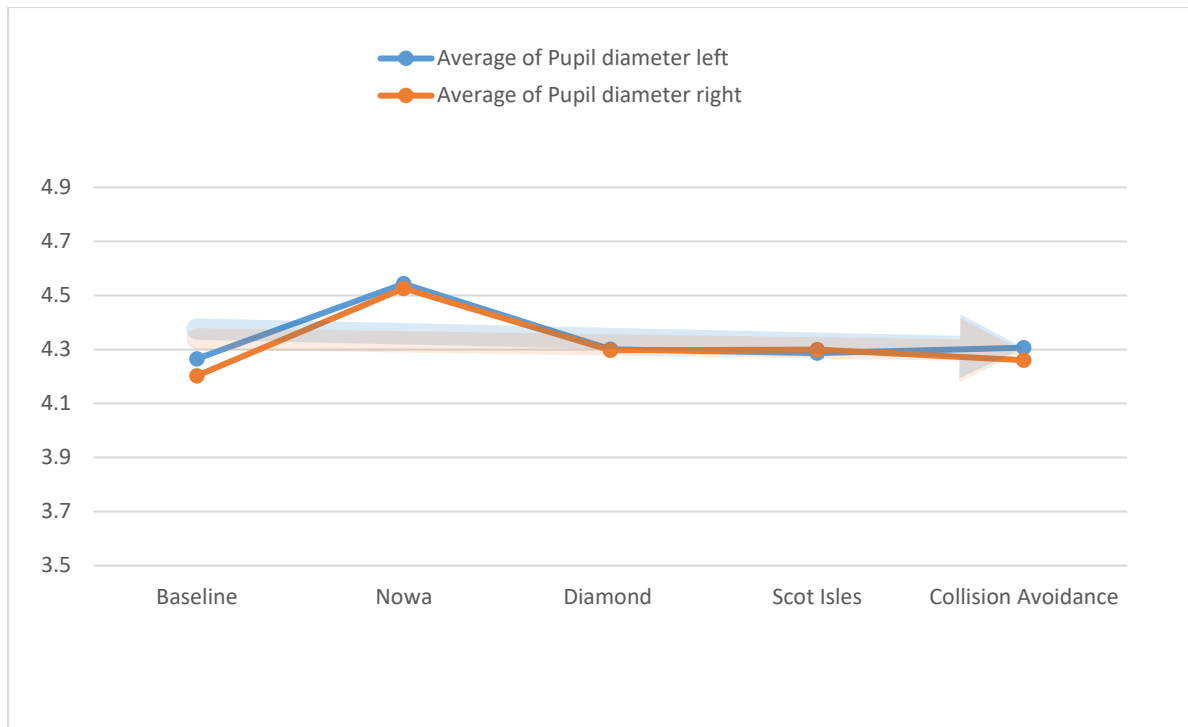


Figure 0.195 (P17-L) Eye-Tracking result

- **Event 1 Baseline:**

During the baseline event, the participant demonstrated the lowest average pupils with (4.27) and (4.20) for the left and right eyes respectively. The participant was not under pressure as there were no external targets to deal with which should made him calm and low MWL state. . The baseline duration is around (18%) of the scenario time, and the participant in the baseline event spent around (33%) of the event time focusing on the radar and (31%) of the event on ECDIS, and around (21%) of the event time visually scanned the surrounding area to check the situation in the surrounding area. Additionally, small attention was put on the display unit with (1%) and (12%) on the top display unit of the event indicating an initial information check before the targets appeared and indicating that Participant 17 used this time to get familiar with the navigation equipment *Figure 0.196*



Figure 0.196 (P17-L) Heat Map for Baseline

- **Event 2 MV Nowa:**

As the MV Nowa appeared on the radar and was visually detected, the participant's eye pupil diameters increased to (4.54 mm) and (4.53 mm) for the left and right sides respectively. This was due to the participant showing an increase in cognitive engagement, maybe because of the sudden appearance of the MV Nowa and multiple targets, and Participant 17 was surprised by the situation. In addition, the participant spent around (15%) of the experiment time monitoring the MV Nowa. The participant has shown a strong reliance on radar, with (94%) of the event time, and (4%) of the event time observed visually on the screen, and (2%) on the VHF while communicating. However, Participant 17 did not use the ECDIS which indicates that he prefers to use the radar as a navigation system to monitor the target with the support of the lookout for observation Figure 0.197



Figure 0.197 (P17-L) Heat map for MV Nowa

- **Event 3 MV Diamond:**

During this event, pupil dilation decreased slightly to (4.30 mm) and (4.30 mm), indicating that Participant 17 managed cognitive load when the MV diamond appeared. This event took around (19%) of the experiment time. The participant shows that (10%) of the event time focused on the radar indicating less attention on the radar with (61%) of the event time, Participant 17 also focused on screens for visualization for (20%) of the event time, and this was caused when the MV Diamond communicated with Participant 17 and lookout informed the participant of the location of the MV Scot Isles also. Participant 17 tried to observe visually to ensure the location of the MV Diamond and MV Scot Isles to improve the situation awareness. In addition, there was little attention on the ECDIS with (1%) of the event time. The display unit and top display unit got the attention of (12%) and (6%) of the event time, indicating that Participant 17 was getting the ship information from the display unit and was distributing his attention around the bridge even with the presence of the lookout Figure 0.198



Figure 0.198 (P17-L) Heat map for MV Diamond

- **Event 4 MV Scot Isles:**

With this event, the participant's eye diameter was maintained at (4.30 mm) for the left eye and (4.30 mm) for the right, indicating that Participant 17 cognitive load was manageable during MV Scot Isles. This event took around (15%) of the experiment time. The participant focused approximately (98%) of the event time on the radar during this event to assess the situation with the Scot of Isle. However, participant 17 also checked the situation visually with (2%) of the event time checking the external environment. This suggests that Participant 17 relied on the radar to assess the situation and relied on the lookout for the external observation and information during this event Figure 0.199



Figure 0.199 (P17-L) Heat map for MV Scot Isles

Event 5 Collision Avoidance

The pupil diameter remained at (4.30 mm) on the left and (4.26 mm) on the right, demonstrating the same cognitive load when taking action to avoid the risk of collision. The collision avoidance action took around (40%) of the experiment time. During this event, the participant distributed his attention more widely across the bridge systems. The participant focused on the radar with (74%) of the event time while (15%) on the ECDIS, (8%) of the event time on the screen for visualization, and (3%) on the top display unit. This means that Participant 17 distributed his attention on the ship bridge environment when he saw the risk of the collision to monitor the target and relied on the lookout for steering and give information form display unit

Figure 0.200



Figure 0.200 (P17-L) Heat map for collision avoidance

Table 0.34 (P17-L) Points of focus at different scenario events

Row Labels	Display Unit	ECDIS	Engine	VHF	RADAR	Visualisation	Top Display Unit
Baseline	1%	31%	0%	2%	33%	21%	12%
Nowa	0%	0%	0%	2%	94%	4%	0%
Diamond	12%	1%	0%	0%	61%	20%	6%
Scot Isles	0%	0%	0%	0%	98%	1%	0%
Collision Avoidance	0%	15%	0%	0%	74%	8%	3%

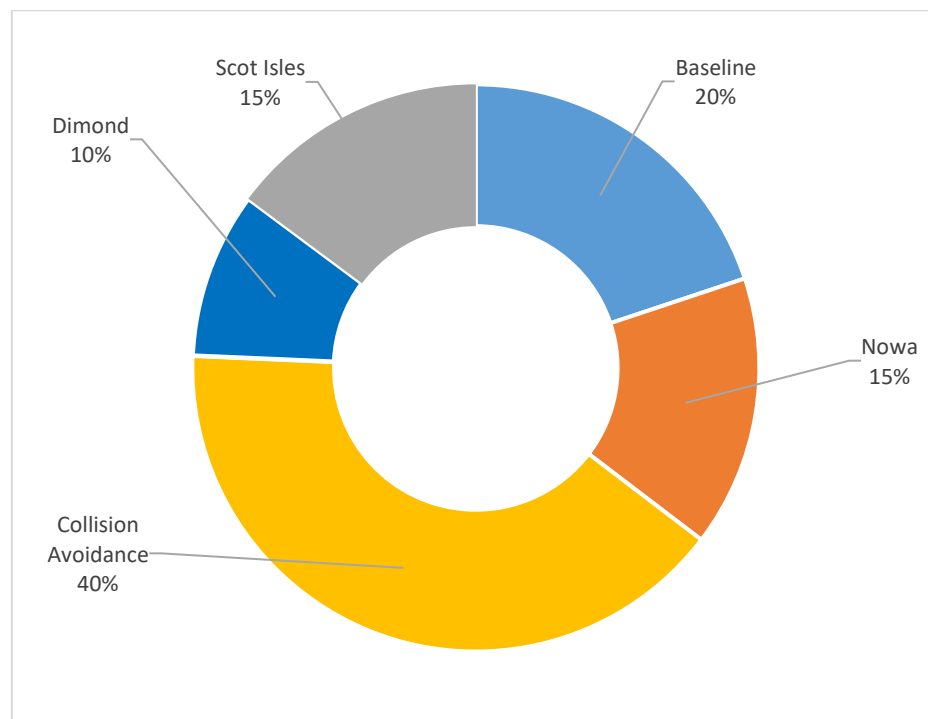


Figure 0.201 (P17-L) Duration time for each event

The Figure 0.202 and Figure 0.203 represent the participant 17 performance through the EEG and Eye-tracking singles which clearly illustrate the cognitive demand through the scenario.

The EEG shows that Participant 17 during the baseline was stable with low cognitive demand. However, when the targets began to appear, a spike appeared from frontal and parietal channels in the MV Nowa event indicating that Participant 17 engaged mentally and stressfully as he monitored the radar and processed communication. The MV Diamond event shows that Participant 17 tried to manage his cognitive load as the signals became more stable. However, in the MV Scot Isles, Participant 17 showed an increase in the delta in frontal channels which reflected his cognitive workload and decision-making while tracking the targets and making decisions. Moreover, during the collision avoidance, Participant 17 managed his cognitive workload and became more stable as he made an effective situational awareness when monitoring the targets on the radar and visually also communicated with the lookout about his attention to each target. In addition, the support of the lookout for steering manually keeps the participant focused on the navigation equipment.

Furthermore, the eye-tracking shows that Participant 17 in the baseline had low cognitive demand and maintained his mentality with the task until he became aware of MV Nowa which indicates some frustration in the beginning and then increasing in cognitive demand and attention when communicated with the target. In the MV Diamond to the collision avoidance event, Participant 17 shows that he tried to manage his cognitive workload and attention and his indicating also form his actions and communication with lookout about his attention as the participant knows what he wants to do.

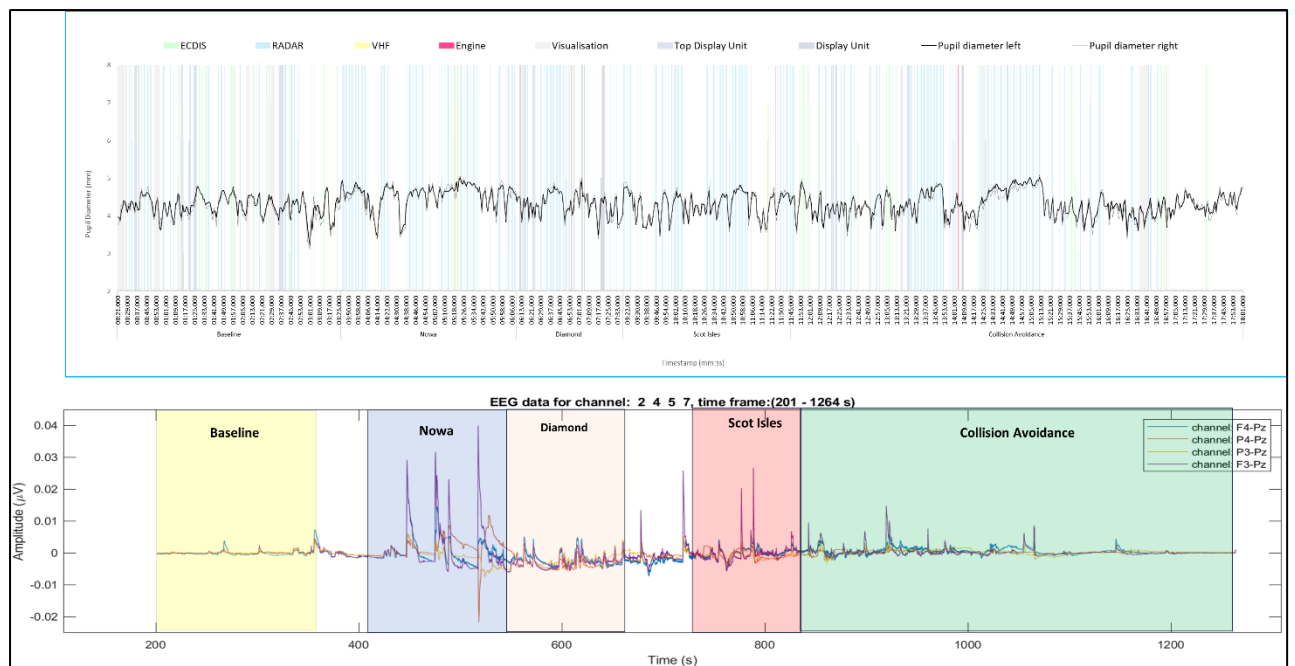


Figure 0.202 (P17-L) EEG and Eye-Tracking

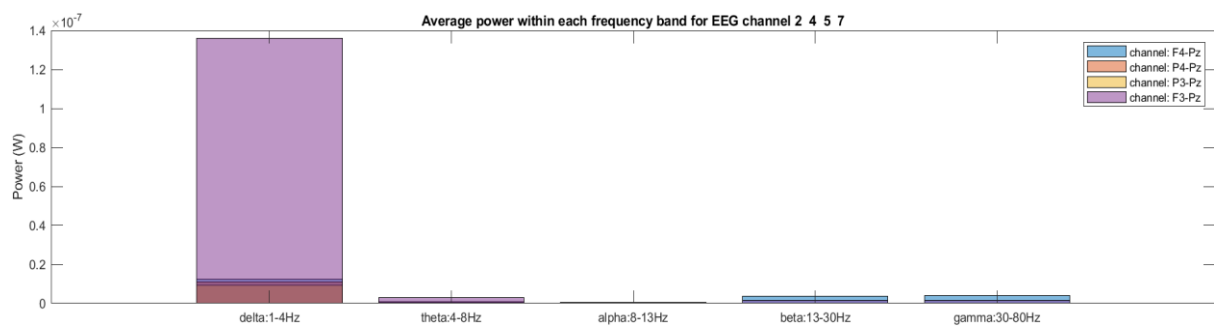


Figure 0.203 (P17-L) Power band

- **Participant 18 (P18-L)**

During the simulator experiment, participant 18 was navigating on the ideal course Figure 0.204 It shows that Participant 18 passed clear without being involved in a collision. The experiment occurred during the participant's interaction with five events:

Event 1 Baseline: Participant 18 was moving around observing the navigation equipment and checking the surrounding area which indicates that Participant 18 wants to get more familiar with the ship bridge environment.

Event 2 MV Nowa: participant 18 moved to the radar when the targets appeared. During his observation on the radar. Participant 18 acquired MV Now and MV Diamond to get the information. After that, the lookout informed him about the situation with MV Nowa. Then, participant 18 checks the surrounding area and look at each target around the ship which indicates an effective situation awareness. Later, participant 18 received a communication from MV Nowa informed him to maintain the course and speed. The answer from Participant 18 is to stand by and I will confirm later. After that, participant 18 monitored the target and observing other targets on the radar. During the monitoring, the look informed Participant 18 about the ship on the starboard quarter which is MV Diamond and also about the ship crossing from port side which is MV Scot Isles. Afterwards, participant reduced the speed and then communicate Mv Nowa to confirm for the manoeuvring to pass from stern.

Event 3 MV Diamond: after reducing speed and confirmed the manoeuvring with MV Nowa. Participant 18 received the call from MV Nowa informed him to maintain the course and the speed to overtake from starboard side which was confirmed by participant 18 and also participant 18 mentioned to Mv diamond that he will reduce the speed.

Event 4 MV Scot Isles: the participant 18 confirmed with Mv Diamond and then look at the MV Scot Isles on the radar. Therefore, participant 18 communicate with MV Scot Isles twice but there was no answer. After that, participant 18 informed the lookout to check the area on the port side. Moreover, participant 18 was checking the surrounding area to improve his situation awareness. Later, participant 18 communicate with engine room to mentioned them that he will reduce speed and got confirmed from engine room.

Event 5 Collision Avoidance: the participant ordered the lookout to take the steering and change to manual. Then, the participant 18 reduced the speed and ordered the lookout to alter

the course to the port side. in the meantime, participant 18 contact MV Scot Isles but still no response. Therefore, the participant 18 communicate with the Dover Coast guard explain the situation and his attention. later, he communicates with the engine room that he will reduce the speed and make a full stern to decrease the speed. The participant 18 kept monitoring the MV Scot Isles visually until passed clear.

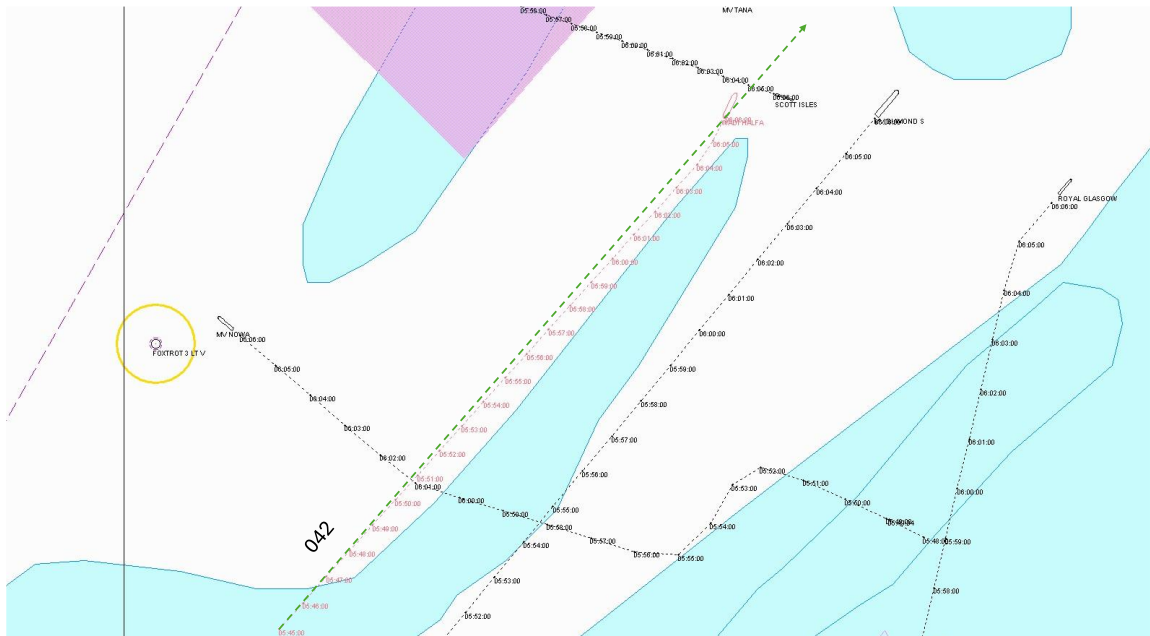


Figure 0.204 (P18-L) Navigation chart

Additionally, the heat map provides the participant's visual attention distribution during the ship bridge training simulation Figure 0.205. It offers a clear visual focus throughout the events. The red zones indicate the area with high focus. The heat map demonstrates that the participant was focusing effectively around the ship bridge by observing the situation on the navigation equipment and visually.



Figure 0.205 (P18-L) Heat map

Table 0.35 (P18-L) EEG result

Time		Event	Duration	MWL	Stress	Attention
00:00.0	03:01.0	Baseline	03:01.0	0.11	0.00	0.52
03:27.8	04:49.2	Nowa	01:21.4	0.09	1.00	0.63
04:49.2	08:00.8	Diamond	03:11.6	0.17	0.00	0.61
08:00.8	08:50.9	Scot Isles	00:50.1	1.00	0.31	0.31
11:56.2	21:50.3	Collision Avoidance	09:54.1	0.35	0.00	0.29

Based on the EEG results Participant 18's performance metrics are illustrated in Table 0.35 and Figure 0.206 we can observe how the cognitive demand (MWL, Stress, and attention) differentiation across the different events in the simulator training as follows:

- **Event 1 Baseline:**

During the baseline, participant 18 showed low mental workload and stress levels while moderate attention was shown. This suggests that the participant was calm because there were not any targets, and no immediate risk existed. However, participant 18 showed moderate attention possibly checking the equipment and the surroundings demonstrating initial situational awareness.

- **Event 2 MV Nowa:**

When the targets began to appear, Participant 18 stress increased significantly with increasing attention to high with low MWL. High stress reflected the pressure of managing and communicating multiple targets while Participant 18 tried to manage his MWL and attention.

- **Event 3 MV Diamond:**

The next event, MV Diamond, shows low stress with low attention and high MWL. In this event, Participant 17 reduced the speed when the scenario got complex and this was an effective action when he saw a critical situation, this suggests that Participant 18 was managing his MWL and stress while increasing his attention.

- **Event 4 MV Scot Isles:**

Participant 18 was informed about the MV Scot Isles by the lookout. After confirming with MV Diamond, Participant 18 communicated with MV Scot Isles but there was no response which reflects the increasing of his MWL to high and stress to moderated. Moreover, participant 18 attention was improving his situational awareness when he instructed the lookout to check the surroundings and then he reduced the speed immediately.

- **Event 5 Collision Avoidance:**

In the collision avoidance event, Participant 18 showed moderate MWL with very low attention and moderate attention which reflects that Participant 18 tried to manage his cognitive load when communicating with the Coast Guard about his attention and reduced speed more to avoid the collision.

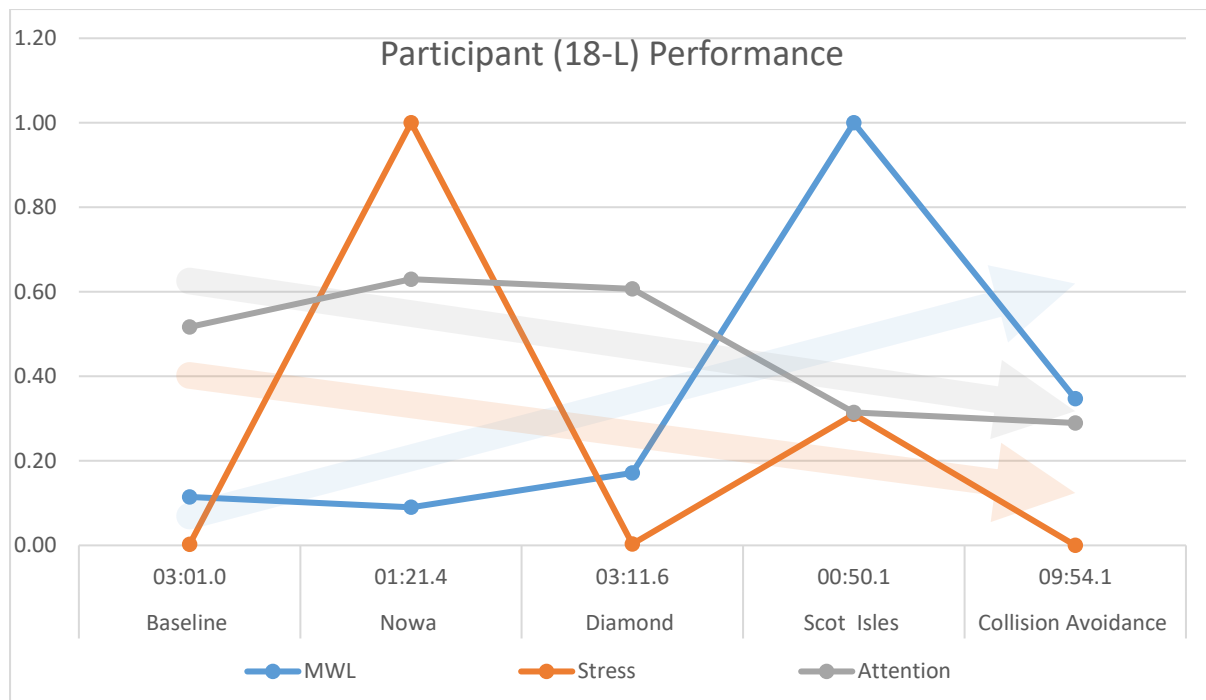


Figure 0.206 (P18-L) EEG result

Furthermore, the pupil diameter for both eyes give a comprehensive view of participant 18's performance through the events. Participant 18 began with low cognitive demand and started to increase slightly then during the MV Diamond began to decrease and manage until the collision avoidance event Figure 0.207. The participant 18 eye pupil size and focusing were changed as shown in each event as follows Table 0.36 and Figure 0.213

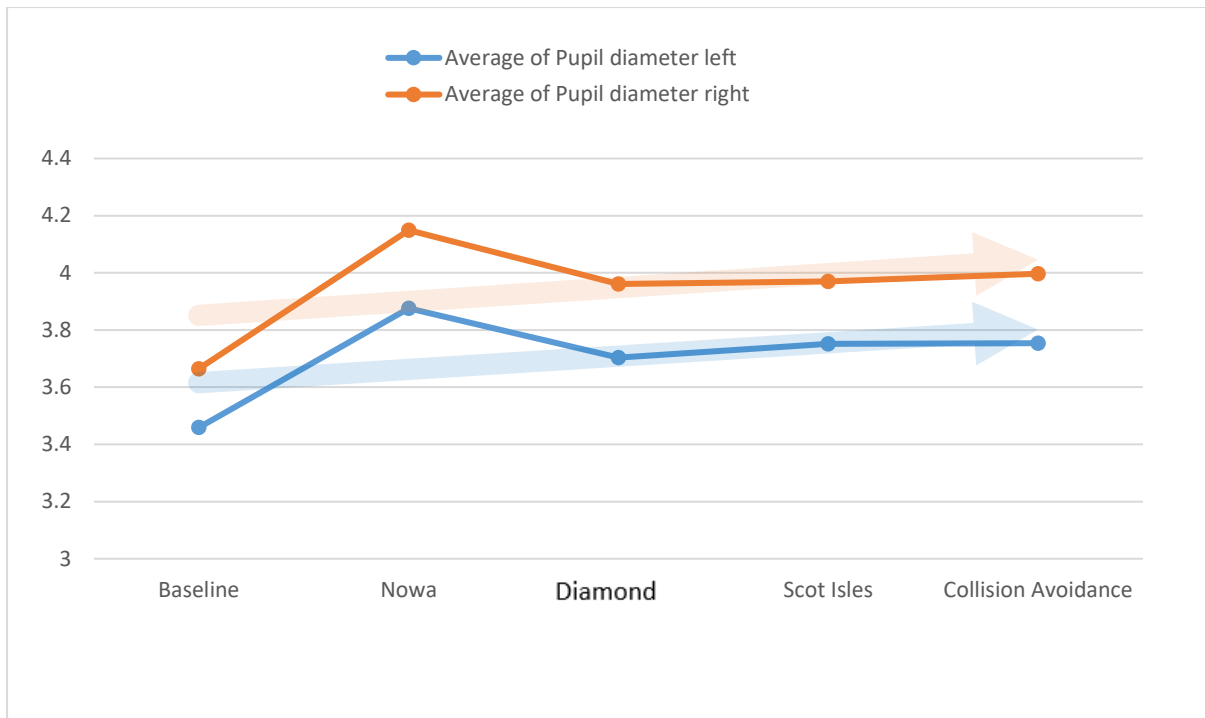


Figure 0.207 (P18-L) Eye-Tracking result

- **Event 1 Baseline:**

During the baseline event, the participant demonstrated the lowest average pupils with (3.46) and (3.66) for the left and right eyes respectively. The participant was not under pressure as there were no external targets to deal with which should made him calm and low MWL state. The baseline duration is around (16%) of the scenario time, and the participant in the baseline event spent around (27%) of the event time focusing on the radar and (20%) of the event on ECDIS, and around (23%) of the event time visually scanned the surrounding area to check the situation in the surrounding area. Additionally, attention was put on the display unit with (21%), (2%) on the top display unit, and (5%) on VHF and engine of the event time, indicating that Participant 18 distributed his attention around the ship bridge to get familiar and improve his situational awareness Figure 0.208



Figure 0.208 (P18-L) Heat map for baseline

- **Event 2 MV Nowa:**

As the MV Nowa appeared on the radar and was visually detected, the participant's eye pupil diameters increased to (3.87 mm) and (4.15 mm) for the left and right sides respectively. This was due to the participant showing an increase in cognitive engagement, maybe because of the sudden appearance of the MV Nowa and communication, and Participant 18 was surprised by the situation. In addition, the participant spent around (25 %) of the experiment time monitoring the MV Nowa. The participant has shown a strong reliance on radar with (90%) of the event time, and (2%) of the event time observed visually on the screen. However, Participant 18 used the ECDIS (1%) and (6%) for display unit which indicates that he prefers to use the radar as a navigation system to monitor the target and relied on the lookout for external observation Figure

0.209



Figure 0.209 (P18-L) Heat map for MV Nowa

- **Event 3 MV Diamond:**

During this event, the pupil reduced to (3.70 mm) and (3.96 mm), indicating that Participant 18 tried to manage his cognitive load when the scenario got complex. This event took around (4%) of the experiment time. The participant shows that (97%) of the event time focused on the radar. However, (1%) of the event time Participant 18 also focused on screens for visualization, and (2%) on the VHF this was caused when the MV Diamond communicated with Participant 18. In addition, there was no attention on the ECDIS indicating that Participant 18 was using the radar for monitoring and assess the situation while relied on the lookout for the external observation Figure 0.210



Figure 0.210 (P18-L) Heat map for MV Diamond

- **Event 4 MV Scot Isles:**

with this event, Participant 18 tried to maintain his cognitive and attention at (3.75 mm) for the left eye and (3.97 mm) for the right, indicating that Participant 18 cognitively managed after taking some action during MV Diamond. This event took around (3%) of the experiment time. The participant focused approximately (93%) of the event time on the radar during this event to assess the situation with the Scot of Isle. However, participant 18 also checked the situation visually with (1%) of the event time checking the external environment, and (6%) of the event time using VHF for communication. This suggests that the participant distributed his attention to the ship bridge navigation equipment and relied on the lookout for external observation

Figure 0.211



Figure 0.211 (P18-L) Heat map for MV Scot Isles

- **Event 5 Collision Avoidance**

The pupil diameter remained at (3.75 mm) on the left and (3.99 mm) on the right, demonstrating the same cognitive load when taking action to avoid the risk of collision. The collision avoidance action took around (52%) of the experiment time. During this event, the participant distributed his attention more widely across the bridge systems. The participant focused this time less on the radar with (66%) of the event time while (9%) on the ECDIS, and (10%) of the event time on screen for visualization, and (10%) on the display unit. This means that Participant 18 distributed his attention on the ship bridge environment when he saw the risk of the collision to monitor the target and try to manage his cognitive demand and situation awareness Figure 0.212



Figure 0.212 (P18-L) Heat map for collision avoidance

Table 0.36 (P18-L) Points of focus at different scenario events

Row Labels	Display Unit	ECDIS	Engine	VHF	RADAR	Visualization	Top Display Unit
Baseline	21%	20%	3%	2%	27%	23%	2%
Nowa	6%	1%	0%	1%	90%	2%	0%
Diamond	0%	0%	0%	2%	97%	1%	0%
Scot Isles	0%	0%	0%	6%	93%	1%	0%
Collision Avoidance	10%	9%	3%	2%	66%	10%	0%

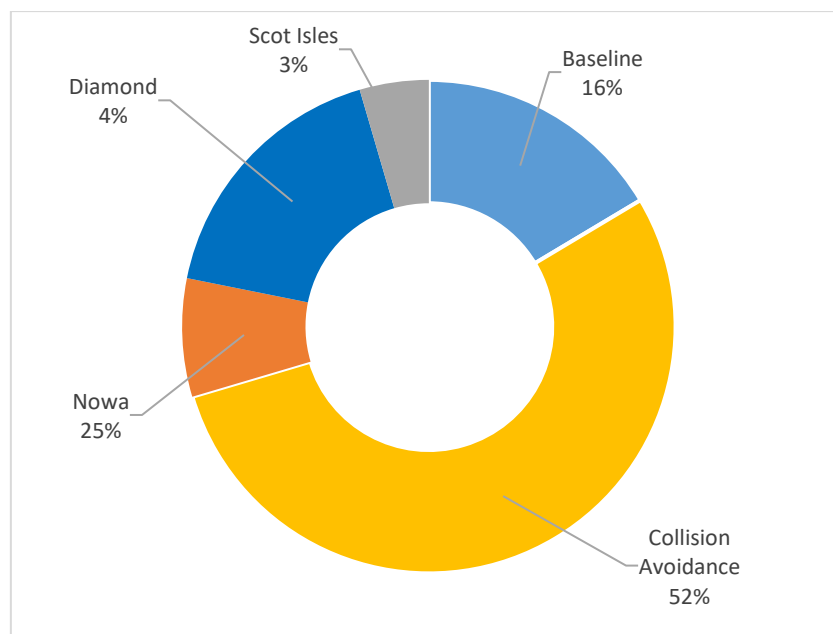


Figure 0.213 (P18-L) Duration time for each event

The Figure 0.214 and Figure 0.215 represent the participant 18 performance through the EEG and Eye-tracking singles which clearly illustrate the cognitive demand through the scenario.

The EEG shows that Participant 18 during the baseline remains stable with low cognitive demand. However, when the targets began to appear, abnormal activity on the EEG signals during the MV Nowa and MV Dimond occurred due to the frustration during communication or could be resulted from an issue with the device during movement. However, Participant 18 during MV Scot Isles, showed active cognitive load, particularly with the frontal channel with an increase in the delta indicating the decision-making of the participant. Moreover, during the collision avoidance, stabilized EEG amplitudes reflect confidence and reduced cognitive load as the participant executed an effective action to avoid collision. Furthermore, the eye-tracking shows that Participant 18 in the baseline experienced low cognitive demand, and the variation of the eye pupil diameter reflects the engagement with the ship bridge equipment during familiarisation. During the MV Nowa and MV Diamonda low eye pupil size appeared, and this could be because Participant 18 was fatigued as a result of the complex situation in some positions. However, Participant 18's cognitive demand was maintained during the MV Scot Isles and collision avoidance event suggesting focused effort and confidence during critical decision-making.

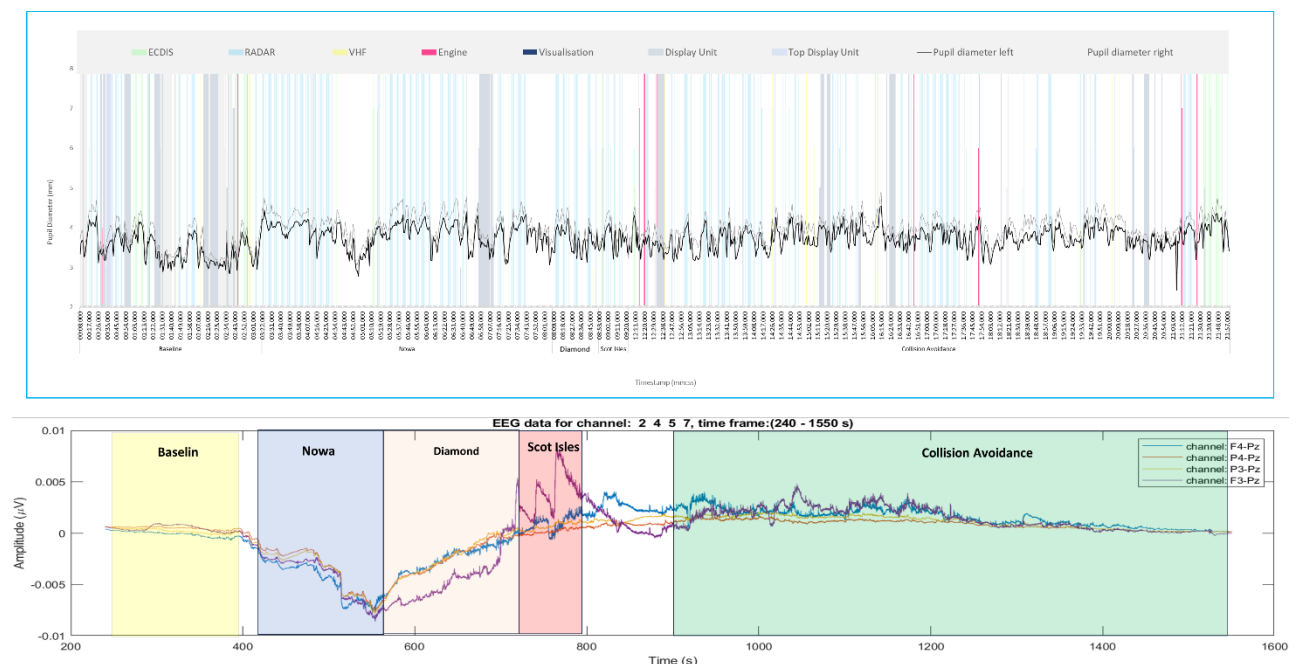


Figure 0.214 (P18-L) EEG and Eye-Tracking

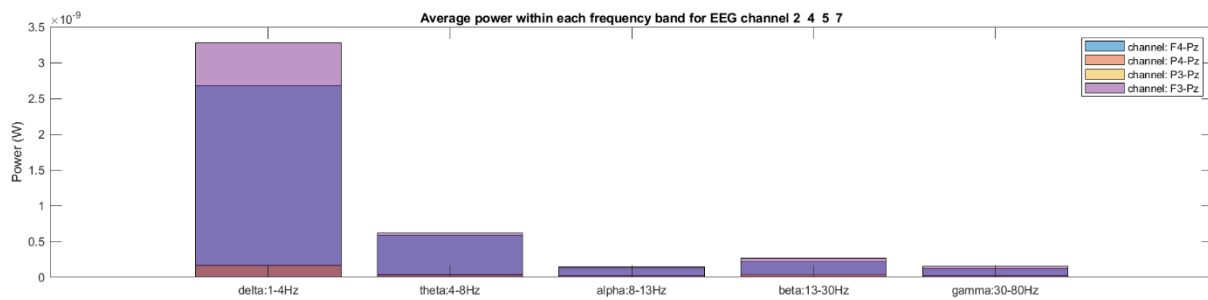


Figure 0.215 (P18-L) Power band

- **Participant 19 (P19-L)**

During the simulator experiment, participant 19 was navigating out of the ideal course Figure 0.216. It shows that Participant 19 passed clear without being involved in a collision. The experiment occurred during the participant's interaction with five events:

Event 1 Baseline: Participant 19 was moving around using the navigation equipment and checking the surrounding area, which indicates that Participant 19 wants to get more familiar with the ship bridge environment.

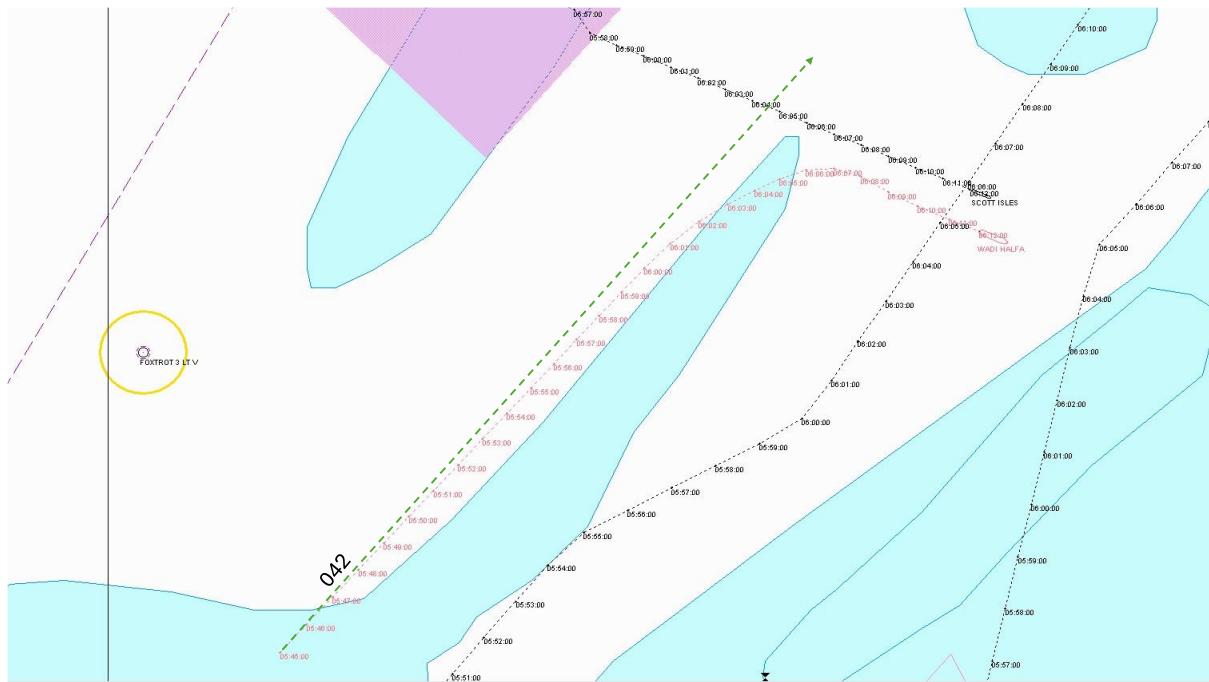
Event 2 MV Nowa: the participant moved to the radar and acquired the ships ahead. He was not aware of MV Nowa. After that, the lookout informed Participant 19 about the situation with Mv Nowa. Participant 19 confirmed and instructed the lookout to communicate with the Bosun to make the anchor stand by and ready. After the communication with the Bosun was done, Participant 19 ordered the lookout to take the steering and change it to manual. Later, Participant 19 received a call from MV Nowa informing him to maintain the course and speed. The participant confirmed the manoeuvring.

Event 3 MV Diamond: after that, the lookout informed Participant 19 about the ship on starboard quarter which is MV Dimond. Participant 19 acquired the target and used the screen to visualize the location visually. During Participant 19 observation, the lookout informed Participant 19 about the ship crossing from the port side, which is MV Scot Isles, then Participant 19 acquired the target and got the information. After that, participant 19 moved

around the bridge and communicated with the Bosun to confirm if Ancho was in the standby position. Later, participant 19 received a communication from Mv Diamond informing him to maintain the course and speed. Participant 19 confirmed the manoeuvring.

Event 4 MV Scot Isles: after finishing the communication with the MV Diamond. Participant 19 monitors MV Scot Isles on the radar. Then, the participant 19 communicate MV Diamond that he will start to alter the course to the starboard side to avoid the ship on the port side which is MV Scot Isles. The participant later monitors the target on the ECDIS and radar. After that, the participant communicated with MV Diamond for the second time to ensure that she started to alter the course to starboard, while his communication participant 19 reduced the speed.

Event 5 Collision Avoidance: after communication with Mv Diamond done. Participant 19 started to alter course to the starboard by giving order to the lookout. The participant monitors the scoot isles on the radar and ECDIS. Afterward, the participant 19 communicate with Scot Isles but there was no response. Therefore, the participant 19 keep altering the course to starboard and monitor the target visually and on the navigation equipment.in addition, the participant 19 contact with the Dover VTS to inform them that the ship will do 360 turn to avoid the collision with the ship on the port side. Later, he communicates the master asking him to come to the bridge. However, the ship passed clear and that was the end of the experiment.



Additionally, the heat map provides the participant's visual attention distribution during the ship bridge training simulation Figure 0.217 . It offers a clear visual focus throughout the events. The red zones indicate the area with high focus. The heat map demonstrates that the participant was focusing on navigation equipment and relied on the lookout for external observation.



Figure 0.217 (P19-L) Heat map

Table 0.37 (P19-L) EEG result

Time		Event	Duration	MWL	Stress	Attention
00:00.0	03:02.0	Baseline	03:02.0	0.77	0.04	0.19
03:12.7	05:53.3	Nowa	02:40.5	0.52	0.26	0.21
06:08.0	07:20.1	Diamond	01:12.0	1.00	1.00	0.00
09:16.0	11:53.7	Scot Isles	02:37.7	1.00	0.19	0.21
12:20.1	24:21.5	Collision Avoidance	12:01.4	0.00	0.00	1.00

Based on the EEG result and Participant 19's performance metrics illustrated in Table 0.37 and Figure 0.218 we can observe how the cognitive demand (MWL, Stress, and attention) differentiation across the different events in the simulator training as follows:

- **Event 1 Baseline:**

During the baseline, Participant 19 showed a high mental workload and low stress level while low attention was shown too. This suggests that the participant was engaged with the ship bridge environment despite there were not any targets and no immediate risk existed.

- **Event 2 MV Nowa:**

When the targets began to appear, Participant 19 detected the MV Now which changed Participant 15's MWL to moderate with low stress and attention. However, Participant 19 communicated with the head of the ship crew (Bosun) for anchoring procedures to keep it ready for any emergency which effective way of emergency preparedness.

- **Event 3 MV Diamond:**

The next event, MV Diamond, shows significantly high MWL and stress with very low attention. this could be occurred because Participant 19 tried to handle multiple targets with the pressure of managing communication and monitoring task. Therefore, the attention was reduced and relied on the lookout for external observation.

- **Event 4 MV Scot Isles:**

Participant 15 was informed by the lookout about Scot Isles. It shows that Participant 15 still had high MWL with low stress and attention. Participant 19 in this event managed his stress but with handling multiple targets and communication the cognitive workload was still high.

- **Event 5 Collision Avoidance:**

In the collision avoidance event, Participant 19 managed his cognitive demand by taking multiple actions until became parallel with the ship target and kept clear which reduced his MWL and stress while his attention increased. In addition, the lookout was a steering manual which made Participant 19 focus more on the critical situation.

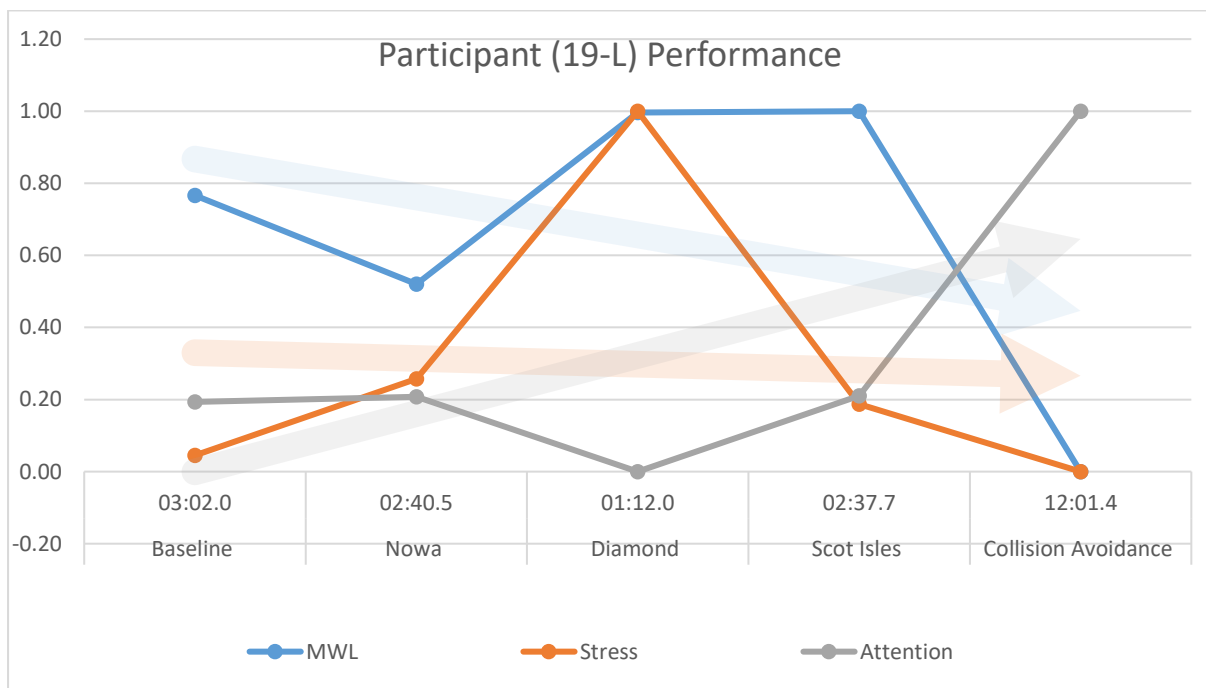


Figure 0.218 (P19-L) EEG result

Furthermore, pupil diameter for both eyes give a comprehensive view of Participant 19's performance through the events. Participant 19 began with low cognitive demand and started to increase slightly during the MV Nowa then decreased with MV Diamond and increased again with MV Scot Isles then decreased with the collision avoidance indicating that Participant 19 was trying to manage his cognitive demand Figure 0.219. The participant 19 eye pupil size and focusing were changed as shown in each event as follows Table 0.38 and Figure 0.225 Figure 0.225

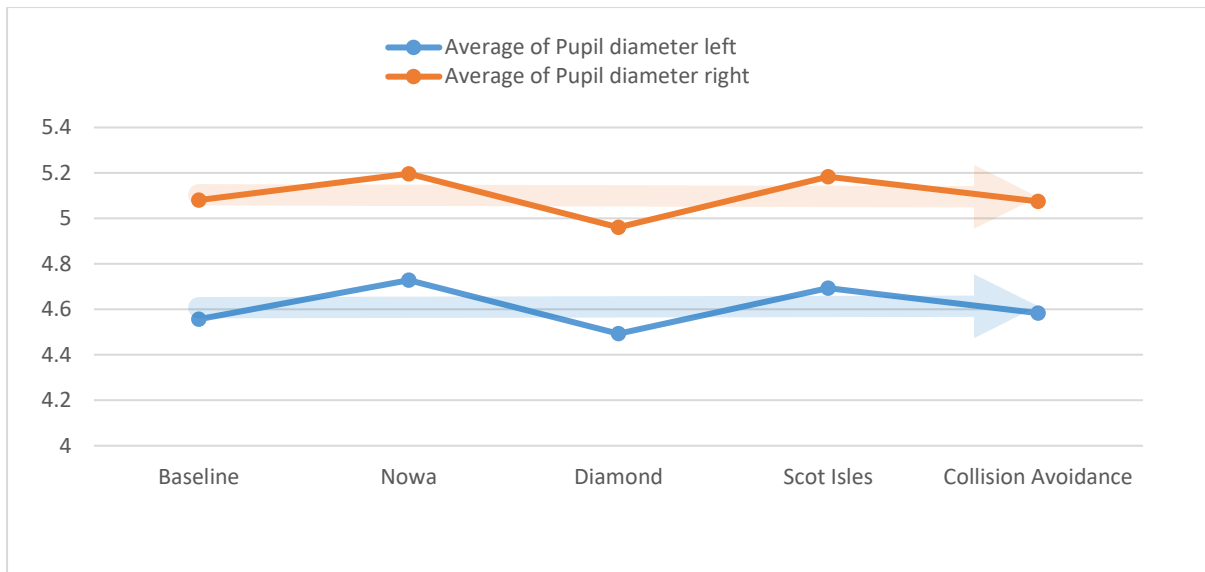


Figure 0.219 (P19-L) Eye-Tracking result

- **Event 1 Baseline:**

During the baseline event, the participant demonstrated the lowest average pupils with (4.56) and (5.08) for the left and right eyes respectively. The participant was not under pressure as there were no external targets to deal with which should made him calm and low MWL state. . The baseline duration is around (43%) of the scenario time, and the participant in the baseline event spent around (34%) of the event time focusing on the radar and (51%) of the event on ECDIS, and around (1%) of the event time visually scanned the surrounding area to check the situation in the surrounding area. Additionally, a small attention was put on the top display unit with (1%) of the event indicating initial information check before the targets appeared and indicates that Participant 10 used this time to get familiar with the navigation equipment Figure 0.220



Figure 0.220 (P19-L) Heat map for baseline

- **Event 2 MV Nowa:**

As the MV Nowa appeared on the radar and was visually detected, the participant's eye pupil diameters increased to (4.73 mm) and (5.19 mm) for the left and right sides respectively. This was due to the participant showing an increase in cognitive engagement maybe because of the sudden appearance of the MV Nowa, and Participant 19 was surprised by the situation. In addition, the participant spent around (12%) of the experiment time monitoring the MV Nowa. The participant has shown a strong reliance on radar with (73%) of the event time, and (7%) of the event time observed visually on the screen. However, Participant 19 used the ECDIS which around (18%) indicates that he prefers to use the radar as a navigation system to monitor the target and rely on the lookout for external observation Figure 0.221



Figure 0.221 (P19-L) Heat map for MV Nowa

- **Event 3 MV Diamond:**

During this event, pupil dilation decreased slightly further to (4.49 mm) and (4.96 mm), indicating that Participant 19 tried to manage his cognitive load when the MV diamond appeared. This event took around (6%) of the experiment time. The participant shows that (94%) of event time focused on the radar indicating overreliance on attention on the radar. However, (5%) of the event time Participant 19 also focused on ECDIS and very low attention on the visualisation which indicated that Participant 19 relied on the lookout for observation

Figure 0.222



Figure 0.222 (P19-L) Heat map for MV Diamond

- **Event 4 MV Scot Isles:**

with this event, the participant's eye diameter slightly increased to (4.69 mm) for the left eye and (5.18 mm) for the right, indicating that Participant 19 cognitive increased again and this might be because of the communication failure with MV Scot Isles. This event took around (12%) of the experiment time. The participant focused approximately (74%) of the event time on the radar during this event to assess the situation with the Scot of Isle. However, participant 19 also checked the situation on the ECDIS with (25%) of the event time, and very little attention on the visual observation. This suggests that the participant distributed his attention in the ship bridge environment between the navigation equipment and relied on the lookout for external observation Figure 0.223



Figure 0.223 (P19-L) Heat map for MV Scot Isles

- **Event 5 Collision Avoidance**

The pupil diameter reduced to (4.58 mm) on the left and (5.07 mm) on the right, demonstrating less cognitive load after taking action to avoid the risk of collision. The collision avoidance action took around (56%) of the experiment time. During this event, the participant distributed his attention more widely across the bridge systems. The participant focused this time less on the radar with (68%) of the event time while (26%) on the ECDIS, and (1%) of the event time

on screen for visualization, and (1%) on the display unit. This means that Participant 19 distributed his attention to the ship bridge environment between the navigation equipment also and relied on the lookout for the external observation Figure 0.224



Figure 0.224 (P19-L) Heat map for collision avoidance

Table 0.38 (P19-L) Points of focus at different scenario events

Row Labels	Display Unit	ECDIS	Engine	VHF	RADAR	Visualisation	Top Display Unit
Baseline	0%	51%	4%	0%	43%	1%	1%
Nowa	0%	18%	2%	0%	73%	7%	0%
Diamond	0%	5%	1%	0%	94%	0%	0%
Scot Isles	0%	25%	0%	0%	74%	0%	0%
Collision Avoidance	1%	26%	1%	1%	70%	1%	1%

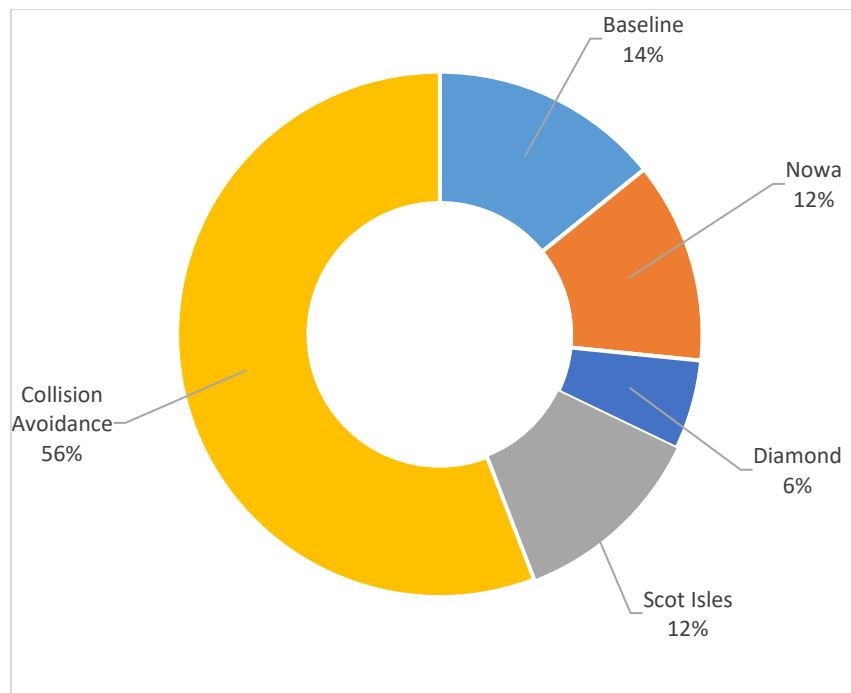


Figure 0.225 (P19-L) Duration time for each event

The Figure 0.226 and Figure 0.227 represent the participant 19 performance through the EEG and Eye-tracking singles which clearly illustrate the cognitive demand through the scenario.

The EEG shows that Participant 19 during the baseline experienced stable cognitive demand indicating a relaxed state as Participant 19 familiarized themselves with the ship environment. However, when the targets began to appear, fluctuation increased in EEG signals, particularly in channels associated with frontal and parietal regions, suggesting heightened cognitive activity while managing the appearance of MV Nowa and confirming the communication for manoeuvring. However, more variation appears during MV Diamond reflecting cognitive strain and stress during the management of multiple targets including communication. During the Scot Isles, elevated amplitude and more variable EEG signals correspond to an increased mental workload while managing interaction with MV Scot Isles and communicating with the lookout. Moreover, with the collision avoidance event stabilized signals appeared to indicate stable and managed cognitive demand

Furthermore, the eye-tracking shows that participant 19 in the baseline had low cognitive demand and maintained his mentality with familiarisation. It shows that with the appearance of the targets

Participant 19 tried to manage and maintain his cognitive workload and attention during the whole scenario. However, there is a descending position in all events indicating that Participant 19 fatigued when the event became critical with multiple tasks and communication with the lookout at the same time.

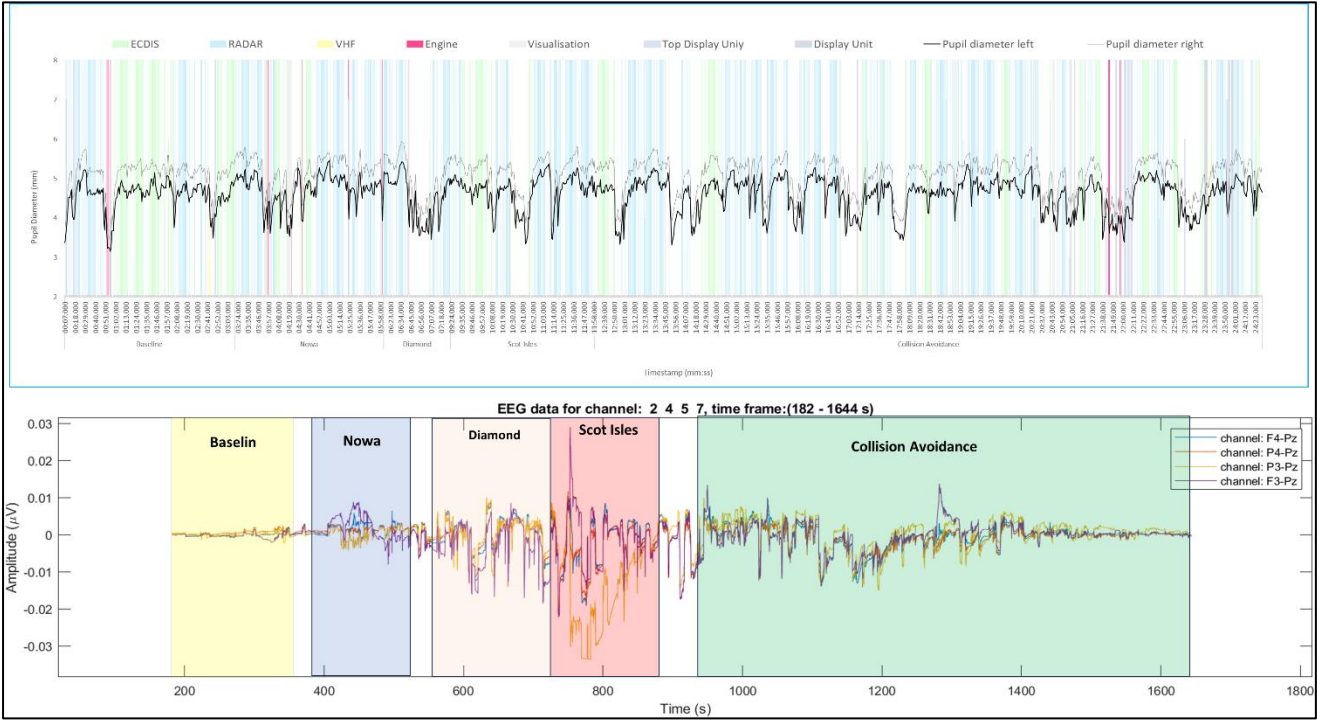


Figure 0.226 (P19-L) EEG and Eye-Tracking

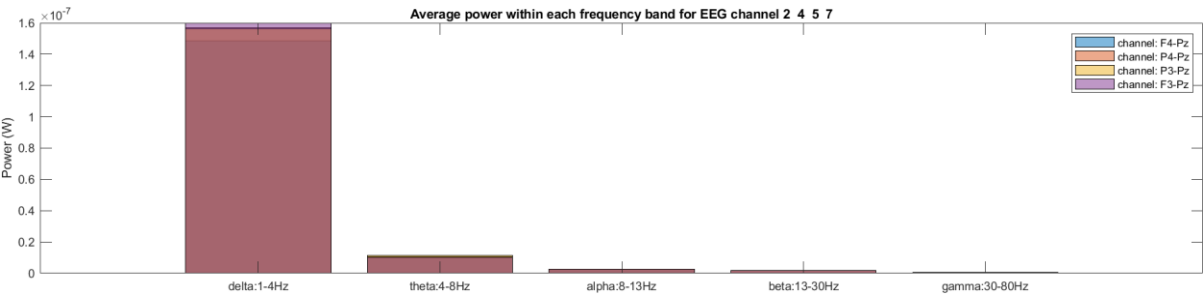


Figure 0.227 (P19-L) Power band