AR me hearties: An Evaluation of Augmented Reality as a Navigational Aid for Situational Awareness

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Abstract

A lack of a navigator's situational awareness (SA) is one of the leading causes of maritime accidents, especially vessel collisions. In earlier studies augmented reality (AR) has been shown to improve SA on vessel bridges. However, the technology is still under-developed, with widespread commercial solutions yet to appear on the market. AR could also play a role in reducing a navigator's head-down time (HDT). An AR interface was used to test its effect on the SA & HDT of participants in a quasi-experimental setting. The SA Global Assessment Technique was used to measure the SA of 17 participants using two different interface set-ups and the SA Subjective Workload Dominance method was utilised to measure their preference. Finally, an exploratory interview was used to discover possible explanations and improvements to the AR interface. The results showed that, while the addition of an AR interface improved mean SA (by 14%), this was not significant. The addition did significantly reduce mean HDT (by 266%) and head-down occurrences (HDO, by 62%) and was overwhelmingly preferred by participants (by 2890%). The interviews revealed that participants saw the value of the AR interface in improving information access and vessel detection but raised concerns over potential increased clutter and overtrust in AR. Several improvements to the AR interface were also suggested. This study demonstrates the potential benefits of AR on SA within the maritime domain, especially regarding HDT. Further research is needed using different interface set-ups, night-time/poor-visibility scenarios, various use cases, high-fidelity simulators, and applied improvements.

Keywords

Augmented Reality (AR)

Situational Awareness/Situation Awareness (SA)

Head-down time (HDT)

Head-down occurrences (HDO)

Situation Awareness Global Assessment Technique (SAGAT)

Situation Awareness Subjective Workload Dominance (SA-SWORD)

Human Machine Interface (HMI)

Human-Computer Interaction

Maritime

Navigation

Operator

Safety-critical

OpenBridge

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1 Introduction

1.1 Maritime Navigation and Safety

The maritime shipping, fishing, transport, and offshore sectors are essential parts of the global economy. Over 80% of the world`s trade involves transport by sea, consisting of approximately 2 billion tons of crude oil, 500 million tons of gas and 15 million Twenty-Foot Equivalent Units of cargo annually (UNCTAD, 2021). Transporting goods by sea is more cost-efficient and less carbon intensive compared with transport by land (ICS, 2023). Around 55,000 merchant vessels are making transportation at this cost-efficient scale possible (Statistica, 2021). Each vessel is crewed by seafarers, certified according to the Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) (IMO, 2011). During normal operations, a crude oil carrier of around 300m carrying 300,000 tons of crude oil, may only have a crew of 25, with only a single navigator keeping watch on the bridge at any time (Deloitte, 2011). This single navigator is responsible for the safe navigation of the ship (IMO, 2011). The navigator`s main safety responsibility lies in avoiding collisions with other vessels and preventing grounding, any of which could cause property damage, potential loss of life and/or environmental damage.

Navigation on the bridge is aided by tools such as the radar, Automatic Radar Plotting Aid (ARPA), and electronic navigation systems (Dokkum, 2021). However, The International Regulations for Preventing Collisions at Sea (COLREGS) rule 5 requires navigators to:

"at all times maintain a proper lookout by sight and hearing as well as by all available means appropriate to the prevailing circumstances and conditions so as to make a full appraisal of the situation and of the risk of collision" (IMO, 2016).

Rule 5 is emphasised because building a mental picture of what vessels surround one`s own, and how they are moving in relation to each other, is essential to avoid vessel-on-vessel collisions (Dokkum, 2021). A good watch officer, just like a good driver, must strive to detect other vessels timely and always anticipate their future movements. Navigators/watch officers should use all tools at their disposal and not rely on any single one (Dokkum, 2021). Training as a navigator or officer of the watch is highly regulated by the STCW, and particular emphasis is put on looking outside, instead of mainly looking down, and relying on navigational bridge aids such as the radar (IMO, 2011). Observation, visually, of the area surrounding the ship is therefore a critical aspect of safe navigation. The role rule 5 plays in the safety of the maritime sector is accentuated when analysing accident statistics.

Between 2012-2021, 892 vessel losses occurred and while the majority were caused by extreme weather, onboard fires, or machinery failure, 31 vessel casualties were caused by vessel collisions (Allianz, 2022). The 2021 Marine Casualties and Incidents Report by the European Maritime Safety Association stated that around 50% of all shipboard accidents occurred due to human error, and they recommended focusing on improving human factors (EMSA, 2022). An additional study, covering maritime accidents between 2002-2016, stated that around 25% of collisions could be attributed to "inadequate lookout" (rule 5) and 31% of human errors leading to collisions lay in the "inappropriate use of technology" (Sampson et al., 2018). These causes should be avoidable and while improved training may help (Griffioen et al., 2021), technology can also play a role. Each vessel loss represents potential lives lost and monetary losses. Efforts should be made to lower the chance of vessel-on-vessel collisions. Accidents primarily caused by "inadequate lookout" and "inappropriate use of technology", especially, present room for improvement. This thesis aims to evaluate how augmented reality (AR) affects situational awareness (SA) and thereby, possibly, demonstrate how it could improve safety in the maritime domain.

1.2 Situational Awareness

COLREG rule 5's latter part states that a navigator on the bridge must*: "make a full appraisal of the situation and of the risk of collision"* (IMO, 2016). In essence meaning that they must be able to perceive the environment around a vessel, comprehend possible dangers and be able to evaluate that a collision may occur if no action is taken. A concrete example could be a seafarer perceiving a small sailboat dead ahead, comprehending that it is a possible danger and evaluating that a collision could occur in the future is no action is taken. These three steps represent situation awareness (SA) as a human factor construct defined by Endsley (1995). According to Endsley`s model, SA consists of perceiving and comprehending the current situation, then being able to project its future status (Endsley, 1995a). If one of these steps is missed, SA would be incomplete and the operator would be less able to make a sound operational decision (Endsley, 2011). In a broad sense SA represents the relevant information required by an operator to make operational decisions (Endsley, 2011). SA is therefore essential to making safe decisions. Research shows that inadequate SA accounts for the majority of maritime accidents (Sandhåland et al., 2015). It is therefore crucial to improve SA on vessel bridges, through either training or technology.

1.3 Augmented Reality

Augmented Reality (AR) can be defined as allowing *"the user to see the real world, with virtual objects superimposed upon or composited with the real world"* (Azuma, 1997). The first AR-enabled device can be traced back to a 1901 patent by Sir Howard Grubb, which intended to assist in the aiming of firing projectiles by overlaying a targeting reticule on a target (Aukstakalnis, 2017). The development of AR was initially focused on military aviation, where targeting reticules replaced iron sights in warplanes. Head-up displays (HUD) replaced other instrumentation, allowing pilots to read instruments without shifting their view from outside the cockpit (Prinzel & Risser, 2004; Corning, 2018). Parallels can be seen with the maritime domain. As more displays such as radar and ECDIS were introduced on vessel bridges, this behaviour known as head-down time (HDT) began to become more pronounced (Hareide & Ostnes, 2017).

Figure 1- Airplane HUD (Corning, 2018)

AR solutions cover multiple use cases in multiple industries outside of aviation, in for example: manufacturing, healthcare, security, automobile and maritime (Woodward & Ruiz, 2022). However, all these industries share similar issues, namely, that most AR solutions are early concept and untested (Woodward & Ruiz, 2022). Studies covering AR concepts in the maritime domain conclude that these concepts should be evaluated (Laera et al., 2021).

1.4 Situational Awareness and Augmented Reality

AR as an aid towards improving SA is gaining prominence in several applications. Military applications for improving SA through AR are designed around the fact that infantry have constantly shifting situations, plans and need to coordinate efficiently and seamlessly with each other, something which AR could support (Livingston et al., 2011). The security domain saw AR as a useful tool to build SA in a team, especially for members not physically present (Lukosch et al., 2015). Research on AR usage within Unmanned Aerial Vehicles (UAV) showed that AR could significantly improve the SA of UAV operators, mainly by fusing information that was previously on two screens into a single display (Ruano et al., 2017). AR has been investigated as a means to improve SA as a HUD for vehicle drivers. While it shows promise in improving driver SA, an induced risk is that drivers become distracted by the AR-HUD (Kim & Gabbard, 2022). An in-depth analytical review of using AR for SA by Woodward & Ruiz (2022) found that AR seemed to be able to improve SA, but that the design of the AR interface was key. A poorly designed AR interface would be detrimental to SA (Woodward & Ruiz, 2022). The goal is to increase SA but avoid increasing cognitive distractions or information overload.

1.5 Research Gap

There are potential benefits to AR within different domains. However, there are still gaps in the understanding and deployment of AR (Woodward & Ruiz, 2022). AR is still a relatively novel technology and is actively researched. Its current practical application is limited and there is a lack understanding of the real-world effects and consequences of using different AR solutions in different domains (Woodward & Ruiz, 2022). In the maritime domain, AR solutions are still in a conceptual stage and require more research, with most AR solutions untested with end-users (Laera et al., 2021). Additionally, there are risks associated with the adoption of AR. Several studies have linked the adoption of AR to increasing the workload of the user, by providing too much information (Woodward & Ruiz, 2022). Furthermore, overlaying AR objects over a person`s field of view (FOV) can restrict it (Kim & Gabbard, 2022). A clear FOV is essential for transportation sectors that also rely on having visual control over their real surroundings, such as drivers in vehicles. Studies have shown that having an AR overlay can lead to higher levels of distraction in vehicle drivers (Kim & Gabbard, 2022). There are also the risks of unknowns, where due to the novelty of AR, certain effects of its use have not yet been revealed by research.

Due to the speed at which this field is developing, there are very few standards or best practices in adopting AR for maritime use (Nordby et al., 2020). Different AR concepts remain untested, and the plethora of different AR designs and applications show how far the development of AR still has to go. An important gap in AR application research is the lack of SA testing for relevant concepts. Few studies research the effect of their AR solution on SA (Woodward & Ruiz, 2022). The lack of a maritime study, investigating the effect of AR on objective head-down time, also needs attention. The effect of different AR maritime solutions on SA needs more research if the industry is to identify the benefits and risks of AR, in addition to exploring its potential usage for various purposes.

1.6 Research Background

Earlier research shows that one of the barriers to unlocking AR`s full potential is the lack of integration with existing systems on vessel bridges and therefore a common design framework (Gernez et al., 2020). The necessity of integration on vessel bridges is highlighted by the fact that most operate via a multi-vendor framework. Where each system on a bridge is provided by a different vendor, this introduces conflicts, poor information flow and inconsistency (Nordby et al., 2019). These issues led to a research project named OpenBridge, which aimed to deliver a common, open framework for an integrated bridge interface. This project was successfully delivered in 2022 by the Ocean Industries Concept Lab at the Arkitektur- og designhøgskolen i Oslo (AHO) and led to a spinoff project named OpenAR. OpenAR has the same goal, namely providing a common AR interface framework for vessel bridges that is freely accessible to developers. This is to further system integration and avoid inconsistent design (Gernez et al., 2020). To validate the effectiveness of an AR interface design more broadly, it should be tested and then refined. This thesis aims to investigate the effect of AR on SA and HDT in a bridge setting, using the OpenAR interface, and is part of WP1 of the OpenAR project.

1.7 Research Scope

This study focuses on an individual user`s SA, with a sole navigator operating on the bridge, who must build SA individually. This study thereby discounts SA within a team. A quasi-experiment is used to measure the effect of AR on SA, using the design concept of OpenAR. The Situation Awareness Global Assessment Technique (SAGAT) is utilised to measure participants` objective SA, in various traffic scenarios. While a Situation Awareness Subjective Workload Dominance (SA-SWORD) tool is used to measure the preference of the user in building SA; both using a traditional bridge set-up (with radar) or a bridge set-up with AR. Additional insights from participants on the AR interface design are gathered through an exploratory, semi-structured interview, to further improve the interface design. This scope synthesises into two research questions.

1.8 Research Questions & Hypotheses

The two research questions (RQ) are as follows:

RQ1. *What effect does an AR interface, in a maritime navigation setting, have on the situational awareness (SA), head-down time (HDT), head-down occurrences (HDO) and preference of an operator?*

RQ2. Given the feedback of the participants, what, if any, improvements can be made to the OpenAR interface design?

The alternative (H_1) and null (H_0) hypotheses for RQ1 are shown below:

$H_1$1.1 – *An AR interface has **an** effect on the SA of an operator, in a maritime navigation setting.*
$H_0$1.1 – *An AR interface has **no** effect on the SA of an operator, in a maritime navigation setting.*

$H_1$1.2 – *An AR interface has **an** effect on the HDT of an operator, in a maritime navigation setting.*
$H_0$1.2 – *An AR interface has **no** effect on the HDT of an operator, in a maritime navigation setting.*

$H_1$1.3 – *An AR interface has **an** effect on the HDO of an operator, in a maritime navigation setting.*
$H_0$1.3 – *An AR interface has **no** effect on the HDO of an operator, in a maritime navigation setting.*

$H_1$1.4 – *Operators, in a maritime navigation setting, **prefer** the use of an AR interface.*
$H_0$1.4 – *Operators, in a maritime navigation setting, **do not prefer** the use of an AR interface.*

1.9 Research Structure

The following section, section 2, investigates the state of current research in AR and SA. It justifies the research need and identifies research gaps through a literature review. Section 3 covers the methodology where the methodological theory, approach and analysis is covered. Section 4 covers the results of the experiment. Section 5 discusses the results, limitations and potential areas for future research. While section 6 contains the final findings and concluding statements.

2 Literature Review

2.1 Method

To get a sense of the status of the relevant research field and where potential research gaps exist, a literature review was conducted using a literature review matrix (Garrard, 2017). Specific search queries were used to acquire an initial sample of relevant, peer-reviewed articles. Subsequently, the snowball method, where relevant articles were chosen from the references of found articles, was used to identify additional relevant articles to analyse. These articles were used to define key concepts relevant to this study, in addition to understanding the current body of knowledge within SA, AR and HDT.

Table 1- Search Queries

Date	Database	Search Query	No.
11-11-22	SCOPUS	((TITLE-ABS KEY (augmented AND reality) AND TITLE-ABS -KEY (situation AND awareness)) AND PUBYEAR > 2009) AND (LIMIT-TO (DOCTYPE , "ar")) OR LIMIT TO (DOCTYPE , "re")) AND (LIMIT-TO (LANGUAGE , "English"))	78
12-11-22	WOS	augmented AND reality (Topic) AND situation AND awareness (Topic) AND 2010-2023 (Year Published) AND Article or Review Article (Document Types) AND English (Language)	83
12-11-22	IEEEXplore	("All Metadata":augmented reality) AND ("All Metadata":situation awareness), Filters Applied (Journals & 2010-2023)	13
11-11-22	SCOPUS	(TITLE-ABS-KEY (augmented AND reality) AND TITLE-ABS-KEY (maritime)) AND PUBYEAR > 2009 AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "re")) AND (LIMIT-TO (LANGUAGE , "English"))	23
12-11-22	WOS	augmented AND reality (Topic) AND maritime (Topic) AND 2010-2023 (Year Published) AND Article or Review Article (Document Types) AND English (Language)	19
12-11-22	IEEEXplore	("All Metadata":augmented reality) AND ("All Metadata":maritime), Filters Applied (Journals & 2010-2023)	2

Table 1 shows the search queries and the number of results for each database used. Search queries were limited to publication dates between 2010-2023, English language and peer-reviewed journal articles. Terms used were "augmented AND reality", "situation AND awareness" and "maritime". Unrelated articles were not included in the analysis. It should be noted that this method is not the beginning of a comprehensive systematic literature review, as that is beyond the scope of this study. Rather, it is a method, with which to gain a starting point for the literature review of this study. This starting point aims to gather knowledge on the latest developments within the research scope and provide an initial sample from which to snowball deeper.

2.2 Situational Awareness

SA, as a concept, began to be widely adopted in the 1980s & 1990s, especially within the aviation sector and United States Airforce (Salmon et al., 2008). Its origins can be traced to the famous "observe, orient, decide and act" (OODA) loop (Boyd, 1987). Where SA would encompass the "observe" and "orient" parts of the loop. Several models have been developed to provide a framework for understanding SA. Smith and Hancock's (1995) model is based on a perceptual cycle and building a mental model (Salmon et al., 2008; Smith & Hancock, 1995). This model states that individuals must build a "mental map" of a situation to gain an understanding of it and thereby facilitating the choice in taking a course of action. The Bedny & Meister (1999) model is based on activity theory, where an individual must invent a series of activities that permit an ideal end-state of a situation. The most well-known and widely adopted SA model was developed by Endsley in 1995 (Wickens, 2008; Endsley, 1995a) .

Endsley (1995) defines SA as:

"being aware of what is happening around you and understanding what that information means to you now and in the future"

While Endsley`s model has received criticism and been modified, it remains the standard model for understanding situational awareness (Wickens, 2008). It characterizes situational awareness as one of the first steps in the decision-making process. Where an operator can achieve full SA by passing through three levels of SA:

SA-1: "Perception of elements in the current situation"
SA-2: "Comprehension of current situation"
SA-3: "Projection of future status"

After achieving SA, the operator can decide and finally act, thereafter the operator receives feedback on their action and the process repeats. Endsley goes further by creating a framework of factors that can affect SA (Endsley, 1995a). Endsley argues that several factors can affect SA. Such as within-system factors: system capability, interface design, stress & workload, complexity, and automation. Additionally, individual factors could also affect SA: goals & objectives and preconceptions (Endsley, 1995a). This study focuses on the role of interface design as a factor affecting SA. SA as a concept, as Endsley developed it, remains solid and its role in accidents has become more apparent (Beaty, 1995). It is therefore paramount for operators to have sufficient SA to minimize the risk of accidents occurring. SA is not only a concept at the individual level, namely, how an individual achieves SA, but also present at a group/team level (Stanton et al., 2006).

On vessel bridges, navigators do not always operate alone, especially in stressful scenarios they may have the assistance of a lookout or helmsman. These additional people on the bridge also build SA and therefore contribute to the team or team SA (TSA). Endsley`s model can therefore be scaled up (Stanton et al., 2017). Salas argues that TSA is essentially individual SAs combined, whereby the key to good TSA is high-quality information exchange (Salas et al., 1995). Additionally, TSA differs from individual SA in the comprehension step. Where differing comprehensions of the situation on an individual basis can affect the whole TSA, which in turn modifies other team members` SAs (Salas et al., 1995). In essence, individual SAs merge into a single TSA and feedback of this TSA in turn affects the individual SA again, facilitated by information exchange (Salas et al., 2005). SA can be even further integrated to include technical systems.

Distributed SA (DSA) looks at SA as a product of "socio-technical systems" (STS), instead of each individual separately or as a team of individuals (Stanton et al., 2006). Within this model, technical systems are included in the team setup. A STS could include multiple individuals and technical systems (for example sensors) that together build DSA (Stanton et al., 2017). This type of SA is especially prevalent within safety-critical industries (Hollnagel, 2014). DSA emerges from the system of individuals and technical artefacts (Stanton et al., 2017). Since DSA is distributed among actors, a lack of it can also not be blamed on a single individual, but rather on the system and interaction of its components (Stanton et al., 2017). These three models, individual SA, TSA and DSA, represent the three main perspectives of SA. Users building SA along these models are largely dependent on technology and systems to maintain SA and these systems should accommodate SA-building (Endsley, 2011).

Endsley highlights how designing systems to improve SA should be centred around the user (Endsley, 2011). It suggests a fine balance; to design a well-functioning user interface (UI), that shows sufficient levels of relevant information while avoiding information overload. 'Information overload' refers to the user being unable to process the sheer volume of information presented (Endsley, 2011). She additionally highlights some "SA demons" that counteract SA. Such as tunnel view, stress, information overload, high complexity and "out-of-the-loop syndrome" where an operator is unaware of the actions being taken by an automated system (Endsley, 2011). Endsley highlights that training can play an important role in operators being aware of these demons and being able to anticipate them, but that good design remains paramount (Endsley, 2011).

Crew training is one method of potentially improving SA, but this has had mixed results and is underdeveloped (Jaram et al., 2021). Most moves towards improving operator SA in the maritime domain have been through technology, namely, navigation aids on the bridge. Radar/ARPA systems are the best examples of these, improving all levels of SA by detecting moving targets, providing detailed information, and projecting their movement into the future (Dokkum, 2021). This provides operators with a target vessel`s closest point of approach (CPA) and when that CPA occurs (time to closest point of approach; tCPA). This information is essential to modern collision avoidance at sea and whilst most seafarers can estimate CPA and tCPA through rudimentary visual observation, there is a strong reliance on radar/ARPA (Dokkum, 2021). An Electronic Chart Display and Information System (ECDIS) on a bridge fills the same role for anti-grounding SA. It assists the operator in building SA on subsurface and navigational collision threats, such as buoys and shallow depths. Both the Radar and ECDIS are vital tools for navigators, but diligently and regularly observing one's actual surroundings is still compulsory as defined by COLREGS (IMO, 2016). Technical skills taught to seafarers to improve their SA, such as radar/ECDIS monitoring, should work in tandem with an awareness to build SA.

Awareness of the importance of SA building is taught to seafarers through Crew or Bridge Resource Management (CRM). CRM was initially adopted in aviation to train "human factor" or non-technical skills (NTS) and it has a special focus on SA as one of these skills (Johnson, 1995). This followed a realisation that the majority of aviation accidents were due to a lack of NTS (Kanki et al., 2010; Havinga et al., 2017). Studies showed that while the effect of this training on trainees was generally positive, it was domain-dependent (Salas et al., 2006). As the usage within aviation grew, other sectors, especially safety-critical domains, such as power generation, adopted the training of NTS (Praetorius et al., 2021). These NTS complement technical skills, focused on "cognitive, social and personal resource" areas (Praetorius et al., 2021). The maritime sector adopted CRM from aviation and implemented a similar version of NTS training after a comparable spate of human error induced accidents (Havinga et al., 2017).

Most navigators are now actively trained in how to build SA and are aware of the basic SA model, which shows the emphasis put on SA within maritime safety training (Griffioen et al., 2021). This training is aimed to reduce the role of poor SA in accidents, thereby improving maritime safety.

SA's role in maritime accidents has been researched. Hetherington et al. (2006) in a review concluded that between 50 and 80% of all accidents were primarily caused by human error, whereby 70% of these human errors were induced by poor SA (Hetherington et al., 2006). Chauvin (2013) further identified the loss of SA as a major source of maritime accidents, appearing in more than 30% of cases (Chauvin et al., 2013). Sandhåland (2015) investigated collisions between attendant vessels and offshore facilities in the North Sea and found that poor SA led to 18 of the 23 accidents. 13 of these 18 accidents were due to a failure to reach SA-1 – perception of the current situation. The study also found that inadequate bridge design was a significant factor in precipitating this lack of SA in the officer on the bridge (Sandhåland et al., 2015). Additional studies have found similar results, concluding that lack of SA was the primary cause of maritime accidents (de Maya & Kurt, 2020; Jaram et al., 2021). Improving this SA, especially in SA-1 (perception) could potentially reduce the number of SA-induced accidents.

2.3 Augmented Reality

AR involves the superimposition of virtual images over the user`s real-world view. AR can be considered part of the reality-virtuality (RV) continuum, a term coined by Milgram and Kishino (1994). They consider this a spectrum, where reality is at one extreme and virtuality at the other extreme (Milgram & Kishino, 1994). The real environment in this case would be the real world, consisting of no virtual objects. While the virtual environment would consist of no real objects and be completely virtual. Anything in-between these extremes would be considered mixed reality (MR). Skarbez et al. (2021) suggested that the virtual environment should be split in two, arguing that there are two versions of a virtual environment. One where the user is immersed in a perfect virtual representation of the real world, but where the user still senses that they are "not really there". While the other version would represent a perfect "Matrix-like" virtual world (Skarbez et al., 2021).

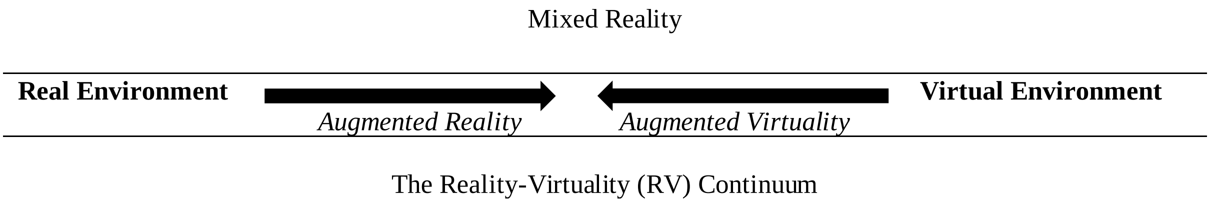

Figure 3 - Milgram`s & Kishino`s RV Continuum (1994)

This continuum is shown in Figure 3 and highlights that AR`s place on the spectrum lies near the real-environment side of the spectrum. This stresses that while AR has elements of virtuality, it is inherently rooted in the real world. Augmented virtuality (AV), however, is inherently in the virtual world, with some elements of the real-world present (Milgram & Kishino, 1994). A virtual reality (VR) headset would lean closer to the virtual environment side of the spectrum, as most perceived elements (sound/sight) are inherently virtual, but smell, taste and touch are still elements of the real environment. AR and VR, as they are now, are forms of MR as shown on the RV continuum.

Since its introduction, AR has seen several practical applications. The HUD can be seen as a forebearer to the AR interface, which was introduced in aviation (Holder & Pecota, 2011). Research in AR's application as a HUD widened to cover vehicles, dismounted soldiers, drones and the maritime domain (Woodward & Ruiz, 2022). A distinction must be made between a HUD and an AR-HUD. A HUD can be purely physical, for example, a car dashboard, whilst an AR-HUD "combines real and artificial elements in the line of sight" (Li et al., 2022).

Modern AR technology has many facets. AR can be displayed via a head-mounted display (HMD), such as Microsoft HoloLens (Microsoft, 2022). One principle of presenting AR is "optical see-through" AR, where images are presented directly on the wearer`s real-world view. Additionally, AR can be displayed via HMD with "video see-through" where the user sees a video feed of the outside world via a display. This display then has an AR interface overlayed (Aukstakalnis, 2017). Other than through AR HMDs, AR can likewise be made available via mobile devices or on a display, where AR is overlayed on a live video feed of a mobile device. An example of this is Google Maps AR navigation tool, which allows users to see their route live via their smartphone screen (Hall, 2022). This commercial interest is evident.

AR is of great commercial interest. The Microsoft HoloLens is an example of AR technology being adapted for commercial use in the industry. Microsoft highlights some case studies in industry, such as in manufacturing, where workers can be more efficient through reducing downtime or providing live instruction via AR (Microsoft, 2023). The medical field is another example, where surgeons can use AR to read information hands-free or be able to see an AR overlay of internal information concerning the patient as in Figure 2 (Johns Hopkins, 2021). Outside of manufacturing or healthcare, AR is seeing increase use within transportaion domains.

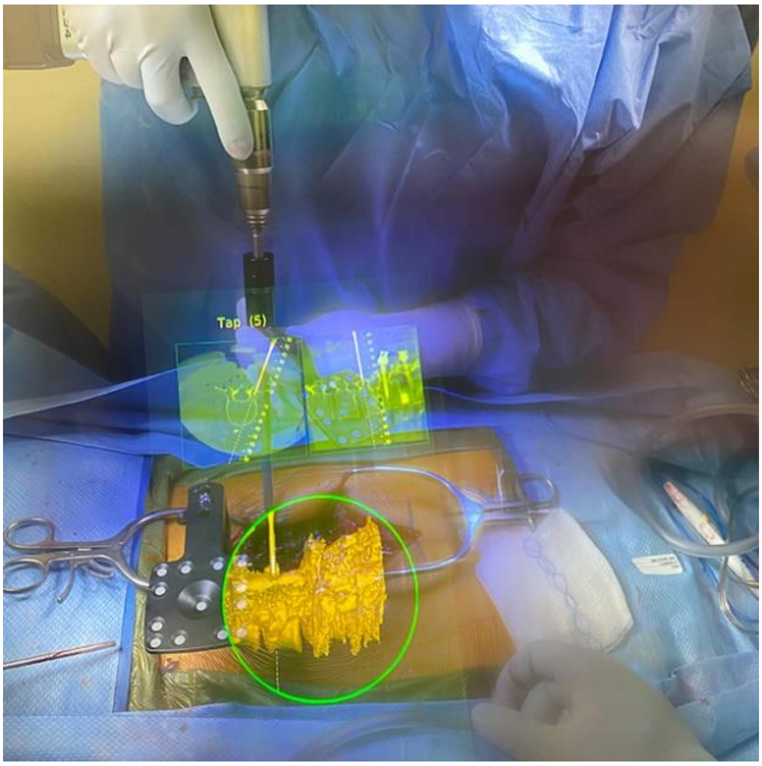

Figure 2- AR view of a surgeon (Johns Hopkins, 2021)

Within the transportation domain, car manufacturers are experimenting with using AR to create a HUD for vehicles. This is for much the same reason as when they were developed for planes, to keep the eyes of drivers on the road and not on their instruments (Woodward & Ruiz, 2022). AR has also gained interest in the maritime field, with several studies investigating AR developments, for example, a maritime HUD, AR-assisted ice-breaking and anti-collision in remote vessel operations (Laera et al., 2021). AR could moreover potentially assist with autonomous vessel supervision or the remote operation of vessels (Laera et al., 2021). AR has the potential to change how navigators operate on bridges as it did in aviation, by improving the safety and effectiveness of operators.

Interest in AR has also broadened within research. Some examples include: its use by maintenance technicians in overlaying relevant information on smart glasses (Sara et al., 2022), supporting hearing-impaired children by representing sound in AR (Sun et al., 2022), aiding in gamifying education (Çelik & Yangın Ersanlı, 2022), increasing customer engagement by displaying online products in AR (Barta et al., 2023), in the medical field (Bruno et al., 2022) and even enhancing the viewing experience of live sports to fans (Goebert et al., 2022). This shows that AR has many uses other than in HUDs and transportation. It is a tool that can be used for various ends and should be designed and applied to fit its intended use.

There are also a variety of ways AR can be presented within the maritime domain. A review summarised the different technologies in use by the maritime industry for the adoption of AR (Laera et al., 2021). AR in this sense can either be stereo or monoscopic (using two eyes or one eye respectively). Stereoscopic viewing allows the user to utilise depth cues. The displays themselves are either HMDs employing optical see-through or video pass-through technology (Laera et al., 2021). Another technology used are mobile AR systems (MAR), using a video feed with an AR interface overlay. Laera et al (2021) additionally defines HUDs to be considered an HMD version of AR. Frames of reference within the overlay of information can be categorised (Laera et al., 2021). An AR display can be either world-relative (WR), body-relative (BR), screen-relative (SR) or hybrid (Gabbard et al., 2014; Laera et al., 2021). WR entails that the AR visual asset is fixed to a world location, for example, a CPA notification on a ship. BR involves a visual asset fixed to the user’s body, so if the user shifts view, the asset moves too. SR implies that the visual asset is fixed to a screen, while hybrid could involve a combination of various methods (Laera et al., 2021). The review further categorises the various technology choices made by maritime AR solutions, by splitting the way visual assets can be shown. This split is done according to spatiality, either 3D or 2D (Laera et al., 2021). Regardless of the type of AR solution, the design of an AR interface is crucial to ensure that its benefits are realised.

HMIs should be based around human centred-design and avoid the risks of AR, namely information overload, distraction and visually blocking the real world (Endsley, 2011). There is a lack of an AR design framework in maritime UI design, specifically for the bridge (Nordby et al., 2020). Nordby et al. (2020) adapted the existing UIs and framework of OpenBridge towards AR. Each function could be represented in a different display format to maximise the advantage of AR (Nordby et al., 2020). Nordby et al. (2020) further argues that, since the information presented in AR is presented in the user's FOV and should block as little of the real world as possible, there are limited areas for the presentation of information. They suggest a framework for the presentation of information around three areas (Nordby et al., 2020):

1. A masked area represents an area where no information can be displayed, to prevent information from blocking a crucial FOV area.
2. Free pinning - information the user may freely place themselves.
3. An area where information is displayed, for example on the horizon, via a bar or on the sea surface for a route or anti-grounding.

Norby et al. (2020) also argues that AR on the bridge should change and present information differently, depending on the user’s physical location on the bridge. Bridge users must be able to move around freely, and different areas of the bridge may require distinct types of information to be shown (Nordby et al., 2020). AR has potential within the maritime sector, but a design framework should be developed further, maximising the advantages of AR, whilst minimising the risks of its introduction on the bridge.

2.4 Head-Down Time

One of the main agreed-upon potential benefits of AR is the shortening of HDT (Hareide & Porathe, 2019). HDT encompasses the time that an operator is not attending to the primary visual field, namely, outside. Instead, the operator has their head down, viewing an “auxiliary tool” (Wilkins, 2018). This could, for example, be a screen displaying navigation software to an operator, who should primarily attend to the outside view (Wilkins, 2018). Moving this auxiliary tool from a head-down position to a head-up position, via a HUD or AR could potentially reduce HDT while not removing the aid from the auxiliary tool (Wilkins, 2018).

The concept of the HUD to reduce HDT originated in military aviation, where HUDs were introduced as a way to improve operator performance (Prinzel & Risser, 2004). They allowed a pilot to have the benefit of having instrument information in the same field of view as the “outside” view, allowing for optimum flight control (Prinzel & Risser, 2004). Other endeavours to reduce HDT in aviation entailed using sound. Experimentation with using 3-D audio to replace a head-down display (HDD) in a cockpit improved target acquisition, perceived workload and situational awareness (Parker et al., 2004). In other domains, using AR or a HUD to prevent driver distractions caused by HDT showed their potential in automobiles (Kim &

Gabbard, 2022). Research comparing the use of HDDs and HUDs in automobiles revealed that the HUD provided better driver performance and had increased performance over a traditional HDD (Ablassmeier et al., 2007). An additional study found that replacing a HDD with a HUD increased the response time of drivers to urgent events and decreased their stress (Y.-C. Liu & Wen, 2004). Further research into using AR instead of a physical HUD to reduce HDT in automobiles showed that AR further improved operator performance in terms of HDT than a typical HUD (Bauerfeind et al., 2022).

Regarding HDT, the maritime domain is no different. Research has shown that bridge navigators can spend more than 50% of their time looking down at their instruments, instead of looking outside (Hareide & Ostnes, 2017). This includes significant backtracking between navigation instruments and looking outside, implying a high level of head-down occurrences (HDO) (Hareide & Ostnes, 2017).While occasionally looking down at a radar can potentially help build SA, too much HDT is known to be detrimental to SA (Y.-C. Liu & Wen, 2004). A study by Holder & Pecota (2011) investigated the use of a HUD in reducing HDT in a bridge setting. The HUD was designed in much the same way as an AR and was shown to be able to reduce subjective HDT. Subjective HDT being the HDT participants themselves perceived. Participants also expressed a preference for the HUD over traditional systems. However, participants did express concern over the potential for distraction from the HUD (Holder & Pecota, 2011). Critically, this study did not investigate the effect of the HUD on SA specifically or objectively measure HDT. Reducing HDT seems possible using a HUD or AR interface. Thereby potentially improving operator performance, although little research has been done on this in the maritime domain.

2.5 Augmented Reality Maritime Adoption

Specifically for the maritime domain, AR has seen significant interest and potential. AR`s potential lies in the fact that an operator on a ship`s bridge could look outside through a window to build SA assisted by AR, unbound by a physical display (Grabowski et al., 2018). This reduction in HDT could be the key to unlocking AR`s benefits. Several examples of the application of these AR technologies in the maritime domain already exist (Laera et al., 2021).

Laera (2021) summarised the different design choices. Initially, AR was overlayed over a camera feed and its primary application was on remote high-speed vessels (Laera et al., 2021). This application was also generally limited to anti-collision scenarios. As development continued, more anti-grounding elements were added to AR interfaces. Elements such as: heading, speed, waypoints and danger/warning/safe areas and applicability also started incorporating manned oceangoing vessels (Laera et al., 2021). AR also saw increased interest in routing through sea ice (Bergström et al., 2018; Frydenberg et al., 2021; Okazaki et al., 2017). The information incorporated on the AR interface was mainly limited to: speed, compass, route and dangerous areas. Takenaka et al. (2019) experimented more with the concept of collision avoidance, incorporating a compass with a collision danger area on an AR interface. AR developments in the maritime domain seem to therefore focus either on collision avoidance or vessel routing and either on remote high-speed craft or oceangoing manned vessels leading to different AR concepts.

A review of AR concepts, summarising their interface elements and technology readiness concluded that 63% of AR maritime solutions covered in the review are monoscopic, while 27% were stereoscopic (Laera et al., 2021). The author notes that development is seemingly moving away from monoscopic devices towards stereoscopic, and from MAR devices towards HMDs. Current systems also mainly use a hybrid frame of reference, combining both WR and SR frames of reference, followed by WR. Laera et al. (2021) comments that the relatively small amount of WR HMD AR solutions is most likely due to the difficulty in integrating legacy systems and technology limitations. In terms of interface aspects, most AR solutions include basic navigational information, such as: compass, heading, speed etc. Most also include anti-grounding information, route info etc. However, relatively few give traffic information (18%), showing that traffic situations in AR design are still relatively untested (Laera et al., 2021). In Laera`s review, the author points out that most AR solutions have been untested and that causes the technology readiness level (TRL) scores of most AR solutions in the maritime domain to be low (Laera et al., 2021).

A few experiments have tested the potential of AR in improving SA. A Maritime Augmented Reality System (MARS) was developed for remote vessel operation and the SA of operators tested. This study found that SA at certain levels seemed to improve by using AR, but that it also seemed to increase operator workload. Additionally, participants preferred using this AR interface over a regular interface (Hong et al., 2015). Crucially, the MARS was designed for remote operation, not for onboard operators. Another experiment investigating the relationship between AR and SA awareness researched how wearable augmented reality displays (WARDs) could assist maritime operators on the bridge in building SA (Rowen et al., 2019). Results seemed to suggest that while WARDs did increase SA they also increased workload and reduced operator performance, concluding that the main advantage of a WARD is unshackling the operator from a screen in situations where their mobility is necessary (Rowen et al., 2019). Both experimental studies concluded that the potential benefits of AR on SA in a remote operation or on-board scenario were apparent and that further research was needed in understanding the specific relationship between AR and SA to help designers and operators with AR (Hong et al., 2015; Rowen et al., 2019). While most AR solutions are still conceptual, several examples already exist within the maritime industry.

The maritime industry has begun to move forward with the adoption of AR and several commercial examples exist. Furuno Envision has developed a solution that superimposes an AR interface over a live video feed (Furuno, 2022). This system is limited, as it is immobile and not an HMD, additionally, being on a screen would most likely not decrease HDT. It seems to mainly assist the operator with linking what is happening outside, with the traditional systems inside. Mitsui O.S.K. Lines developed this concept with Furuno and is rolling this technology out to 24 VLCCs (MOL, 2021). Other industry examples mainly exist within this camera-based AR realm, but then focused on autonomous or remotely operated vessels. Camera AR-based examples that aim to support navigators include OrcaAI (2022) and SEA AI (2022), while examples such as Avikus (2022) and Sea Machines (2018) aim to use AR to assist remote operators and eventually lead to autonomous vessel AI. All these solutions are based on camera technology and present their information via a traditional live-camera feed display, but with a WR AR interface superimposed. Most of the AR solutions investigated by Laera et al. (2021) were at TRL 2. Which entails that they are at a very basic conceptual research level and must still go through experiments to be proven (Mankins, 1995). This underscores that the field of AR within the maritime domain is still very much in an early development phase.

3 Methodology

3.1 Research Questions and Variables

An overview of the RQs, variables and methods used is provided in Table 2 below:

Table 2 - Research questions and variables overview

Research Questions		Variables		Method
1	*What effect does an AR interface, in a maritime navigation setting, have on the situational awareness (SA), head-down time (HDT), head-down occurrences (HDO) and preference of an operator?*	IV	DV	Mixed
1.1	*What effect does an AR interface, in a maritime navigation setting, have on the SA of an operator ?*	Interface	SA	SAGAT
1.2	*What effect does an AR interface, in a bridge maritime navigation setting, have on the HDT of an operator ?*	Interface	HDT	Observation
1.3	*What effect does an AR interface, in a maritime navigation setting, have on the HDO of an operator?*	Interface	HDO	Observation
1.4	*Does an operator, in a maritime navigation setting, prefer an AR interface in addition to a radar in building SA?*	Interface	Preference	SA-SWORD
2	*Given the feedback of the participants, what, if any, improvements can be made to the OpenAR interface design?*	Exploratory		Semi-Structured Interview

3.1.1 Independent Variable

The independent variable (IV) throughout all of RQ1 is the interface used. The interface can either be a graphical user interface (GUI) covering a traditional maritime radar set-up with an outside bridge view. This outside bridge view would be presented with a 45-degree view off each side of the bow. Or it can include an additional AR interface overlayed on the outside bridge view. The addition of an AR interface in this sense is the IV throughout RQ1. Figure 5 shows an example.

3.1.2 Dependent Variables

There are multiple dependent variables within RQ1. These DVs are SA, HDT, HDO and preference. *SA* within RQ 1.1 is partly defined by Endsley's three-level SA model in chapter

2, represented by a measured SAGAT score, although SA in this experiment is limited to SA-1 and SA-2 due to the static nature of the scenarios. *HDT* (RQ 1.2) is defined as the total amount of time (in seconds) spent by a participant not viewing the outside bridge view. *HDO* (RQ 1.3) is defined by the total number of instances a participant looks away from the outside bridge view. *Preference* (RQ 1.4) is defined as the subjective measured preference of a participant on the inclusion of an AR interface on a self-reported scale.

3.2 Participants

Inclusion criteria required that participants have a basic skill as a navigator on the bridge. Namely, at a minimum, proficiency in the role of a lookout and interpretation of a radar system. In-depth navigational knowledge or practical seafaring experience was not deemed necessary, as anti-grounding or anti-collision analysis was not part of the experiment. From a high-level perspective, participants were required to be able to build a basic mental map of a vessel traffic situation, visually and using the radar and/or AR interface to build SA. Narrowing down to more specific requirements, participants were required to be able to:

1. Visually identify vessels and give a relative bearing.
2. Interpret a standard static radar screen.
3. Understand the meaning of the closest point of approach (CPA).
4. Be able to link vessels presented through the interface (AR and radar) with the visual representation.
5. Have a basic understanding of navigation and vessel traffic scenarios.

Consequently, licensed navigators fulfil these requirements. Nautical students were also deemed eligible according to their course syllabus, learning outcomes, and the knowledge and skills they currently possess within their program. Participant recruitment was accomplished via non-probability & snowball sampling. Participants consisted primarily of nautical students from a Norwegian maritime university, but also licenced seafarers from that university`s network. Table 3 & 4 gives an overview of the 17 participants recruited.

Table 3 - Participants' Demographics and Education

Sex		Age		Highest Education		Current Studies		Study Area	
Male	13	Mean	28	High School	9	2nd Year BSc	7	Nautical Science	13
Female	4	Median	24	University	5	3rd Year BSc	4	Other	2
				Diploma	3	Other	3	Not Studying	2
						Not studying	2		
						1st Year BSc	1		

Table 4 - Participant Experience

Lookout Exp		Radar Exp		Seafarer Exp		Years Exp		AR Exp		Years Exp	
Excellent	2	Excellent	3	Yes	10	Mean	7	Yes	3	Mean	1
Good	6	Good	6	No	7	Median	1.5	No	14	Median	1
Satisfactory	9	Satisfactory	7								
Poor	0	Poor	1								
None	0	None	0								

All participants gave informed consent before participating in the experiment and were informed that they could retract from the experiment at any time. Participants received a 100 NOK gift card upon completion of their experiment. The Norwegian Centre for Research Data (NSD) approved the data management plan before the experiment was conducted (NSD project no. 759997). All personal data was managed according to NSD regulations.

3.3 Experimental Design

The RQs were answered in a quasi-experimental setup, using mixed methods in a within-group design. The experiment is considered quasi due to the counter-balanced assignment of participants to both the control and experimental group, in addition to the lack of a pre/post-test. Participants were part of both the control and experimental group in this within-group set-up. All participants were exposed to all scenarios and both instances of the IV. Scenarios were counterbalanced using the Balanced Latin Square method to limit the order effects for each participant. Additionally, all instances of the DV were measured for all participants. Preceding the experiment, a demographic questionnaire was given to gain demographic and background information about the participant. Participants went through a familiarisation step, where the AR interface, experimental set-up and the experiment itself were explained. Multiple methods were used to measure the dependent variables and a mix of quantitative and qualitative data was gathered; the data collection methods are explained further in section 3.6.

3.4 Experimental Set-up

The experiment was conducted in an enclosed laboratory with no outside stimuli. The physical setup is shown below in Figure 3.

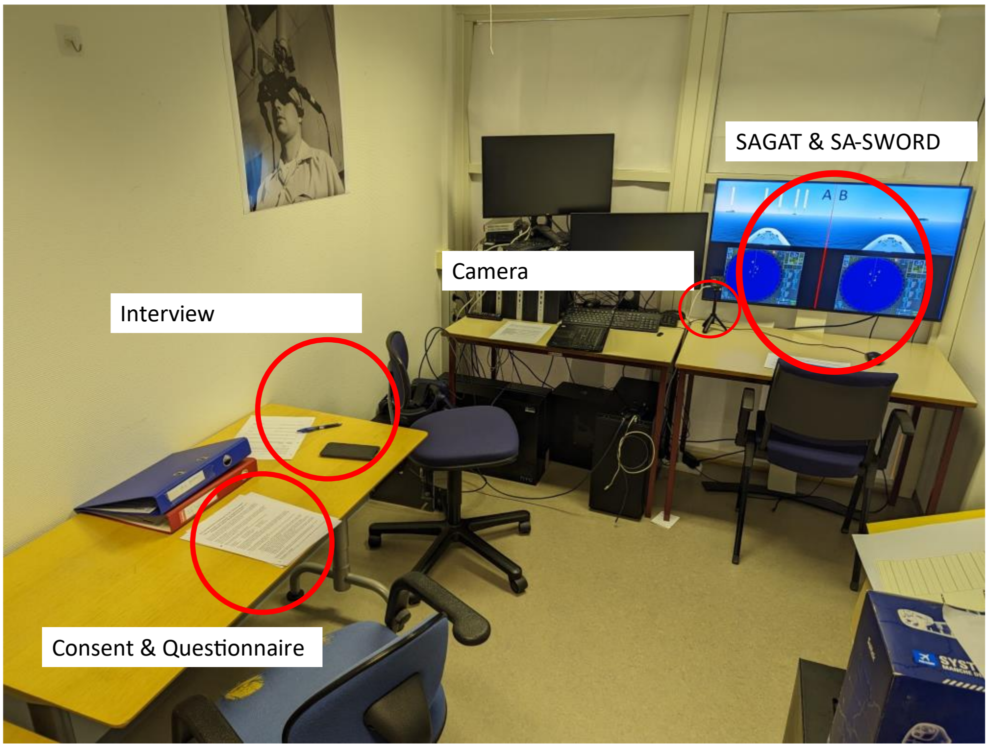

Figure 3 – Experimental Set-up

Observation was used to measure HDT & HDO and was a camera placed in a position to view participant head movement. A printout was used to represent a separate radar display. The demographic questionnaire and interview were conducted at a separate desk.

3.4.1 Hardware

The demographic questionnaire, SAGAT answer sheet, and SA-SWORD response sheet were conducted with pen and paper. A GoPro Black 8 was used to record video at 1080p/60fps, while a factory reset, and isolated Google Pixel 3 XL was used as the digital recording device for the interview. The SAGAT and SA-SWORD scenarios were presented on a 43" Samsung HD TV, with SAGAT radar screens presented in a binder on paper. The display was fed by a desktop PC with the following specs:

- Processor: Intel i7 4 GHZ
- RAM: 32 GB
- OS: Windows 10

All data, except audio and video recordings were collected on paper and later digitalised.

3.4.2 Software

- Microsoft Excel 365 and SPSS (v28) was used for data analysis
- Microsoft PowerPoint 2013 was used for displaying the SAGAT and SA-SWORD on the display
- Kongsberg K-Sim was used to develop the SAGAT and SA-SWORD scenarios
- The design software Figma was used to overlay the AR interface
- Interface artefacts were taken from the OpenAR project, developed by the OICL

3.5 Experimental Procedure

The experimental flow for a single participant is shown below in Figure 4.

Figure 4 - Experimental Flow

Initially, a short demographic questionnaire aiming to collect general participant demographic and background data, but primarily to check participant eligibility, was given. The experimental procedure, interface/set-up and two familiarisation (no AR & AR) traffic scenarios with practice SAGAT queries were then explained.

During the SAGAT phase, participants were exposed for 60 seconds, subsequent to results from a pilot study, to a sequential set of 12 paired static vessel traffic scenarios displayed on a screen. Each trial having either an outside bridge window view, with a separate radar interface from a popular manufacturer (control) or with an additional AR interface developed by the OICL, overlayed on the outside bridge view (experiment). After the designated 60 seconds the display would be blanked, and SA measured using a modified version of the Situation Awareness Global Assessment Technique (SAGAT) (Endsley, 1995b). The AR interface gave the same essential information as the radar, namely: target number, tCPA, CPA, distance, bearing, course, and speed. A paper printout of a static radar matching the vessel traffic scenario was used to simulate the radar and placed in such a physical position, as to emphasise any potential head movement in viewing the radar. Twelve unique scenarios were displayed. Six were defined as control scenarios without the additional AR interface, and six were experimental scenarios with the AR interface. These pairs of six had similar, but not identical traffic scenarios. Each scenario pair had between five and seven vessels; each vessel was uniquely identifiable visually. Scenario pairs also had the same vessel types. Scenarios were paired to minimise the effect of having different scenarios while reducing the participant learning effect. Participants were asked to build SA during the display of each scenario with their respective interface, for which they had 60 seconds. In the end, each participant was exposed to every scenario. During each of the twelve SAGAT trials, HDT & HDO were also measured using video recording. The SAGAT phase is illustrated further in Figure 6.

Following the SAGAT, participant preference in building SA, of each interface setup was measured using the Situation Awareness Subjective Workload Dominance (SA-SWORD) method (Vidullch et al., 1991). The scenario pairs, with and without the AR interface, were compared by the participant and rated on how well the interface assisted with building SA in terms of preference. Figure 7 illustrates this phase. A final semi-structured interview related to RQ2 aimed to explore the participant’s experience using the AR interface and qualitatively identify potential improvements for it. The following section will explain each data collection tool in more detail.

3.6 Data Collection Tools

3.6.1 Demographic Questionnaire

The demographic questionnaire consisted of nine multiple-choice questions, with five of the nine having an open choice for further explanation. Questions covered:

- Sex
- Age
- Education
- Work Experience
- AR Experience

A full text of the questionnaire can be found in appendix A.

3.6.2 SAGAT

The SAGAT is a method of measuring objective SA based on Endsley`s SA model. This method exposes participants to tailored scenarios where they build SA, a scenario may then freeze or end and the participant must answer SA tailored queries without aids based on the scenario (Stanton, 2013). Following this, the answers of the participant are compared with the correct answers, resulting in an SA score. This method has been reviewed and used extensively. While it has limitations, the SAGAT is well-validated (Endsley, 2021). The advantage of the SAGAT is that it naturally allows for static scenarios and measures objective SA. Participants are not asked what they consider their SA to be, rather, it is measured and quantified objectively. A full text of all SAGAT queries can be found in appendix B.

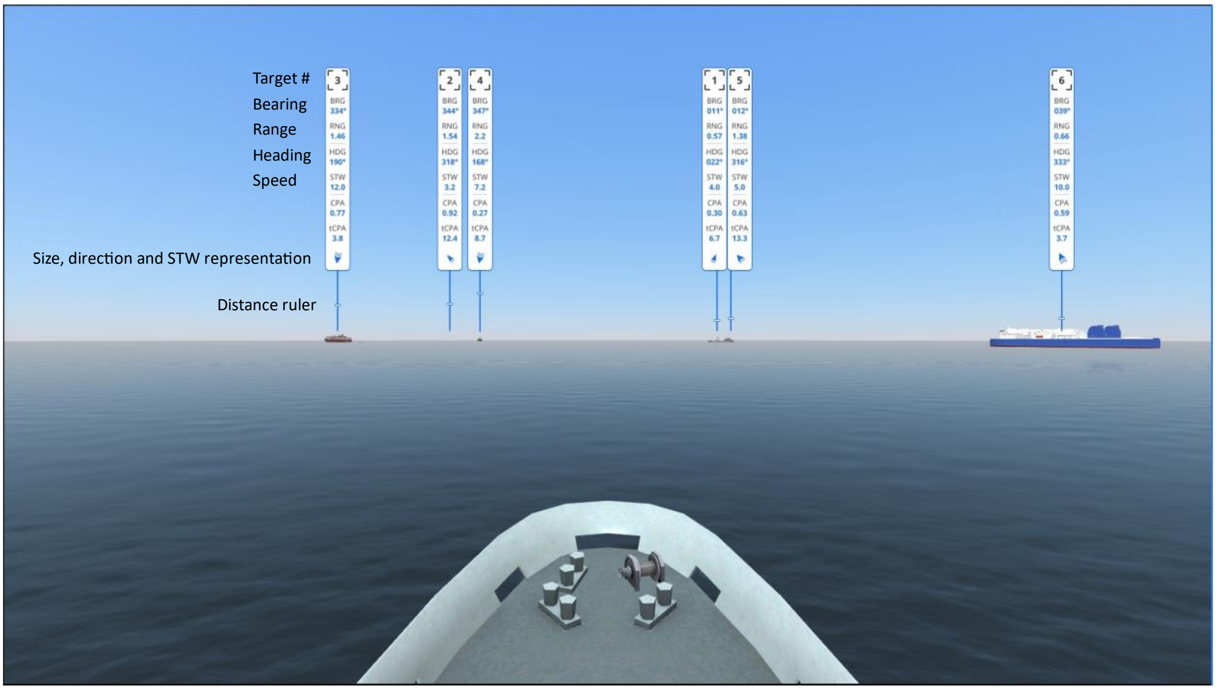

Figure 5 - AR Interface and Scenario Example

Measured SA was operationalised using Endsley`s three-level model, as defined in the SAGAT guidance (Stanton, 2013), namely, perception (SA-1), comprehension (SA-2) and projection (SA-3). However, due to the static nature of the scenarios and the relatively low fidelity of the experimental setup, only the perception and comprehension levels of SA were measured in this study. The SAGAT queries were consequently tailored to these two levels. This limitation is covered further in section 5.4.

Each of the twelve scenarios had one SAGAT query which was randomly selected for each participant from a pool of twelve queries. The SAGAT queries were applicable to each scenario, irrespective of the interface. However, four queries required visual SA (looking outside of the bridge), four required instrument SA (radar or AR interface) and four would require coordination between both instruments and visual. These choices were made to force participants to not only build SA, using their radar or AR interface but also visually. SAGAT query answers were binary, but the answer format could differ as long as the correct vessel or number of vessels was given. Correct answers to SAGAT queries could be given as:

1. Target #
2. Type of vessel
3. Relative bearing of vessel
4. Distance of vessel
5. Description of vessel position

Due to the random order of SAGAT queries, answers would also be unique to each trial and tailored appropriately. In the end, all participants were exposed to all 12 scenarios and 12 SAGAT queries, in random order and combination. The SAGAT queries and scenarios can be found in appendix B & C. Depending on the number of correctly answered questions, each participant was then given an objective SA score.

3.6.3 Head-down Time & Head-down Occurrences

During the SAGAT, HDT was measured by recording the participant using a GoPro. The radar screen printout was physically positioned in such a way that the participant was forced to physically look down to view the radar. The video recording was analysed post-hoc, overall HDT and HDO were measured manually. HDT was measured in terms of time (seconds) not viewing the outside bridge display and HDO was the number of instances the participant did not view that display. Eye contact away from the out-of-bridge view (the screen) was considered “head-down”. Participants were not informed that HDT & HDO would be measured to avoid bias to their movements.

Figure 6 - SAGAT with Camera Set-up and Paper Radar

3.6.4 SA-SWORD

To measure the preference of the participant over either the radar interface setup (control) or the setup with the AR interface (experiment), the SA-SWORD technique was used. The SA-SWORD was initially developed to measure the user preference for different interface artefacts assisting with building SA (Stanton, 2013). An example would be users choosing which of 2 displays offers them the best SA. This method is subjective and aims to strengthen the objective measurements (Stanton, 2013).

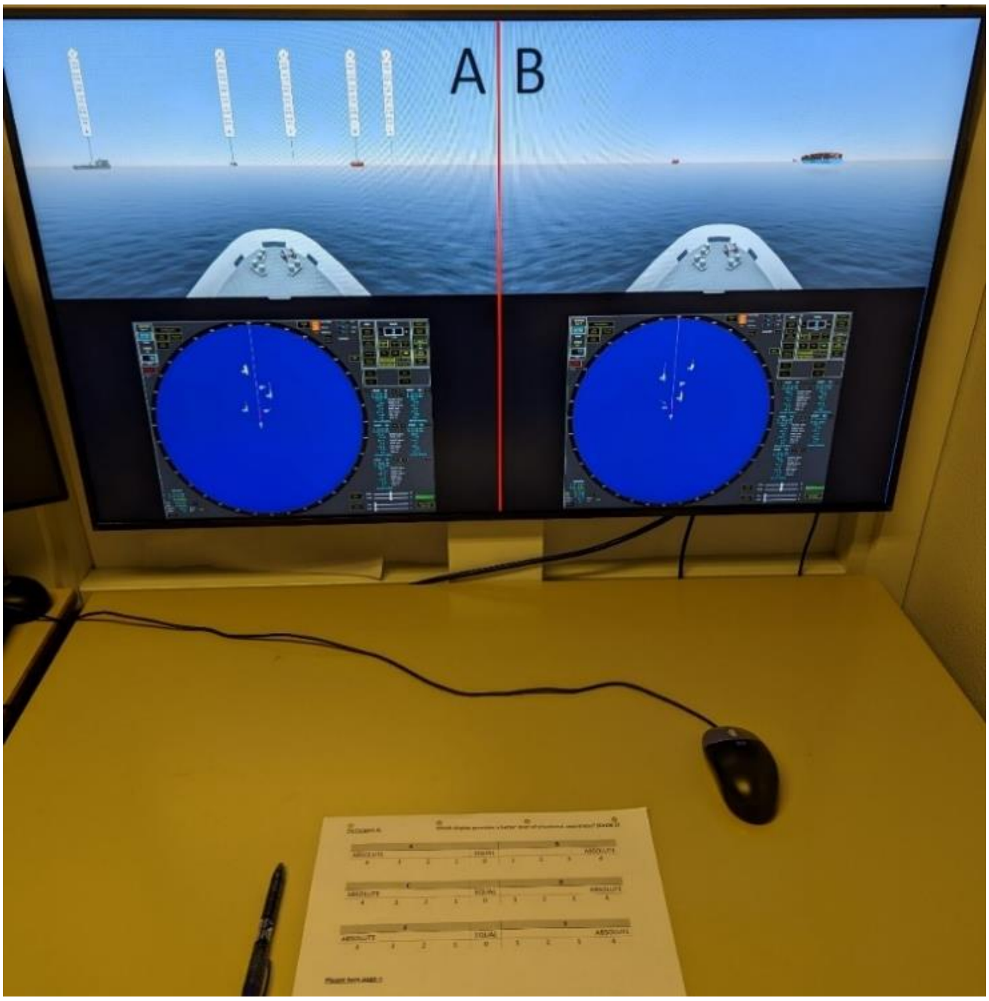

Figure 7 - SA-SWORD Set-up

In the SA-SWORD, scenarios are presented in a side-by-side comparison of both interface displays. The participant then rates each display on how well they assist with building SA. This was done for the six scenario pairs and the scores are added up, to give an overall preference score for the participant of either display. These scenarios were the same as those used in the SAGAT. An example of the SA-SWORD can be found in appendix D.

3.6.5 Semi-Structured Interview

The semi-structured interview was exploratory and had the goal of gathering qualitative data to explain the results of the SAGAT and SA-SWORD, in addition to answering RQ2. The interview lasted approximately 10 minutes, consisted of six questions, was audio recorded, and followed an interview guide. Questions were aimed at investigating the participant`s experience and identifying potential improvements to the AR interface. The full interview guide can be found in appendix E. Topics covered included:

- Participant experience of the experiment
- Participant opinion of the scenarios
- Participant opinion of the AR interface

3.7 Data Analysis

Table 5 summarises the gathered data and methods of analysis. Data collected included demographic data, SAGAT scores, HDT/HDO, SA-SWORD scores, and the qualitative results from the semi-structured interview. Demographic data was only used to control for participant background, but not analysed as a predictor variable.

Table 5 - Data Analysis Overview

RQs	Variables		Data	Analysis
	IV	DV		Parametric
RQ 1.1	Interface	SA	SAGAT Score	Paired Samples t-test
RQ 1.2	Interface	HDT	Total HDT (s)	Paired Samples t-test
RQ 1.3	Interface	HDO	Total HDO (n)	Paired Samples t-test
RQ 1.4	Interface	Pref.	SA-SWORD Score	Paired Samples t-test
RQ 2	Exploratory		Semi-Structured Interview	Thematic Analysis

All data for RQ1 were analysed using a Paired Samples t-test. Pairs being the paired control and experimental scenarios. For the SA-SWORD a positive score from a participant for one display would result in a score of zero for the other display, while a draw between the pair would result in a score of zero for both.

Qualitative data was thematical analysed following the framework of Braun & Clarke (2006). Semi-structured interviews were thematical analysed and responses coded according to the similarity, patterns, and relevance of responses. These coded excerpts were subsequently categorised, according to overlying themes and sub-themes.

4 Results

The following section will present the analysis of both the quantitative data from RQ1 and qualitative data from RQ2.

4.1 Research Question 1

A Paired Samples t-test was conducted using SPSS on the data from RQ1. All assumptions for both samples were met after testing for normality using the Shapiro-Wilk test using SPSS. The Shapiro-Wilk test was used due to the small sample size (n=17). Table 6 shows the results from the Paired Samples t-test.

Table 6 - Results of Paired Samples t-test

RQ	Variable	Shapiro-Wilk		Descriptive Statistics				Paired Samples t-test		
		Sig.	*Normal*		*Mean*	*N*	*Std. D*	*t*	*df*	*Two-Sided p*
1.1	SAGAT	0.092	Accept	EXP CONT	3.41 3.00	17 17	1.54 1.06	0.979	16	0.342
1.2	HDT	0.568	Accept	EXP CONT	82.18 219.03	17 17	42.62 55.89	-9.021	16	<0.001
1.3	HDO	0.995	Accept	EXP CONT	25.82 41.94	17 17	10.74 11.56	-5.344	16	<0.001
1.4	SA-SWORD	0.318	Accept	EXP CONT	13.59 0.47	17 17	4.68 1.23	10.793	16	<0.001

The results for each sub-RQ of RQ1 are presented below. Their corresponding boxplots in Figures 7-10 serve to visualise the overall data:

RQ1.1: What effect does an AR interface, in a maritime navigation setting, have on the SA of an operator? The t-test shows that the overall mean score from the EXP trials (3.41 SAGAT score) in the SAGAT was higher than the CONT trials (3.00 SAGAT score). Where a SAGAT score of 6 was the maximum score for both. A relatively low t-value (0.979) indicates a low level of difference in the results between EXP & CONT trials. The two-sided p-value of 0.342 did not pass the **α** value of 0.05, there was therefore no significant difference in the SAGAT results between EXP & CONT trials. Hence RQ1.1`s H_0 - *An AR interface has no effect on the SA of an operator, in a maritime navigation setting* is not rejected.

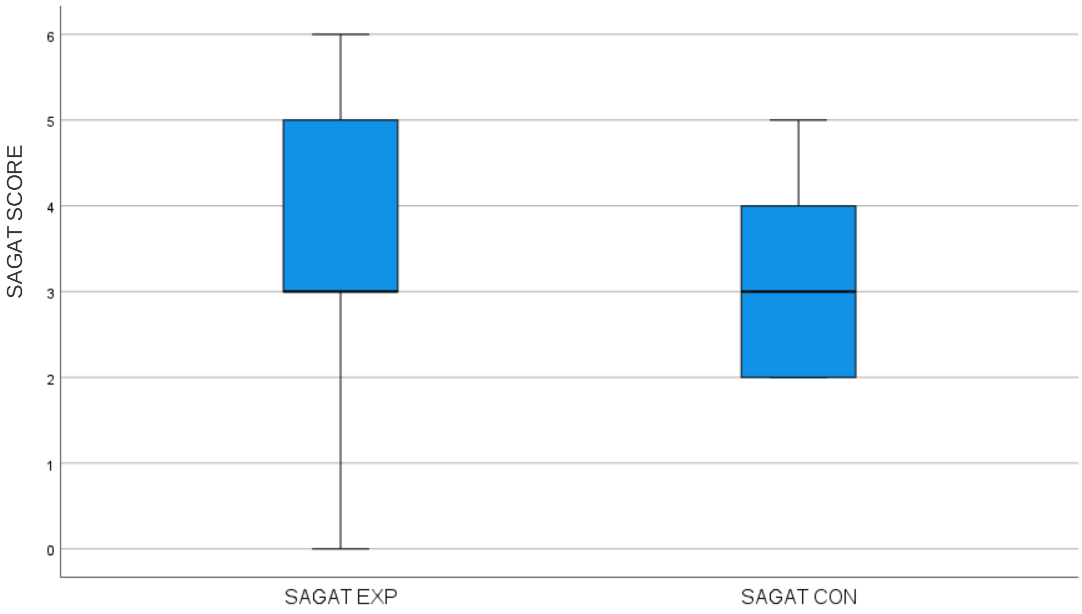

Figure 2 - Boxplot for RQ1.1

The Figure 7 boxplot for RQ1.1 shows the overall results from the SAGAT EXP and CONT trials, where SA was measured for both scenarios with and without an AR interface. It shows that while the median is the same for both groups, overall distribution is skewed more heavily towards a higher SAGAT score for the EXP trials, while the minimum and maximum scores are more extreme than for the CONT. The CONT trials have a more even and concentrated distribution with a minimum score of 2.

RQ1.2: What effect does an AR interface, in a bridge maritime navigation setting, have on the HDT of an operator? The t-test shows that the overall mean HDT from the EXP trials (82.18s) was lower than in the CONT trials (219.03s). Resulting in a 2.67-factor reduction in mean HDT for EXP trails compared to CONT trails. A relatively high t-value (-9.021) indicates a high level of difference in HDT between EXP & CONT trials. The two-sided p-value of <0.001 passed the **α** value of 0.05, there was, therefore, a significant difference in HDT between EXP & CONT trials. Hence RQ1.2`s H_0 - *An AR interface has no effect on the HDT of an operator, in a maritime navigation setting* is rejected.

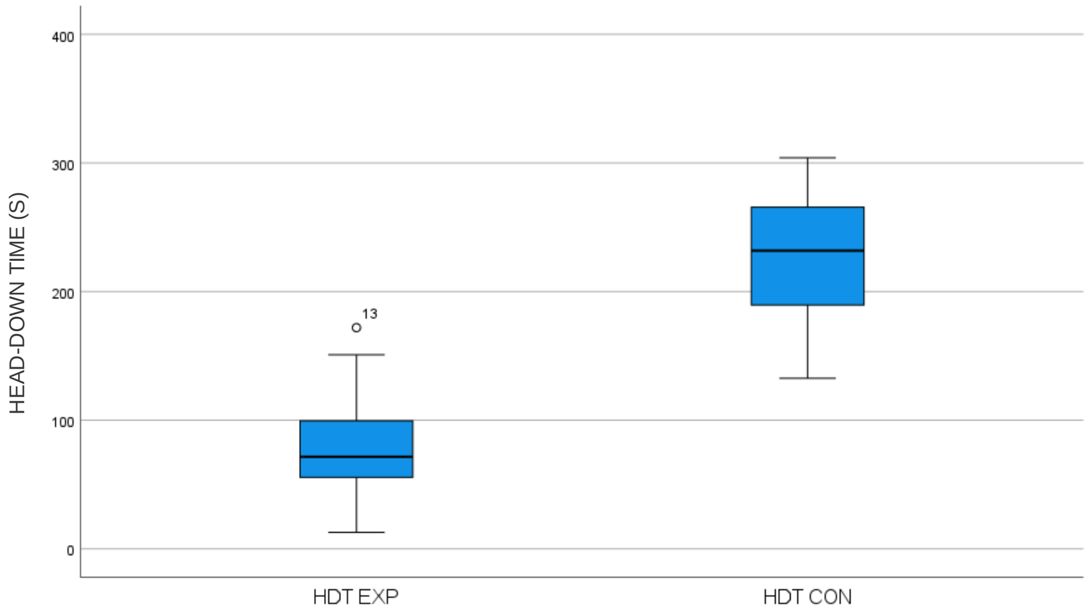

Figure 3 - Boxplot for RQ1.2

The Figure 8 boxplot for RQ1.2 shows the overall results for HDT in the EXP and CONT trials where total HDT was measured for both scenarios with and without an AR interface. It shows that the median HDT is lower for the EXP trials when compared to CONT trials. The overall distribution is visually similar for both groups.

RQ1.3: What effect does an AR interface, in a bridge maritime navigation setting, have on the HDO of an operator? The t-test shows that the overall mean HDO from the EXP trials (25.82) was lower than in the CONT trials (41.94). Resulting in a 1.62-factor reduction in mean HDO for EXP trails compared to CONT trails. A relatively medium t-value (-5.344) indicates a medium level of difference in HDO between EXP & CONT trials. The two-sided p-value of <0.001 passed the **α** value of 0.05, there was, therefore, a significant difference in HDO between EXP & CONT trials. Hence RQ1.3`s H_0 - *An AR interface has no effect on the HDO of an operator, in a maritime navigation setting* is rejected.

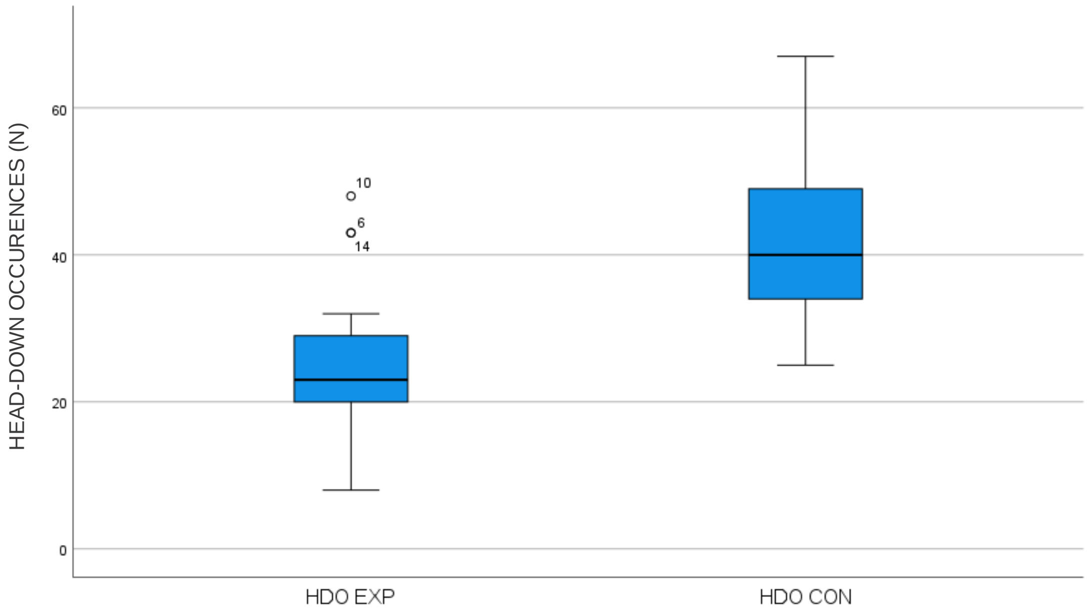

Figure 4 - Boxplot for RQ1.3

The Figure 9 boxplot for RQ1.3 shows the overall results for HDO in the EXP and CONT trials where total HDO were measured for both scenarios with and without an AR interface. It shows that the median HDO is lower for the EXP trials when compared to CONT trials. Overall distribution for the EXP trials is more concentrated than for the CONT, with CONT trials being more skewed towards the high end.

RQ1.4: Does an operator, in a maritime navigation setting, prefer an AR interface in addition to a radar in building SA? The t-test shows that the overall mean score from the EXP trials (13.59) in the SA-SWORD was higher than the CONT trials (0.47). Where 16 was the maximum score. A relatively high t-value (10.793) indicates a high level of difference in the results between EXP & CONT trials. The two-sided p-value of <0.001 passed the **α** value of 0.05, there was, therefore, a significant difference in the SA-SWORD results between EXP & CONT trials. Hence RQ1.4`s H_0 - *Operators, in a maritime navigation setting, do not prefer the use of an AR interface* is rejected.

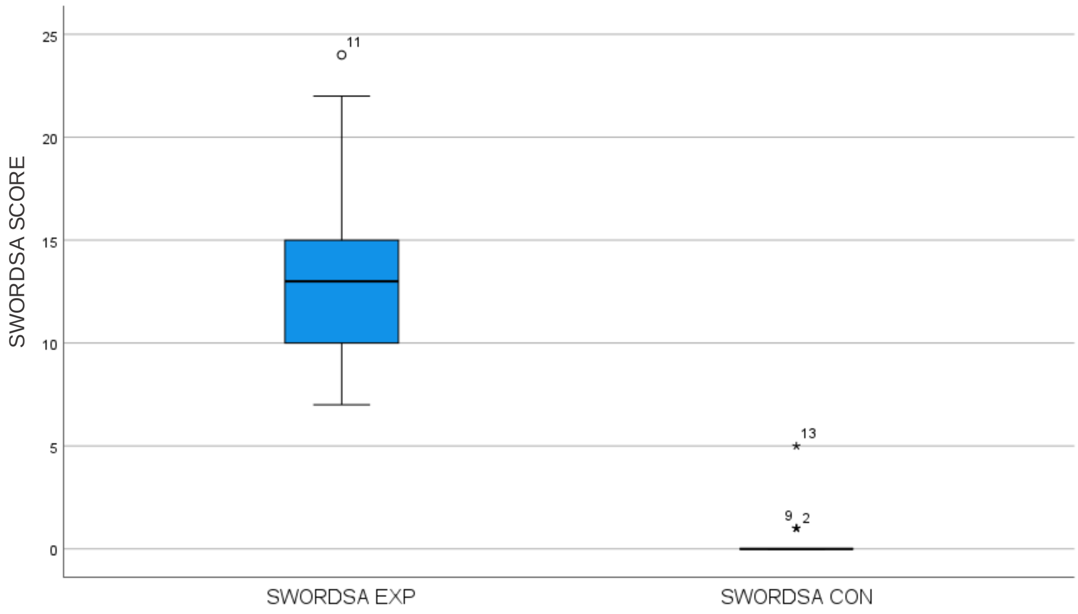

Figure 5 - Boxplot for RQ 1.4

The Figure 10 boxplot for RQ1.4 shows the overall results for the SA-SWORD for the EXP and CONT trials where preference scores were measured for compared scenarios with and without an AR interface. It shows that the median score is higher for the EXP trials when compared to the CONT trials. Overall distribution for the EXP trials is more spread than that for the CONT, with CONT trials being heavily skewed towards the low scores.

4.2 Research Question 2

The qualitative data resulting from the semi-structured interview was thematically analysed using the method of Braun and Clarke (2006) and aimed to answer RQ2. Three core themes were identified; namely Perceived Benefits, Expressed Concerns and Future Adoption, each with five sub-themes. Additionally, instances mentioned (N) of each sub-theme were identified to emphasise the importance of each specific sub-theme. Excerpts from participant interviews serve to illustrate each sub-theme. Themes, sub-themes and instances mentioned are highlighted in Table 7.

Table 7 - Thematic Analysis Results

RQ	Thematic Analysis Themes					
	Perceived Benefits	*N*	**Expressed Concerns**	*N*	**Future Adoption**	N
2	HDT	*10*	Clutter	*10*	Add Value	*17*
	Information Access	*8*	System Trust	*6*	Role of Radar	*10*
	Small Vessels	*5*	Vessel Concentration	*4*	Explaining Performance	*9*
	Situation Overview	*3*	Situation Overview	*3*	AR Improvements	*7*
	Radar/Visual	*3*	Crew	*3*	Training	*3*

Theme 1: Perceived Benefits

This theme is characterized by the benefits of the AR interface as perceived by the interviewees:

<u>HDT</u> - This sub-theme encompasses any comments made by participants concerning the benefit towards HDT when using AR. In total 10 of 17 participants mentioned a perceived improvement in HDT without prompting. Having information accessible on the outside bridge view influenced their HDT according to them. Participants noted:

- Participant 2 - “*It's nice to spend more time looking out to find your information than to look down.”*
- Participant 5 - *“You don't always have to look down at the radar screen. I don't like to look down because then you lose the vision outside, I like that.”*
- Participant 9 - *“You don't need to take your eye off the ship, so you can pay more attention to what's going on outside.”*

<u>Information Access</u> - This sub-theme highlights the perceived ease of accessing relevant information using AR. Eight of 17 participants expressed a perceived benefit in accessing relevant information due to AR.

- Participant 7 - *“It's quicker. It feels more, more efficient.”*
- Participant 9 - *“Easy access to the CPA, this is the most important part whenever getting with other ships, yeah, it's easy to spot.”*
- Participant 3 - *“With the AR interface, you can get vessels that have small vectors. You can, in the AR interface, see a lot clearer which way they are going.”*

Small Vessels - This sub-theme highlights the perceived benefit of detecting small vessels (sailing vessels & fishing vessels) while using AR. Five of 17 participants expressed a perceived benefit in detecting small vessels due to AR. Notably, the simple, clear labelling of a small vessel using AR meant it could be detected much easier.

- Participant 4 - *"If you're on the bridge and walking around, it's easier if you have the AR to spot smaller vessels or be aware that there are smaller vessels."*
- Participant 13 - *"It was a probably (a benefit) where you had smaller vessels, and you had the AR function sort of pointing towards that vessel."*
- Participant 9 - *"Sometimes it was easier to see a sailboat with the AR, but without the AR I had to look again at another ship and then finally find it, but with the AR it was right there".*

Situation Overview - This sub-theme highlights the perceived benefit of building a general overview of the situation using AR. Three of 17 participants expressed a perceived benefit in gaining a clear overview due to AR. Participants expressed AR's strength at long distances, but weakness at close distances.

- Participant 15 - *"Sometimes it can be hard to find (vessels) in the radar or see them outside, but with the AR, you can have a better view of them in a long long range."*
- Participant 6 - *"Because you were presented the information, you know, much clearer away for each target. Yeah, instead of having to move the cursor around on a radar screen and click it."*
- Participant 13 - *"It was really like awakening because I was like I didn't think it was possible to like see the CPA in the picture so that was really nice because I felt like I got control over the situation much faster."*

Radar/Visual - This sub-theme highlights the perceived ease of connecting radar targets with vessels "outside". Three of 17 participants expressed a perceived benefit in making the visual/radar connection using AR.

- Participant 1 - *"The AR was better when, like the ships were longer away and it was easier to identify the ships from the radar with the AR."*
- Participant 8 - *"It (AR) makes it easier to identify targets looking out of the window."*

- Participant 16 - *"I felt like you get a quicker overview. You have, you kind of need to spend less time analysing the situation."*

Theme 2: Expressed Concerns

This theme is characterized by concerns about the AR interface as perceived by the interviewees:

<u>Clutter</u> - This sub-theme encompasses any comments made by participants concerning the cluttering of the outside view when using AR. In total, 10 of 17 participants expressed concern at the perceived level of increased clutter when using AR.

- Participant 6 - *"Well, it was very good to have the information presented clearly, but after a while it got messy."*
- Participant 8 - *"I think it kind of clutters up the visual view and it provides information about every single vessel all of the time."*
- Participant 7 - *"Well, the bars were quite successful over each individual ship. But maybe they contained too much data. And combined too many decimals and, too much."*

<u>System Trust</u> - This sub-theme encompasses any perceived concerns regarding over-trusting the AR system. In total, 6 of 17 participants expressed some concern over the danger of an overreliance on AR.

- Participant 1 - *"You just get a locked situational awareness".*
- Participant 16 - *"That it could result in trusting that system more that could become more away from using the radar."*
- Participant 10 - *"So, my greatest concern is not getting the right information about all the dangers".*

<u>Vessel Concentration</u> - This sub-theme encompasses any concerns regarding high levels of vessel concentration when using the AR interface. In total, 4 of 17 participants were negative about the AR interface at the perceived level of increased vessel concentrations when using AR.

- Participant 4 - *"If it's a lot of vessels and like 2 vessels or more are close to each other, it can be, it can be confusing and too cluttered."*
- Participant 9 - *"Well, when the ships were closer it got kind of a little messy. It was easier, sometimes, with ships up close without the AR. And when ships were close together. The two bars were kind of merged."*
- Participant 5 - *"For example, if you have like six vessels upon your port side and midships maybe you can acquire one vessel you're interested in."*

<u>Situation Overview</u> - This sub-theme encompasses any perceived advantages of the radar regarding building a general overview of the situation. In total, 4 of 17 participants expressed some concern over the potential benefit of AR in this case.

- Participant 2 - *"When you look at the radar ... I felt like it was closer to me, like knowing which ship is which."*
- Participant 8 - *"I'm mostly just looking at the radar. I think it helps you that you can see all the traffic."*
- Participant 1 - *"With the AR, I was much more focused on the numbers."*

<u>Crew</u> - This sub-theme encompasses any concerns regarding inter-bridge crew communication while using AR. In total, 4 of 17 participants expressed concern about the AR interface due to the perceived negative impact it could have on bridge teamwork.

- Participant 7 - *"I'm also very sceptical about the communication with my bridge team. If all are wearing glasses, you cannot see each other in the eyes. Also, that must be a very high loss to ... communicate with the fellow bridge team and see their body language and that's a big part of it."*

Theme 3: Future Adoption

This theme is characterized by the future steps to be taken for the AR interface as expressed by the interviewees:

Add Value - This sub-theme encompasses if participants perceived the AR interface, overall, as a valuable addition to building SA. All participants said that the AR interface added value.

- Participant 7 - *"Yes. It could add value. If it is improved."*
- Participant 17 - *"I would use it if we had it on the bridge."*
- Participant 12 - *"Yeah absolutely. If that could be implemented, I would like to use it."*

Role of Radar - This sub-theme encompasses any comments made by participants regarding the future role of the traditional radar screen. In total, 10 of 17 participants commented on the future role of radar.

- Participant 8 - *"I don't think it can replace the radar. I think radar is at least, for me, works better because you get a top-down view of your surroundings."*
- Participant 14 - *"I find it sometimes it's good to have a clean view in the radar and work in the radar."*
- Participant 9 - *"Together (radar & AR), not replace".*

Explaining Performance - This sub-theme encompasses any justifications made by participants regarding their SAGAT score. In total, 9 of 17 participants attempted to justify their performance.

- Participant 4 - *"I didn't do so well in the situation awareness, the short-term memory."*
- Participant 14 - *"Automatically I was focused on the CPA and which vessel, I have to look out for and, and which vessel was red."*
- Participant 13 - *"I was tired of looking after things, and then it just, I just forgot everything when the screen was turned off."*

AR Improvements - This sub-theme encompasses any potential improvements that could be made to the AR interface. In total, 7 of 17 participants expressed the potential for additional improvements to the AR interface.

- Participant 6 - *"Some easy function to remove the extra information."*
- Participant 7 - *"What happens if we get fog, fog here and we lost the visual thing and we only use the radar?"*
- Participant 10 - *"(Control over) what type of information I would like to consume and what I would like to not be even presented to me."*

Training - This sub-theme encompasses any mention of the need to train future seafarers in the use of AR. In total, 3 of 17 participants expressed the need for additional training in AR use.

- Participant 17 - *"So, in the in the beginning you know I use so much time just to find out where I have to look. Yeah, find the information I'm looking for and but that's like have you used this for a month on the sea you know exactly where you look to find it."*
- Participant 14 - *"I think it's a practice thing. If we have been used to looking of that kind of layout."*
- Participant 14 - *"That it was, that you're not used to it since you're just so used to using the radar and you get all the info that you need, and you're trained to read situation out of a radar screen."*

5 Discussion

5.1 Key Findings

RQ1.1 aimed to investigate the effect an AR interface could have on the SA of an operator in a maritime navigation setting. This study found that while participants had, on average, a higher SA score with AR than without, this was not significant.

RQ1.2 aimed to investigate the effect an AR interface could have on the HDT of an operator in a maritime navigation setting. This study found that participants had a significantly lower HDT with AR than without.

RQ1.3 aimed to investigate the effect an AR interface could have on the HDO of an operator in a maritime navigation setting. This study found that participants had a significantly lower level of HDO with AR than without.

RQ1.4 aimed to investigate the effect an AR interface could have on the preference of an operator in a maritime navigation setting to use AR in addition to radar. This study found that participants significantly preferred the use of an AR interface in building SA over purely using radar.

RQ2 was exploratory in nature and aimed to investigate potential improvements to the AR interface and explain the results of RQ1:

- The AR interface caused participants to perceive a benefit in HDT reduction, ability to detect smaller vessels, access information, connect radar targets with visual targets and gain a quick overview of the traffic situation.
- The AR interface caused participants to express concern regarding an increase in visual clutter, reduction in the situation overview, reduction in usability when vessels were concentrated, possibility of overtrusting the interface and reduction in crew interoperability in its use.
- Participants mentioned that the AR interface adds value, is an addition not a replacement to the radar and felt like it improved performance. However, future specific improvements to the interface should be made and users trained in its usage.

5.2 Contributions to Literature

This study contributes to the academic literature by, firstly, providing an alternative finding compared to recent studies specifically covering the maritime domain. Regarding the effect of an AR interface on the SA of a user, recent relevant studies, such as that of Rowen et al. (2019), concluded that SA was significantly improved upon using a Wearable AR Device (WARD). Both in terms of SA-1 (perception) and SA-2 (comprehension), this SA improvement was explained by the ability of users to move around the bridge using WARD while in a dynamic scenario (in contrast to the static onscreen experimental design of this study). Studies using an onscreen AR interface, like in this study, found that while SA-3 (projection) significantly improved with AR, there was no significance found for SA-1 & 2 (Hong et al., 2015). This latter study aligns more with the findings of this study and highlights that the addition of an AR interface in a maritime navigation setting may affect levels of SA differently, depending on the type of interface and scenario. Furthermore, AR used in vessel traffic scenarios, in conjunction with navigation tasks, seems to require a different AR interface/hardware than when used for pure traffic scenarios, as different levels of SA are affected.

All participants expressed the added value of an AR interface on SA building, but some expressed the need for improvements and training in its use. When compared to other domains a HMD utilising an AR interface, has been shown to improve pilots` self-reported overall SA within aviation, especially in visually degraded circumstances, such as fog (Walko & Schuchardt, 2021). Within road transport, an AR interface has been shown to give mixed results regarding SA: AR generally seemed to improve SA at all levels, but this improvement was very dependent on the interface used and scenario SA type measured (Kim & Gabbard, 2022) (Cheng et al., 2023). An additional study investigating the effect of an AR-HUD on the ability of a driver to identify a dangerous situation showed that SA was significantly improved during night driving, compared to daylight driving, where this improvement was not significant. Thereby highlighting the different effects AR can have on SA dependent on visibility circumstances (Cheng et al., 2023). This study shows that there is insufficient evidence to show that AR significantly affects SA. More research is needed to investigate its specific effect using different AR technologies and scenario SA types.

Secondly, this study demonstrates the effect of an AR interface on HDT & HDO within the maritime domain. Only one previous study, from 2011, focused on this effect in a maritime setting, however, this 2011 study utilised a HUD instead of an AR interface and the data it collected on HDT was based on subjective user experiences using the HUD (Holder & Pecota, 2011). This study objectively measured HDT & HDO and found a significant reduction in both when using AR. Participants expressed a noticeable benefit in HDT reduction and gained an increased positive user experience when building SA due to this reduction in HDT & HDO, concurring with Holder & Pecota (2011). The reduction in HDT & HDO was due to the presentation of relevant information in the same field of view as the vessel traffic scenario. This reduction of HDT & HDO suggests areas of potential performance improvements for users in specific use cases. This effect has been proven in various studies in the field of aviation (Prinzel & Risser, 2004), but has now also been demonstrated in the maritime domain. Studies researching HMDs in the medical field concurred that its addition reduced HDT, but not HDO. The magnitude of this HDT reduction was also much smaller than what was shown in this study, perhaps underlining the domain-specific effect of AR on HDT & HDO (D. Liu et al., 2010). Studies within transportation, but outside the maritime domain found that the addition of a HUD for automobiles reduced HDT, but also improved the performance of specific tasks requiring a quick reaction time (Y.-C. Liu & Wen, 2004). Thereby suggesting that a reduction in HDT & HDO in the maritime domain, while not concretely improving SA, may lead to improvements in the performance of other tasks that require a quick reaction time or increased user focus. Such as mooring, DP, small boat launching and helicopter operations.

Thirdly, this study shows that users prefer the use of an AR interface addition, concerning building SA, thereby contributing to the academic consensus. Previous relevant studies namely suggest a similar relationship i.e. that operators appreciate the addition of an AR interface and thereby perceive a self-reported benefit in its use (Rowen et al., 2019). This preference is reflected within the aviation domain as well, where pilots preferred the addition of AR (Walko & Schuchardt, 2021). However, it is clear from the qualitative data that participants have mixed reasons for preferring the AR interface and that in some scenarios, especially those where vessel concentrations and traffic numbers were high, users preferred not to have the AR interface. Users seemed to prefer the addition of an AR interface simply by the fact that it gave easier access to additional information, but acknowledged the potential risk of increasing user workload in certain scenarios, as suggested in previous studies (Rowen et al., 2019). A way to combat potential over-cluttering or information overload is a way for users to customise the information shown and have control over the information being displayed.

Lastly, findings from the post-experiment interview give some explanation of the quantitative results. The effect of an AR interface seems to heavily depend on its design and the scenarios users are presented with. AR seems to perform best as an addition to the radar instead of replacing it completely, with AR being perceived as being the most beneficial in specific circumstances, such as for detecting small vessels or quicker/easier access to information. As for the traditional radar, it was reported to be preferred when users required a top-down view or general overview of vessels. While measuring overall SA is useful, the addition of an AR interface could have a more nuanced effect that has yet to be investigated, potentially revealing very specific use cases. In terms of technology acceptance, this study concurs with other studies within aviation, medical and road transport, showing that users seem willing to use an AR interface if possible (Walko & Schuchardt, 2021; D. Liu et al., 2010; Cheng et al., 2023). Within road transport specifically, Cheng et al (2023) found that this was dependent on gender and driving experience, concurring with Rowen et al (2019), in the maritime domain. Within these domains, studies give mixed results on the type of hardware used, with some studies suggesting that a HMD was heavy and cumbersome (D. Liu et al., 2010), while other studies reported no issues. This difference suggests research could be done on the ergonomics of HMD vs. AR-HUD, especially due to the movement of navigators on the bridge (Rowen et al., 2019). Findings also contribute to highlighting improvements in designing an AR system to assist with building SA through the feedback of participants, as suggested by Woodward and Ruiz (2022).

5.3 Implications for Industry

The findings from this study have relevance to AR interface developers and can serve to help direct its advancement from its current early concept phase. A key implication for developers is that, while the effect of AR on SA is debatable, its effect on HDT & HDO is clear. Bridge navigation equipment providers that aim to significantly reduce both HDT & HDO within maritime navigation should aim to introduce an AR interface tailored to its specific use case. Interview findings showed potential improvements to the AR interface that should be considered by AR interface developers:

- Ability to differentiate vessels that overlap in the AR interface
- Ability to dynamically dismiss and call up information
- Ability to give a top-down radar view on request

- Transparency in showing the accuracy of information and detection
- Ability to communicate with other bridge members using the AR interface when using a WARD, potentially using the AR interface to communicate and interact

Most improvements aim to reduce clutter, improve user customisability, and add more radar-specific advantages. The industry should also develop a training programme for users in tandem with the interface itself so that potential users can get the maximum benefit from the interface. This training should be consistent and integrated within existing STCW regulations (IMO, 2011). Developers should use future AR regulations to tailor training courses to their specific AR solution. The potential introduction of AR solutions into the industry could also bring about other risks and concerns, such as the introduction of an additional avenue for cyber-attacks through the usage of third-party hardware and software. The requirement for redundant systems onboard must also be applied to AR solutions, increasing complexity (IMO, 2021). The overall positivity towards the AR interface expressed by the participants shows that an AR interface would be utilised by users and is considered to add value overall.

5.4 Limitations

The methodology used has some limitations. Participant recruitment proved difficult and thereby explains the low sample size, which limits data reliability. Further limitations consist of the basic experimental set-up and the use of a computer screen and printout to simulate a bridge environment, which limits validity. The use of static vessel traffic scenarios and a static AR interface instead of dynamic scenarios also limits validity. An additional limitation was in the development of the SAGAT. The SAGAT is aimed at measuring the three-level model of SA, while, due to the limitations presented by static scenarios, this methodology only measured SA-1 & SA-2. This limits the results from showing the effect of AR on each distinct level. The scenarios themselves were a limitation, as they focused on pure vessel traffic scenarios and not general navigation or anti-grounding. Additionally, the scenarios were all in daylight with good visibility, thereby not showing the potential effect of darkness or poor visibility concerning SA use. Using a video camera to measure HDT limits the measurement of the participant`s gaze. It only allows for broad head-up or head-down measurement, but finer details of which interface area is of interest to the participant are missed. It also adds the possibility for error in the analysis of the raw video data as subtle eye movements may have been missed. Eye-tracking technology could be an alternative option for more accurate and detailed eye movements and gaze patterns.

5.5 Future Research

Future research should utilise dynamic, high-fidelity vessel traffic scenarios with a 360° field of view, which would add validity to any results aimed at measuring SA. Dynamic scenarios would also allow for a SAGAT to measure the specific SA levels, such as SA-3. Greater variation in scenarios, testing for route-tracking, anti-grounding and night/poor visibility navigation would ameliorate this area of research. Additionally, future research should compare the effect of different hardware solutions, such as HMDs vs screen-based solutions, for an AR interface on SA, and the different effects of AR interface design artefacts on vessel traffic and anti-grounding navigation. Using gaze tracking technology to investigate the finer points of HDT/HDO would perhaps shed light on the specific effect of different AR artefacts. Research should be conducted on exploring potential future improvements to AR interfaces, as AR interface design is still in its infancy. Regarding participant concerns, future research could also investigate the effect of WARDs or HMDs on intra-crew interaction, shared cognition and teamwork. Thereby perhaps also focusing on different SA facets, such as TSA and DSA. Changing the domain of AR testing, to focus on, for example, remote control centres could also prove an area worthy of research.

6 Conclusion

This study aimed to investigate the effect of an AR interface on the SA of participants in a maritime navigational setting, in addition to exploring potential improvements. This aim was split into two research questions. One focused on SA, split into SA, HDT, HDO and preference, whilst the other research question was more exploratory in nature. A mixed-methods approach was used to collect quantitative and qualitative data from 17 participants with a basic nautical background. A SAGAT was used to measure the SA, and observation to measure the HDT and HDO of participants, while exposed to 12 randomised vessel traffic scenarios with and without an AR interface. An SA-SWORD was used to measure preference, while a post-experiment interview was used to gather the qualitative data for RQ2. The experiment found that the addition of an AR interface did not have a significant effect on participant SA, while HDT and HDO were significantly reduced. Participants preferred the addition of the AR interface. The findings resulting from RQ2`s interview gave multiple insights into the use of AR on the bridge and enabled the identification of potential improvements and concerns related to the interface and the use of AR in general. In conclusion, AR seems to have a mixed effect on different levels of SA, depending on interface design, hardware, and use-case, when compared to other studies. AR’s reduction on HDT & HDO is clear and should be applied to specific maritime tasks requiring increased focus. Users prefer the addition of an AR interface and are positive towards adoption but acknowledge that improvements can still be made.

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8 Appendices

8.1 Appendix A – Demographic Questionnaire

Demographic Questionnaire 7-11-2022

Participant Name: **Participant # (leave blank):**

1. Sex:
   - Male ☐
   - Female ☐
   - Rather not say ☐
2. Age:
3. Highest attained education level:
   - High school ☐
   - Diploma (Fagbrev) ☐
   - University degree ☐
   - Other ☐ _______________
4. Current studies:
   - Not studying ☐
   - 1st year BSc ☐
   - 2nd year BSc ☐
   - 3rd year BSc ☐
   - Other ☐ _______________
5. Study area:
   - Not studying ☐
   - Nautical Science ☐
   - Engineering ☐
   - Other ☐ _______________
6. How would you rate your skill level as a bridge lookout?
   - None ☐
   - Poor ☐
   - Satisfactory ☐
   - Good ☐
   - Excellent ☐
7. How would you rate your skill level with a navigational radar?
   - None ☐
   - Poor ☐
   - Satisfactory ☐
   - Good ☐
   - Excellent ☐
8. Do you have work experience as a seafarer on the bridge?
   - Yes ☐
   - No ☐

   If yes,

   Years of experience _______ Rank _____________

Please turn page

Koen Houweling Demographic Questionnaire 07-11-2022

9. Do you have experience using augmented reality?
   - Yes ☐
   - No ☐

   If yes,

   Years of experience _______

8.2 Appendix B – SAGAT Queries

SAGAT Queries 31/01/2023

The SAGAT

<u>Participant #:</u>

During the experiment, quantitative data determining the objective SA of the participants will be measured via a SAGAT. At the end of each (timed) trial, all aids will be turned off or made unavailable. This will entail the “freeze”, during the “freeze” the participant will be asked a randomly selected, but unique query from a set of 12 queries. Queries and answers will be given orally.

The Queries

Queries are split into those where SA can be gained solely from radar, visual or both.

Order	Query	Scen.	Given Ans	Correct Ans	Score
	Familiarization				
-	How many vessels are there?	**RA**		**7**	
-	Which vessels are sailing south?	**AR**		**2**	
	Visual				
	Which vessel is a sailboat?				
	Which vessel is a warship?				
	Which vessel is blue?				
	Which vessel is red?				
	Radar				
	Which vessel has the highest speed?				
	Which vessel has the lowest speed?				
	Which vessel has the smallest CPA?				
	Which vessel has the largest CPA?				
	Both				
	Which vessel is closest?				
	Which vessel is the furthest?				
	How many vessels are on our portside?				
	How many vessels are on our starboard side?				

Scenario Type	# Correct Given Answers (max 6 per type)
Experimental – AR (Scenarios: A, C, E, G, I, K)	
Control – Radar (Scenarios: B, D, F, H, J, L)	

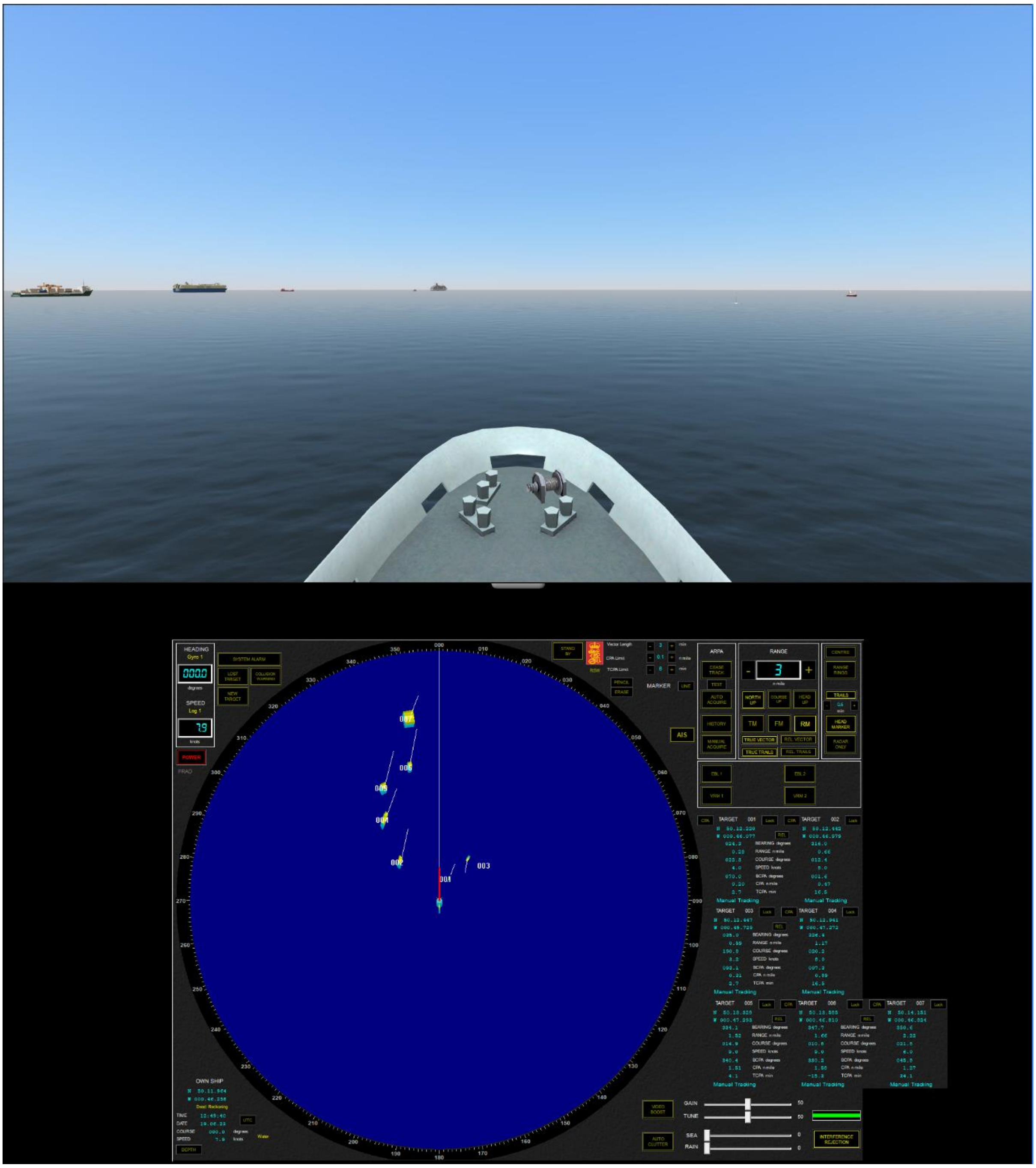
Balanced Latin Square Generator

Number of conditions / Square size 12

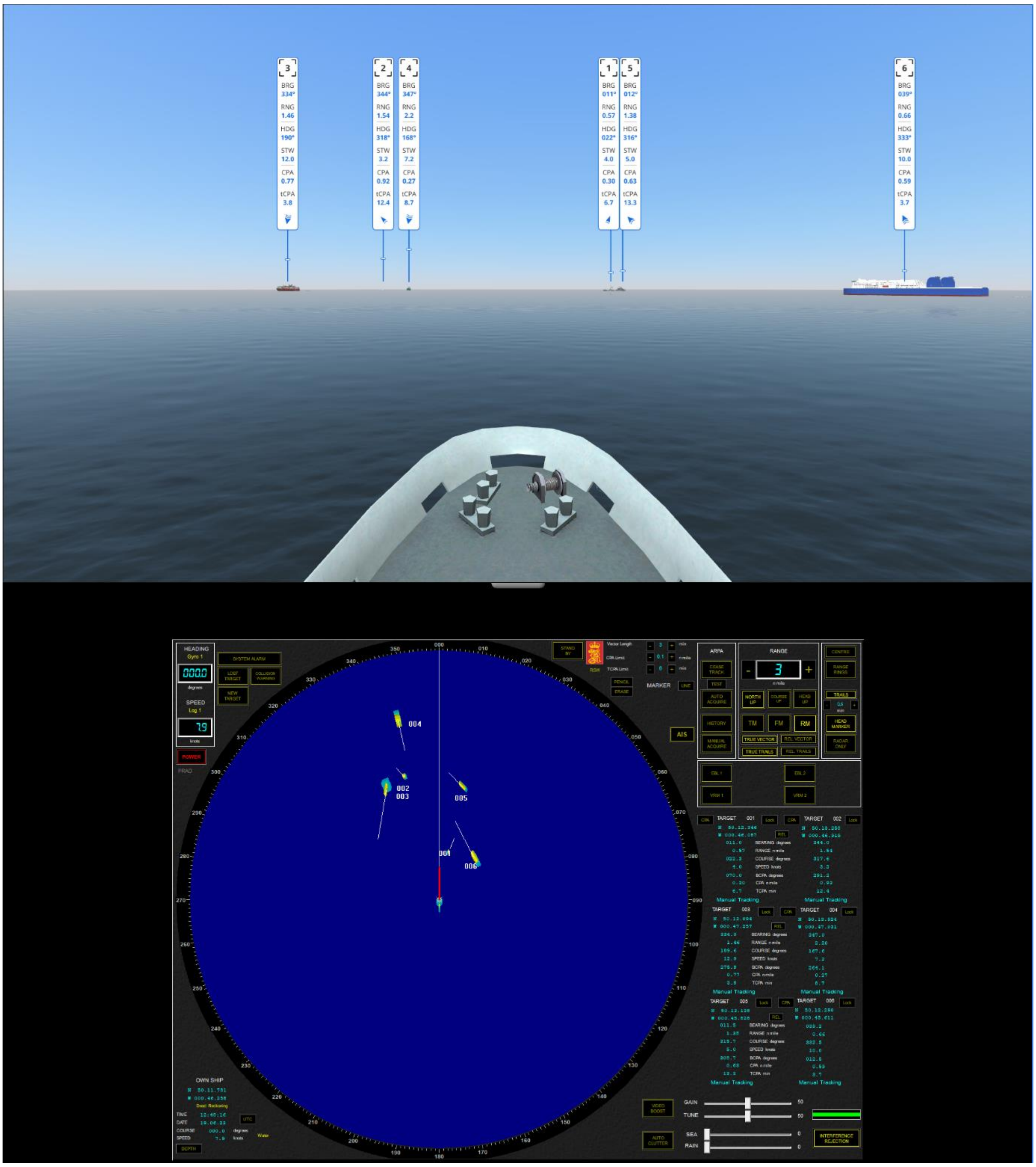
	1	2	3	4	5	6	7	8	9	10	11	12
1	A	B	L	C	K	D	J	E	I	F	H	G
2	B	C	A	D	L	E	K	F	J	G	I	H
3	C	D	B	E	A	F	L	G	K	H	J	I
4	D	E	C	F	B	G	A	H	L	I	K	J
5	E	F	D	G	C	H	B	I	A	J	L	K
6	F	G	E	H	D	I	C	J	B	K	A	L
7	G	H	F	I	E	J	D	K	C	L	B	A
8	H	I	G	J	F	K	E	L	D	A	C	B
9	I	J	H	K	G	L	F	A	E	B	D	C
10	J	K	I	L	H	A	G	B	F	C	E	D
11	K	L	J	A	I	B	H	C	G	D	F	E
12	L	A	K	B	J	C	I	D	H	E	G	F

8.3 Appendix C – SAGAT Scenarios

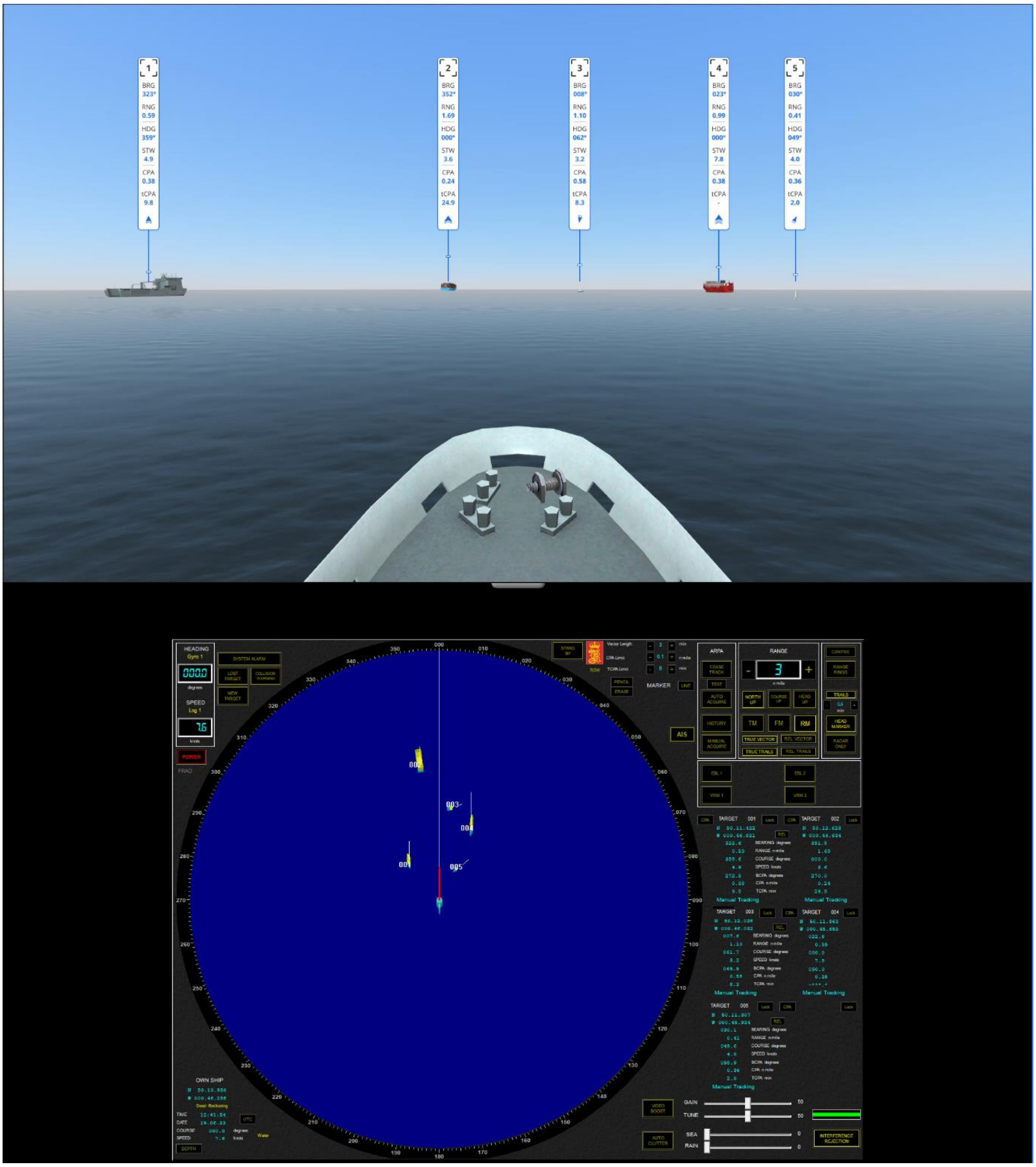
Familiarisation 1



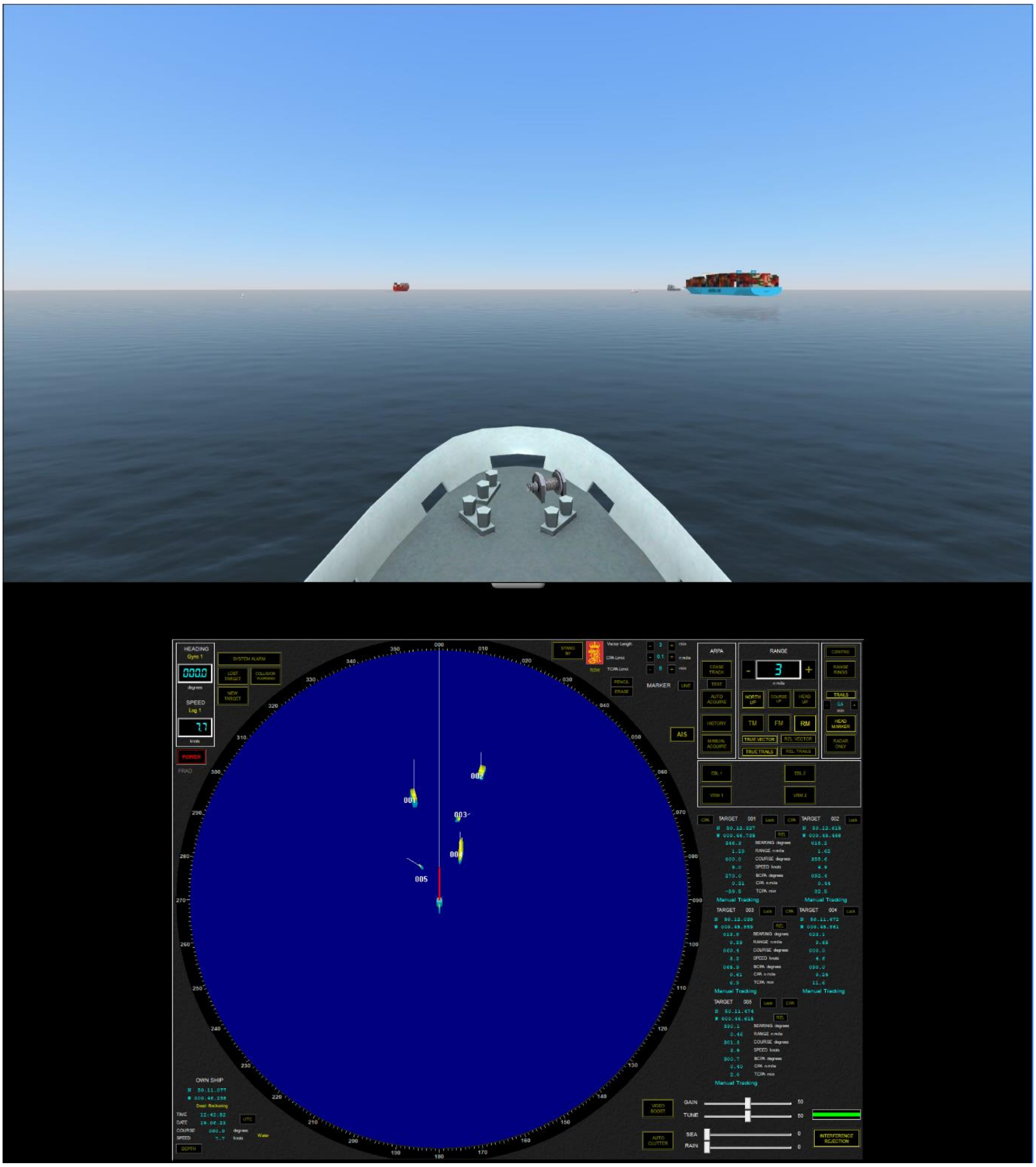
Familiarisation 2



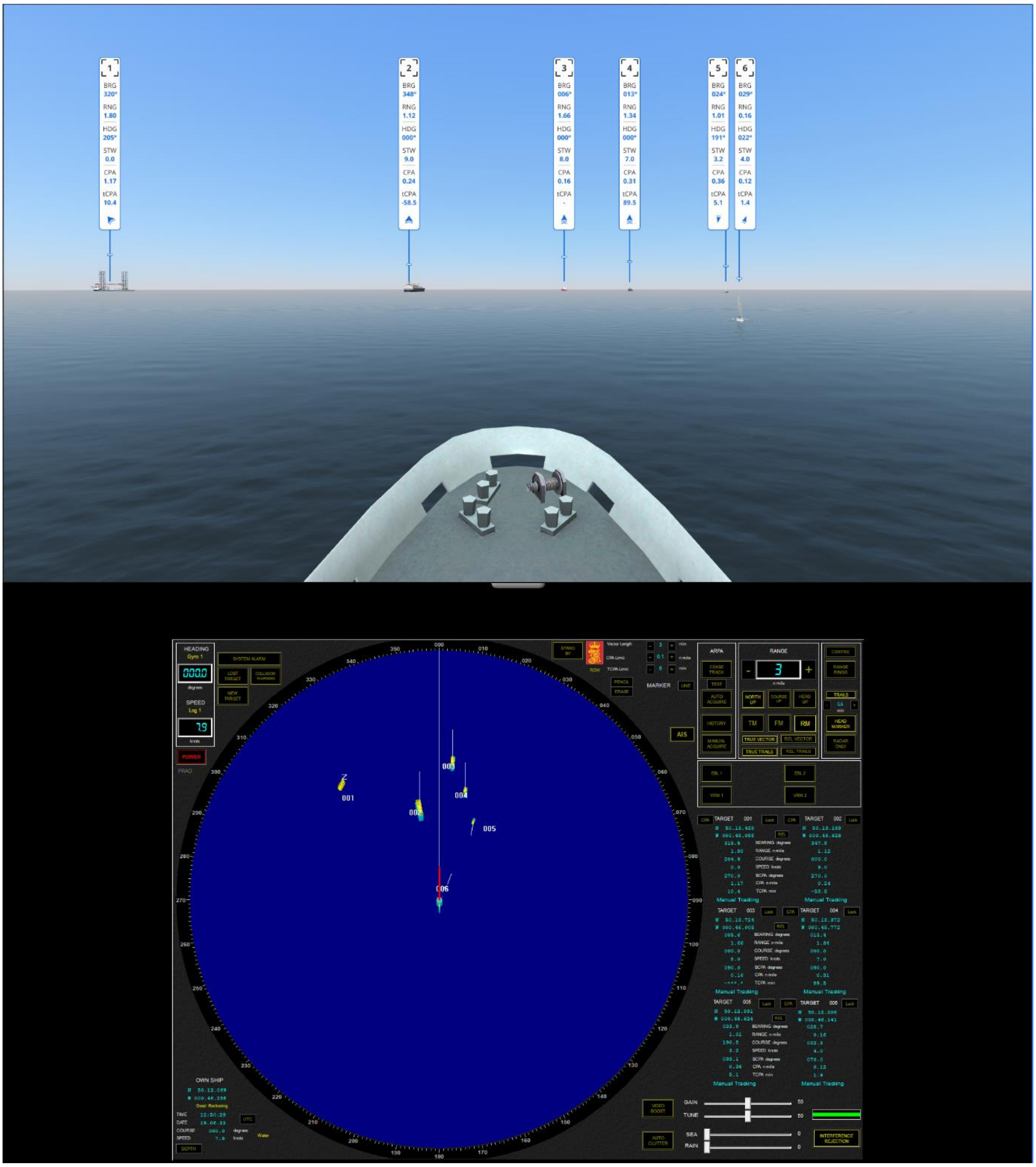
Scenario A



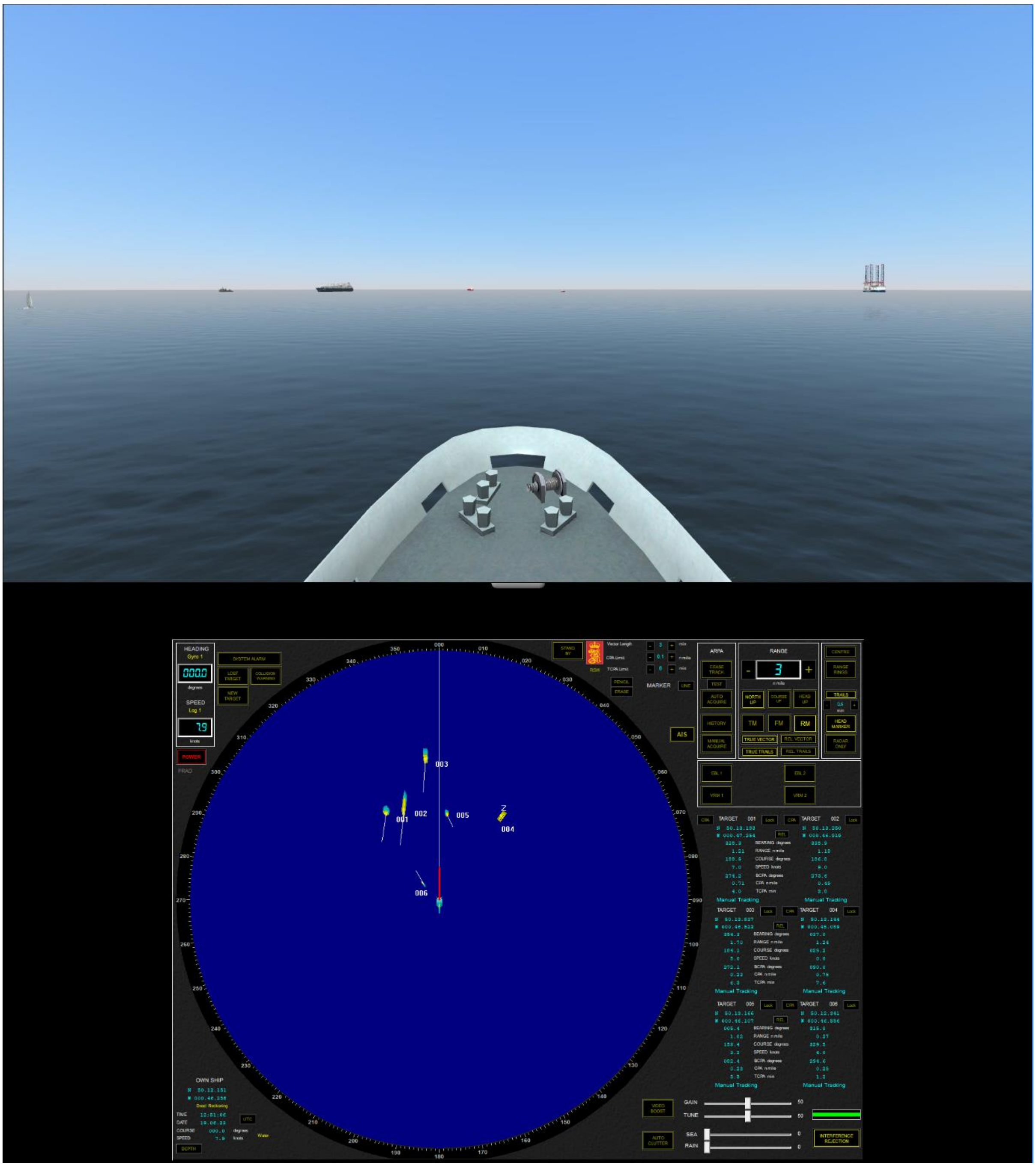
Scenario B


HEADING
SPEED
POWER
MARKER
AIS
ARPA
RANGE
TM
FM
RM
OWN SHIP
GAIN
TUNE
SEA
RAIN

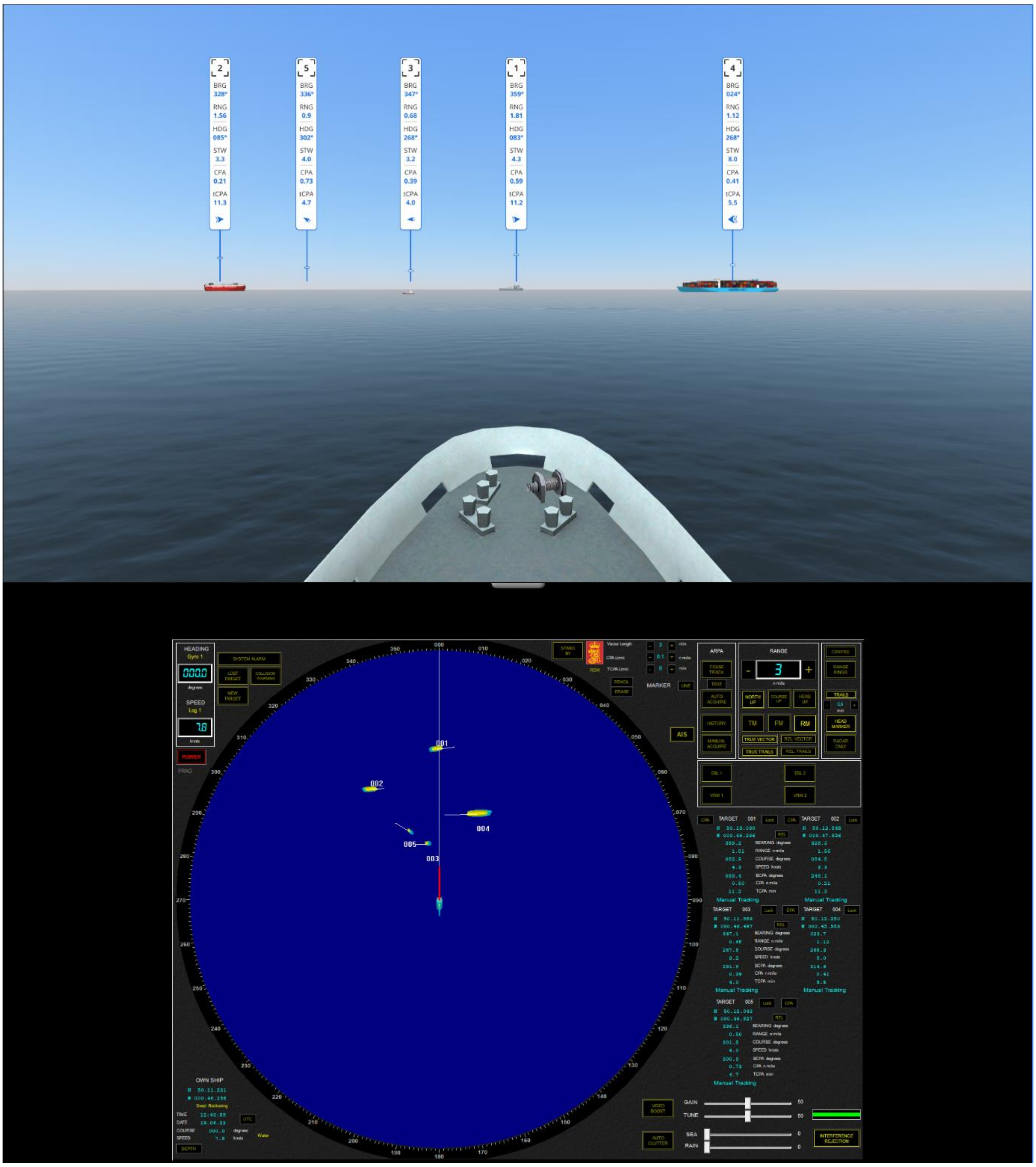
Scenario C


1
BRG 320°
RNG 1.80
HDG 205°
STW 0.0
CPA 1.17
tCPA 10.4
2
BRG 348°
RNG 1.12
HDG 000°
STW 9.0
CPA 0.24
tCPA -58.5
3
BRG 006°
RNG 1.66
HDG 000°
STW 8.0
CPA 0.16
tCPA -
4
BRG 013°
RNG 1.34
HDG 000°
STW 7.0
CPA 0.31
tCPA 89.5
5
BRG 024°
RNG 1.01
HDG 191°
STW 3.2
CPA 0.36
tCPA 5.1
6
BRG 029°
RNG 0.16
HDG 022°
STW 4.0
CPA 0.12
tCPA 1.4

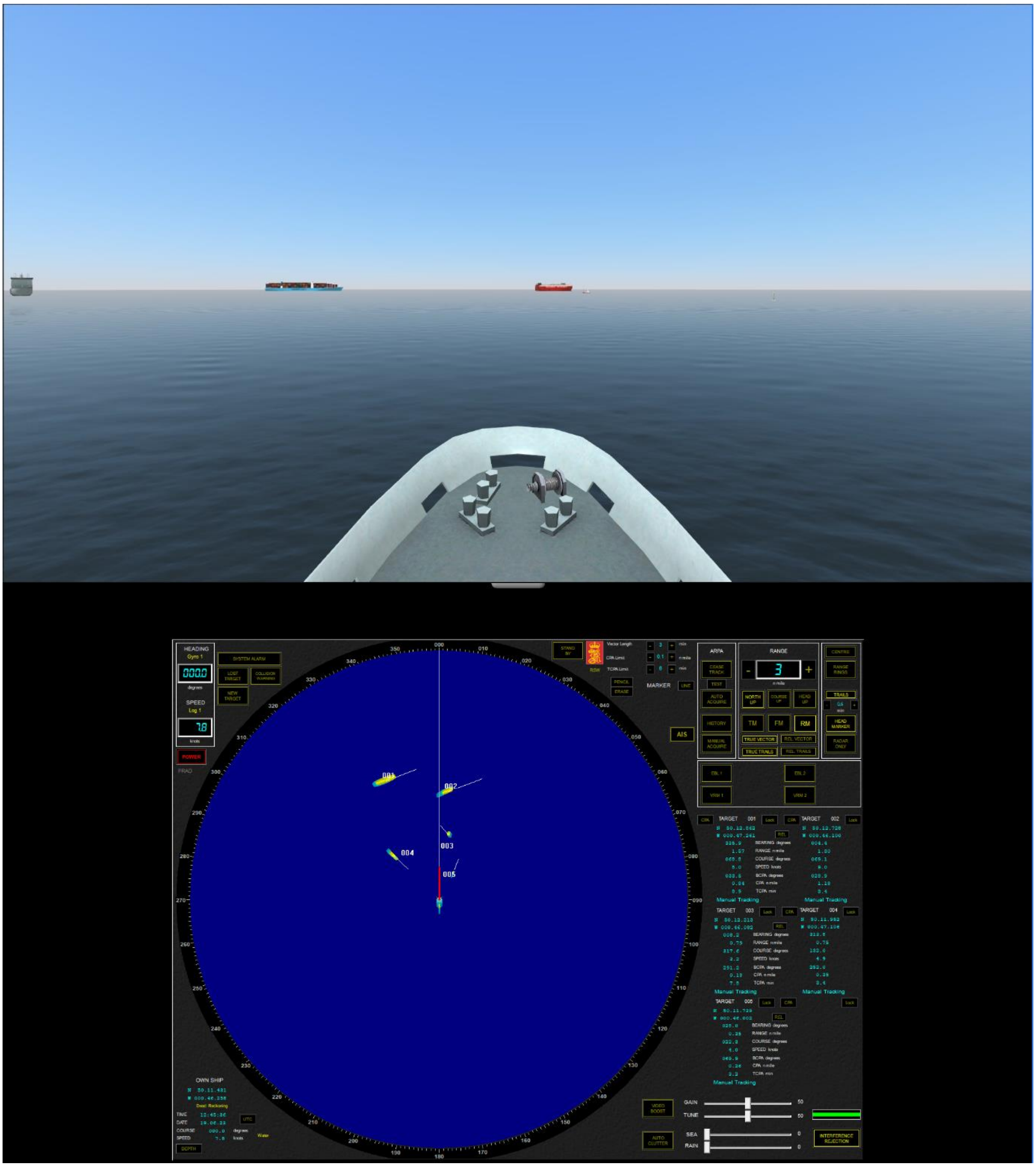
Scenario D



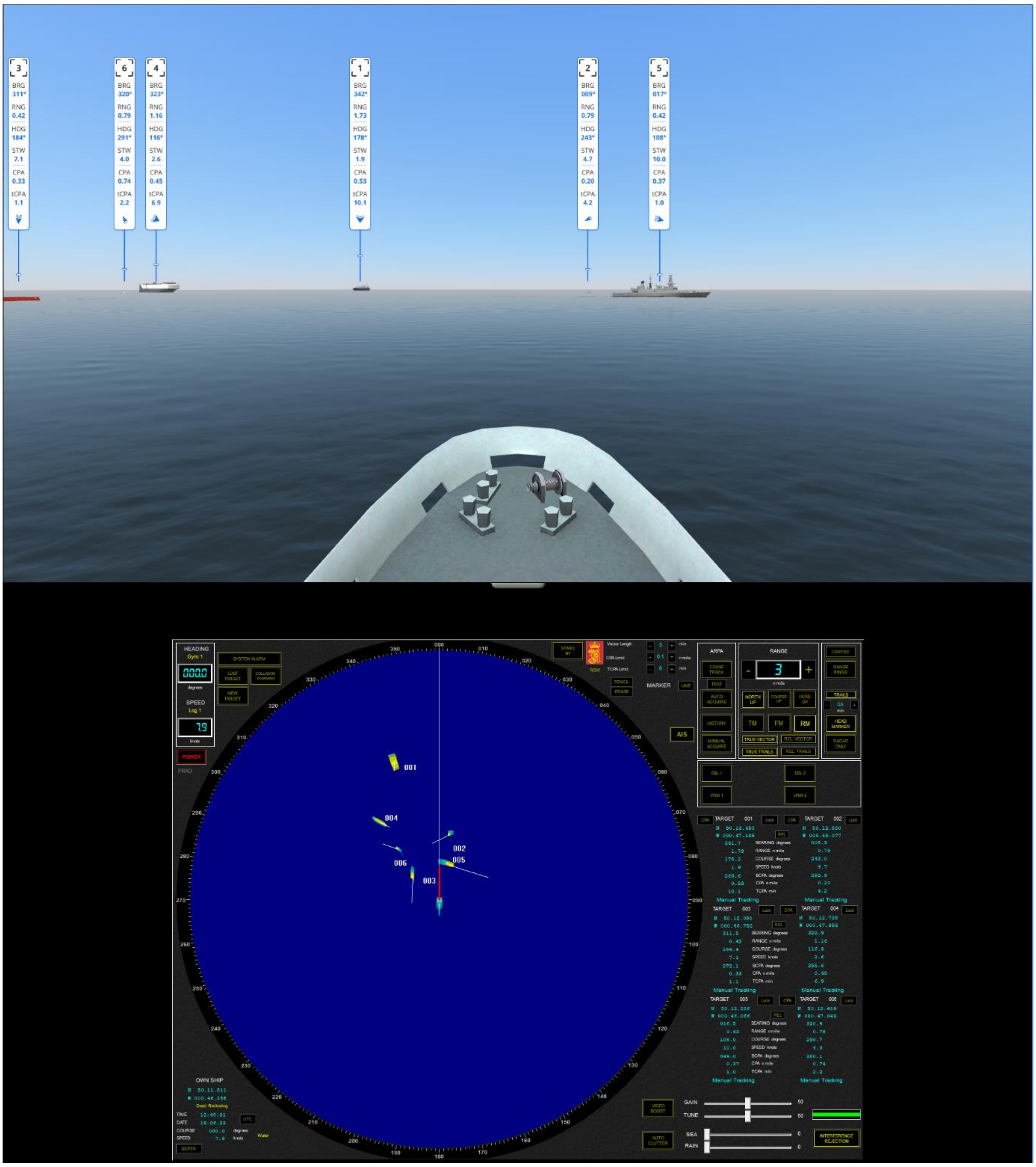
Scenario E


2
BRG
328°
RNG
1.56
HDG
085°
STW
3.3
CPA
0.21
tCPA
11.3
5
BRG
336°
RNG
0.9
HDG
302°
STW
4.0
CPA
0.73
tCPA
4.7
3
BRG
347°
RNG
0.68
HDG
268°
STW
3.2
CPA
0.39
tCPA
4.0
1
BRG
359°
RNG
1.81
HDG
083°
STW
4.3
CPA
0.59
tCPA
11.2
4
BRG
024°
RNG
1.12
HDG
268°
STW
8.0
CPA
0.41
tCPA
5.5
HEADING
SPEED
7.8
001
002
003
004
005
AIS
ARPA
RANGE
3

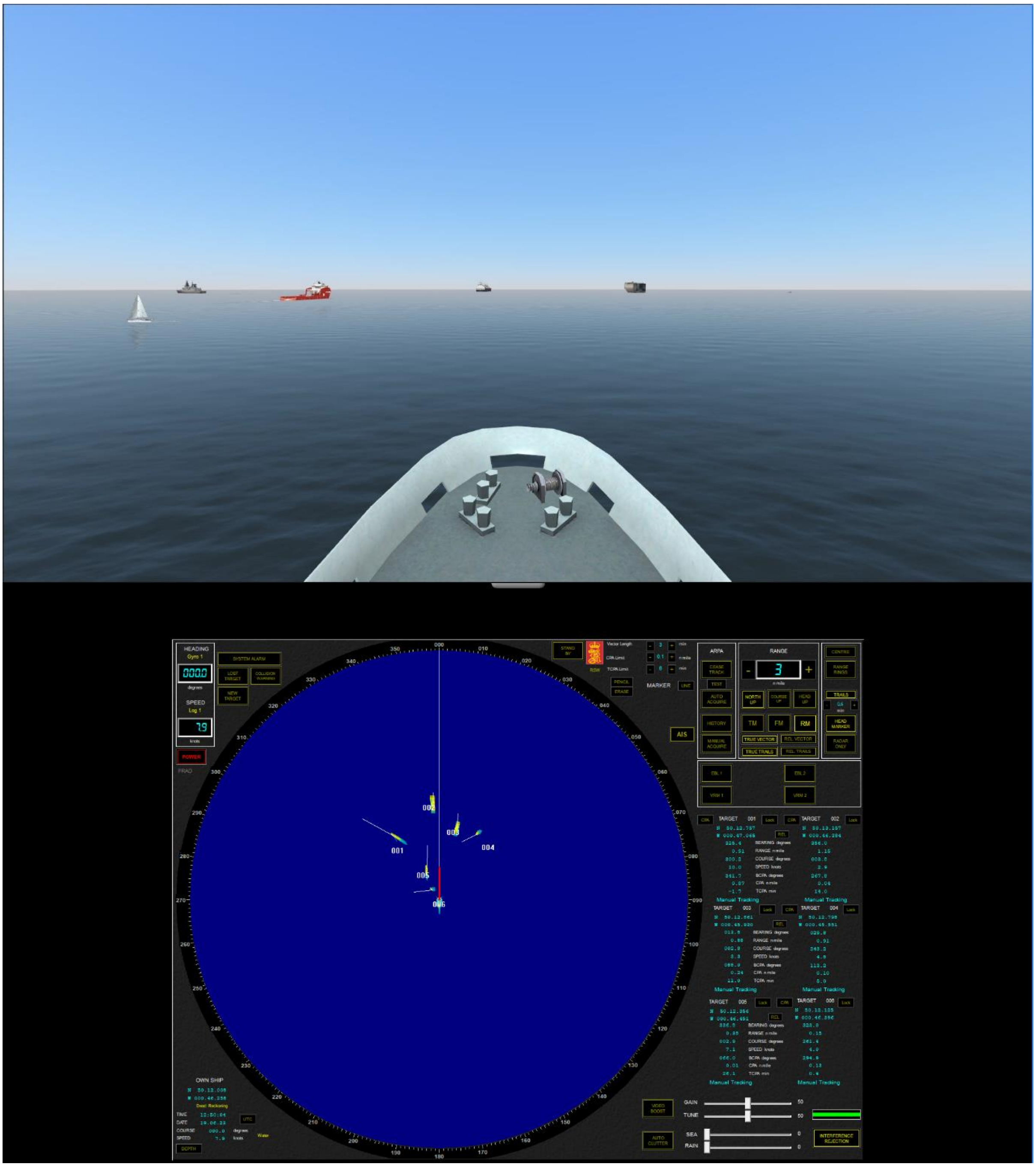
Scenario F



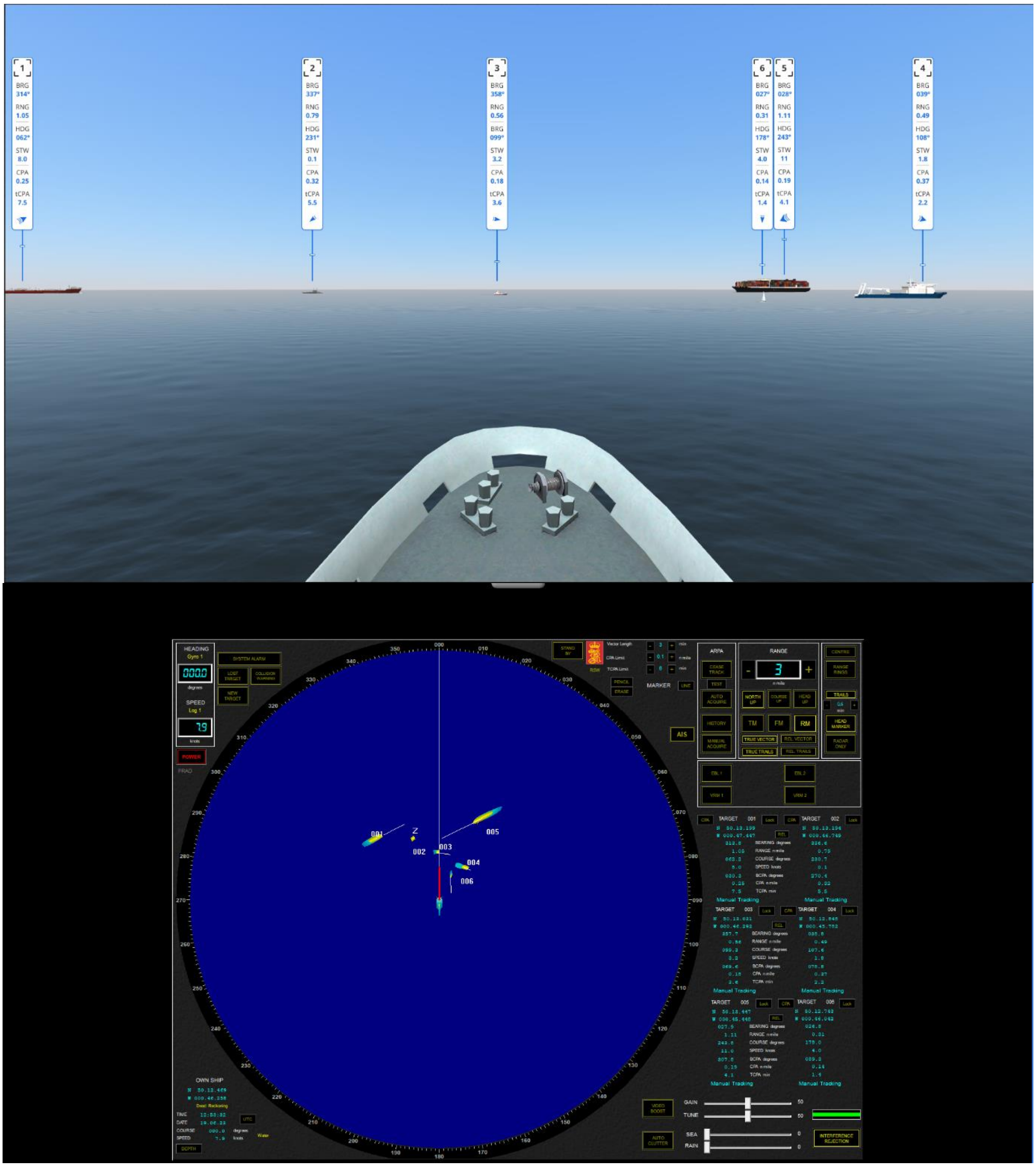
Scenario G


3 BRG 311° RNG 0.42 HDG 184° STW 7.1 CPA 0.33 tCPA 1.1
6 BRG 320° RNG 0.79 HDG 291° STW 4.0 CPA 0.74 tCPA 2.2
4 BRG 323° RNG 1.16 HDG 116° STW 2.6 CPA 0.45 tCPA 6.9
1 BRG 342° RNG 1.73 HDG 178° STW 1.9 CPA 0.53 tCPA 10.1
2 BRG 009° RNG 0.79 HDG 243° STW 4.7 CPA 0.20 tCPA 4.2
5 BRG 017° RNG 0.42 HDG 108° STW 10.0 CPA 0.37 tCPA 1.0

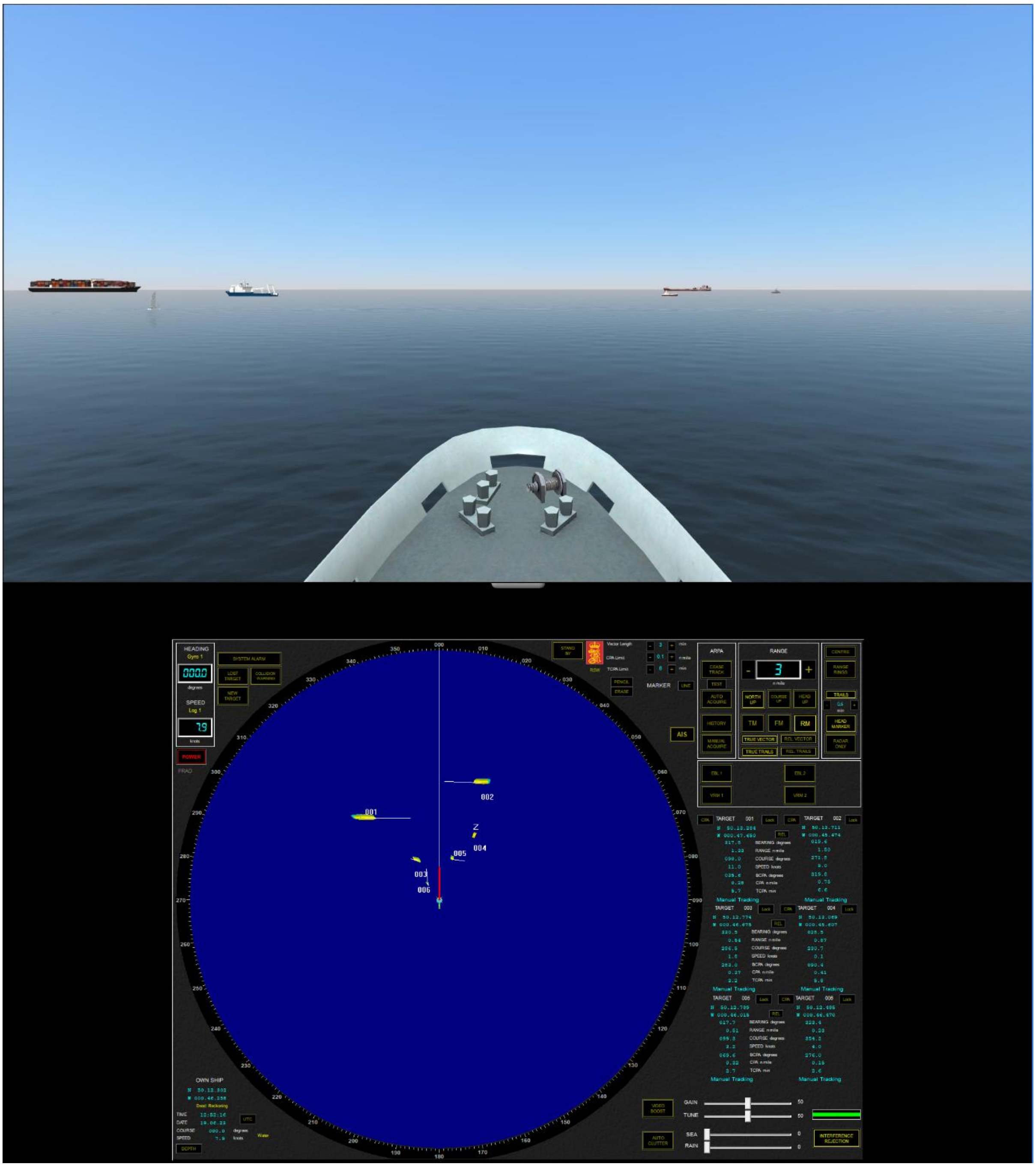
Scenario H



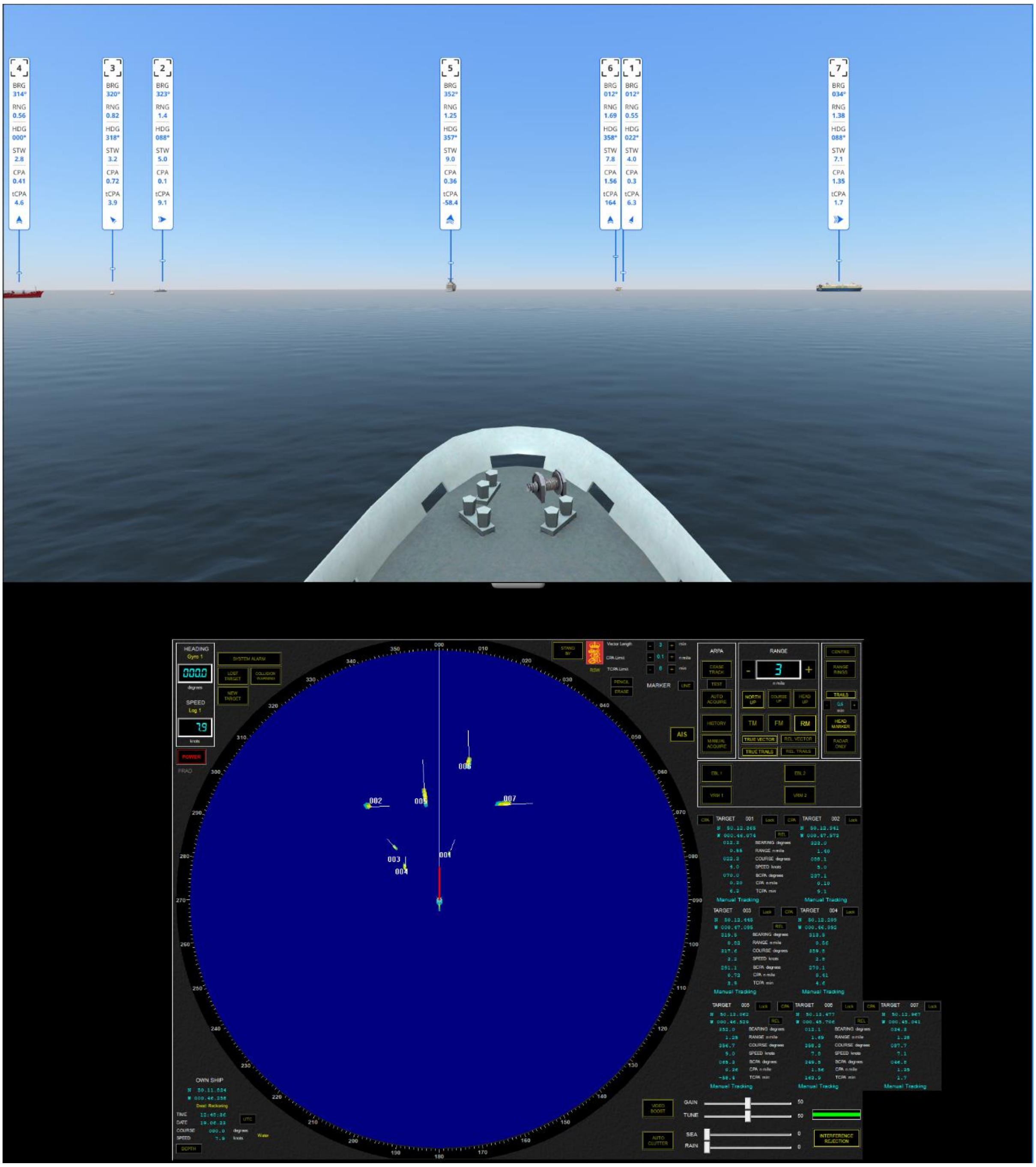
Scenario I


1
BRG 314°
RNG 1.05
HDG 062°
STW 8.0
CPA 0.25
tCPA 7.5
2
BRG 337°
RNG 0.79
HDG 231°
STW 0.1
CPA 0.32
tCPA 5.5
3
BRG 358°
RNG 0.56
BRG 099°
STW 3.2
CPA 0.18
tCPA 3.6
6
BRG 027°
RNG 0.31
HDG 178°
STW 4.0
CPA 0.14
tCPA 1.4
5
BRG 028°
RNG 1.11
HDG 243°
STW 11
CPA 0.19
tCPA 4.1
4
BRG 039°
RNG 0.49
HDG 108°
STW 1.8
CPA 0.37
tCPA 2.2

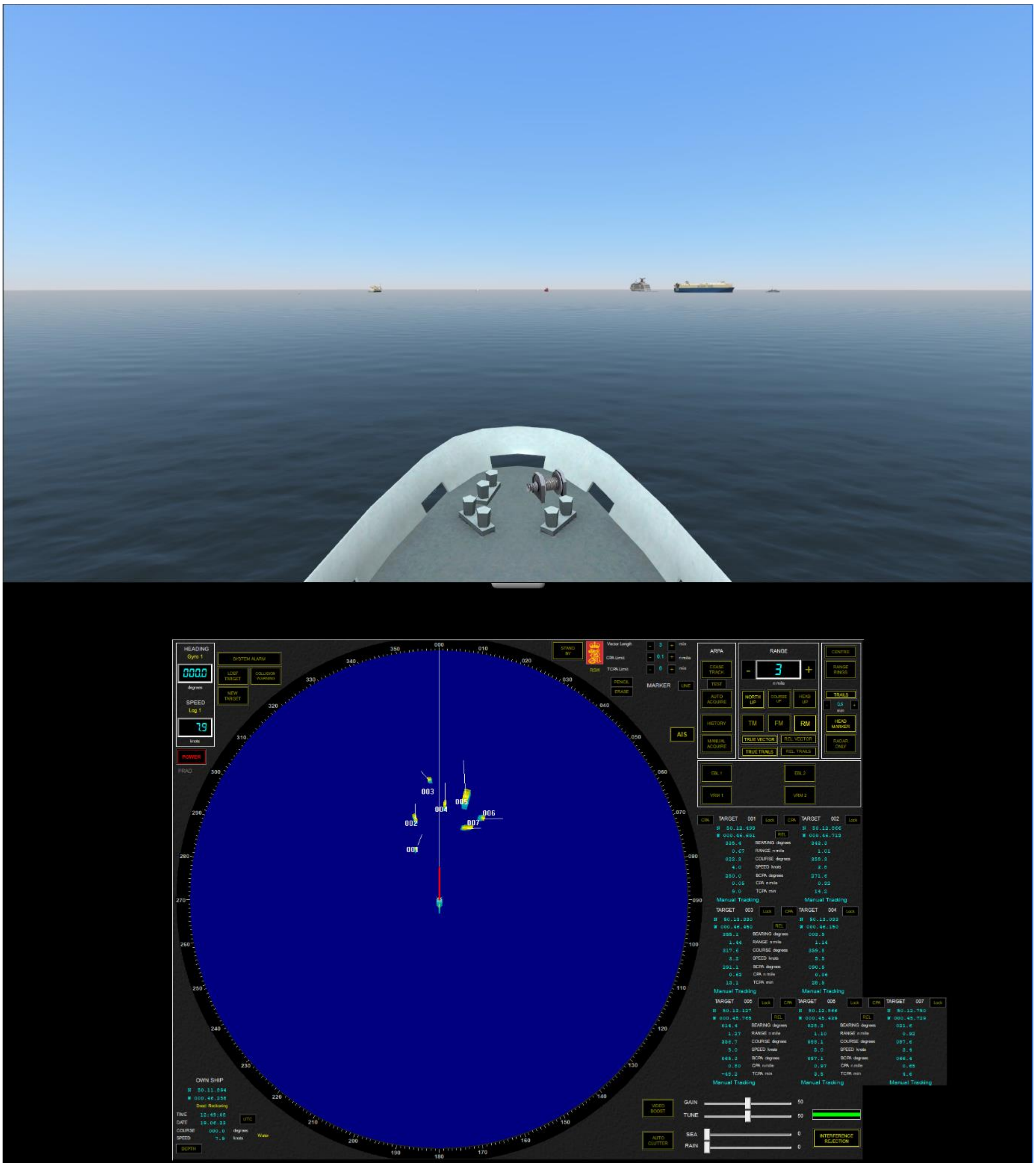
Scenario J



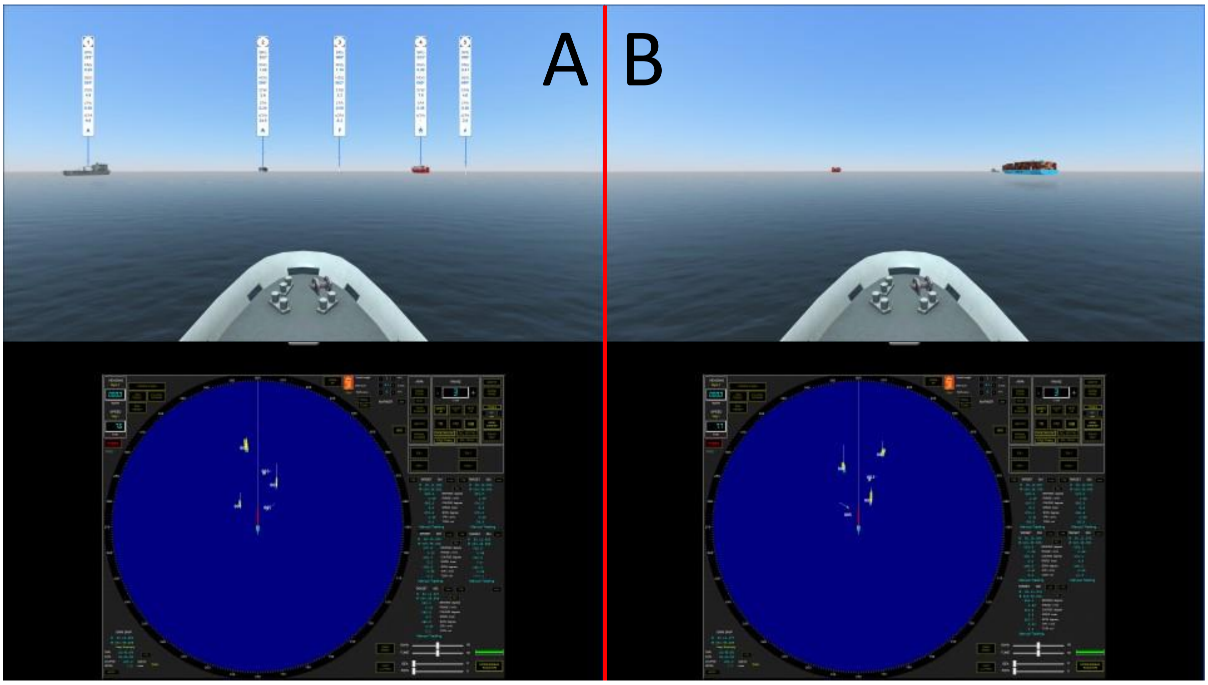
Scenario K



Scenario L


HEADING
SPEED
ARPA
RANGE
AIS
TM
FM
RM
003
004
005
006
007
002
001

8.4 Appendix D – SA-SWORD



Participant #: Which display provides a better level of situational awareness? **(Circle 1)**

A					B			
ABSOLUTE				EQUAL				ABSOLUTE
4	3	2	1	0	1	2	3	4

C					D			
ABSOLUTE				EQUAL				ABSOLUTE
4	3	2	1	0	1	2	3	4

E					F			
ABSOLUTE				EQUAL				ABSOLUTE
4	3	2	1	0	1	2	3	4

Please turn page->

Participant #: Which display provides a better level of situational awareness? **(Circle 1)**

G					H			
ABSOLUTE				EQUAL				ABSOLUTE
4	3	2	1	0	1	2	3	4

I					J			
ABSOLUTE				EQUAL				ABSOLUTE
4	3	2	1	0	1	2	3	4

K					L			
ABSOLUTE				EQUAL				ABSOLUTE
4	3	2	1	0	1	2	3	4

8.5 Appendix E – Interview Guide

Interview Guide 26/10/2022

Semi-Structured Interview Guide

When: After the SWORD-SA

Aim: To explain the results from the experiment i.e., why AR has the effect on SA building it has and to see how the AR interface can be improved.

The interview should be short and flexible to tease out new qualitative data that identifies potential improvements or explains the experiment results. This interview will be conducted post-experiment, after the effect of using AR on a navigator`s situational awareness (SA) has been tested.

Name:	
Participant #:	
DTG:	

Theme	Question	Time
Introduction	We will now conduct an interview. Are you ok with being recorded?	1min
Icebreaker	How did you find the experiment?	2min
Improvements	What aspects of the AR interface were better than the radar interface?	4min
Improvements	What aspects of the AR interface were worse than the radar interface?	4min
Explain Results	Did the AR interface add value?	2min
Explain Results	I noticed you got this result, why do you think you got that?	4min
Thank you	Thank you for participating.	1min
	TOTAL TIME	18min

Time Taken:	