Maritime navigation: Characterizing collaboration in a high-speed craft navigation activity

Tim Streilein[1] [0000-0002-7087-0752], Sashidharan Komandur[1] [0000-0002-9180-4201], Giovanni Pignoni[1] [0000-0003-0730-371X], Frode Volden[1] [0000-0002-0000-690X], Petter Lunde[2] [0000-0003-4738-629X], and Frode Voll Mjelde[2] [0000-0002-4097-3822]

[1] Norwegian University of Science and Technology, Institutt for design, Gjøvik , Norway
postmottak@ntnu.no
https://www.ntnu.edu/design
[2] Norwegian Defence University College, Royal Norwegian Naval Academy, Bergen, Norway
forsvaret@mil.no

Abstract. Communication is an important factor in teamwork and collaboration in safety-critical systems. Operating a safety-critical system such as a military vessel requires maintaining high levels of safety. In maritime navigation, communication is key and collaboration as a team is paramount for safety during navigation. Characterizing this is essential for training and bridge design purposes. Characterizing requires objective tools in addition to visual observation of the navigational exercise. Eye-trackers can fill this gap. Eye-trackers enable measurement of eye movements and dilation measures of the pupil in real time. This can help locate design issues and assist designing training paradigms. In this study two eye-trackers were used to measure joint vision of two navigator simultaneously. Through data of visual attention communication patterns can be characterized with greater richness than just visual observation. As for this case study, in an simulator at the Royal Norwegian Naval Academy in Bergen (Norway), understanding the kind of communication and finding a way to formulate the collaboration will help to characterize communication pattern as a first attempt. This study builds up upon a previous study that improved an off the shelf eye-tracker through hardware additions and software enhancements to accurately measure pupil dilation despite changing ambient light. This study is expected to be a key landmark study that shows the potential of objective tools such as eye-trackers to characterize communication in safety critical systems such as a high-speed navigational environment.

Keywords: maritime · eye-tracker · military vessel · communication · teamwork.

1 Introduction

Communication is key-element of safety-critical systems involving multiple operators, such as navigation of an high-speed military vessel. Efficient bridge teamwork is ensured through precise and established communication. Operations on a military vessel and its performance is highly dependent on the communication (humans interaction) as it is between human-computer interaction. As pointed out by Macrae [8], 42,2% of naval accidents are caused by poor communication between the team members. The recent accident report of the Norwegian Helge Ingstad (frigate) also shows concerns regarding sufficient bridge communication, and failure to build a shared mental model and situational awareness [1].

McCallum [9] notes how sailors do often not ask other crew members for help and often interpret situations on their own; leading to a lack of verified information-flow as more and more things are taken for granted. This behaviour can, therefore, lead to cases such as the accident of Helge Ingstad in 2018 and demonstrates the importance of communication as a tool for improving the team's general awareness of a situation and human errors. Human error happens on the bases of false and incorrect interpretation of the situation; which leads to wrong decision making or improper actions [18]. Therefore, a communication failure can lead to a diverging mental representation of the ship's situation. This representation also has the potential of wrong decision making and might become a safety-critical situation [4].

In the field of control rooms for safety-critical industrial applications, automation is an approach that has proven capable of lowering the chance of human error [2]. Compared to other domains, such as aviation, maritime bridge design still lags in technology adoption [15]. Even though automation should improve the workload during operations, it still has limitations. It can support navigators in their routine, but in case of failure, it can also generate an instant performance demand which could increase stress for the operators [11]. Despite that, it also has been shown that situational awareness could be lowered by the adoption of automation processes [13]. Therefore, the benefits of an automated system depend on how the system is designed or the navigators are trained to overtake in such a safety-critical situation [12]. It is urgent to understand how different situations change human behaviour. The definition of communication patterns is capable of improving the development of automation systems in a safety-critical system such as in military vessels. Prospectively it will help to lower human error and therefore, the safety of the crew.

1.1 Related work

Although the essential communication, in the collaborative environment of safety-critical systems, has been covered by a multitude of studies. For instance, on fields such as aviation and nuclear power plants, showing that understanding and improvement of communication is of high importance[14, 6, 15], there has been a lack of focus on the maritime environment.

A recent study focused on the crew's workload on board of a shipping vessel, including guided tug boats and VTS. It partially shows how communication depends on workload [7]. It is highlighted how communication patterns in the communication dynamics helped to indicate events of interest with a connection to mental workload. Besides conversations recordings (audio analysis), gaze behaviour has shown its importance, as it is associated with performance [16]. This study showed how gaze patterns could measure the performance of athletes in a specific situation, indicating that also gaze tracking could support the analysis of patterns in communication. Weibel et al. [17] have used two wearable eye trackers to track the joint attention of two pilots operating an aeroplane. The study revolves around the development of an effective method to analyze simultaneously multiple data streams in collaboration activities, enabling the tracking of a pilot's behaviour in flight operations. Despite that, Ziv [19] points out that there is still a high demand for analyzing dual (two participants) eye-tracking data. Safety-critical systems often involve more than one operator at a time. Therefore, future research on the topic should focus more on the collaborative aspect as mobile eye-trackers technology becomes more accessible.

1.2 Research question

With this case-study i.e. communication in a military vessel during a navigational activity will be analyzed. The utility of eye-tracking data to understand the communication patterns in this context will also be explored. It will be investigated if the operator's communication can be described and put into a communication pattern in the military vessel background. Using wearable eye-trackers during a routine task will help to get a better understanding of verbal and non-verbal communication. With that as a base, more data can be used to conclude the further behaviour of the operators in that study. The result might be helpful to create new methodologies to evaluate collaboration for training purposes in large vessel simulators.

2 Experiment

2.1 Method background

The experiment has been conducted in collaboration with the Norwegian Defence University College (at the Royal Norwegian Naval Academy in Bergen, Norway), which provided participants (cadets) and use of the simulator facility. Fifteen cadets took part in the experiment plus one member of staff. Each round required two participants (excluding the helmsman) at a time and there were total eight teams. The cadets were graduating students in the operational branch. This implies they have about 300 hours on board the training vessels prior to the data collection.

2.2 Royal Norwegian Navy Simulator

The simulator is equipped with the same Integrated Navigation System (INS) as onboard larger vessels (e.g. Corvettes, Frigates, Submarines or Platform Support Vessel), and is used for navigation training. Figure 1 shows the general setup without the ODB (Optical Bearing Device) lowered. The INS and simulator is provided by a major Original Equipment Manufacturer (OEM), and replicates of the traditional setup with Electronic Chart Display and Information System (ECDIS), Radar, and Conning. The simulator has eight projectors providing a 210 degrees field of view (FOV) in front and 30 degrees FOV astern. For this experiment, the radar was kept off. The team onboard the simulated vessel:

1 **Navigator:** In charge of safe navigation and the leader of the team.
2 **Navigator's Assistant:** Provides the navigator with navigational information, which is aligned with Standard Operating Procedure (SOPs). Conducts nav. tasks for the navigator, e.g. position fixes (are aligned with SOPs).
3 **Helmsman:** responsible for the wheel and throttle of the vessel. Sets speed and steers course as ordered by the navigator.

The Navigator and the Assistant are required to work very closely with explicit closed-loop communication, as neither one of them have the entire picture, thus being dependant on each other. Each run involved two participants, a Navigator and an Assistant. The first run (pilot) involved a staff member as the Assistant. The use of a simulator allows high repeatability of the scenario, traffic and environmental conditions. All experiments were conducted in morning, clear daylight conditions.

2.3 Route

The route starts and ends under the Sotra Bridge near the RNoNA harbour, running clockwise around the Bjorøy island. This route was chosen as it is part of standard training activities and the participants would be in general already familiar to the area. All the participants were given the same navigation plan, which was created by an instructor using standard RNoNA Notations. All Navigators were given five minutes for the team preparation as well as to look through the navigation plan with the Assistant. The scenario was run at the almost constant speed of thirty knots and created with different appearing situations (phases) in order to create a variation in workload:

1 **Phase:** No traffic and easy navigation (baseline).
2 **Phase:** Simple single ship traffic with easy navigation.
3 **Phase:** No traffic and easy navigation (return to baseline).
4 **Phase:** Sudden appearing traffic/near-collision course during narrow and challenging navigation.
5 **Phase:** Complex traffic & easy navigation; the traffic does not require significant actions (compared to phase 4) if the participant acts reasonably.

2.4 Experimental procedure

The experiment was set up in one of the of the simulators of the Royal Norwegian Naval Academy. Data was recorded using multiple devices: overview video of the bridge recorded by a scene camera, eye tracking from both the Navigator and the Assistant (this includes an egocentric video form each participant) and voice recordings.

Fig. 1. Royal Norwegian Navy Simulator in Bergen, assistant (left), navigator (centre) and helmsman (right)

The Pupil Pro eye-tracking glasses[5], was equipped with an egocentric video camera and video tracking of the right eye. It uses infrared technology to record the movement of the eye by the reflecting iris/pupil. Both cadet's eye-movements were recorded at the same time. This particular eye tracker was found suitable for such study as it impedes vision only in minimally thanks to a small eye camera and no frame. The eye-trackers were wired to two different computers with sufficient length to allow the navigator to move freely in the simulator; it has been ensured that the participant would not risk tripping or yanking on the cable. The cadets also were equipped with a clip-on microphone, which wireless recorded each voice separately. Besides the automated data gathering, the experiment involved extensive note-taking and a questionnaire. The questionnaire was administered before the debriefing, and after the session in the simulator. The questionnaire contained questions regarding the route, communication and workload. Most questions were answered by coloring a template of the course.

2.5 Performance Evaluation

The Royal Norwegian Navy (RNoNA) evaluates the performance of high-speed navigation teams by assessing both technical navigation skills (taskwork), and their ability to interact through communication and coordination (teamwork) to support mission objectives. Research on team performance assessment indicates that scoring of performance metrics are best met by balancing teamwork and taskwork constructs [10]. RNoNA subject matter experts have constructed an assessment form that reflects mission essential competencies necessary for safe and efficient high-speed navigation. This observational tool was used to assess each teams' taskwork and teamwork behaviours as they performed the experiment. The route used in the experiment can be broken down into smaller segments labelled with different levels of navigational difficulty. It is expected that teams receiving a low score on observed taskwork and teamwork behaviour within a particular segment also will receive a low score on mission success in the same segment, and vice versa for high performing teams. Additionally, the effect of team performance has on mission success is expected to be more observable in the hardest segments than in segments that are easier to navigate.

2.6 Initial impressions

Emerging communication patterns can be seen in the notes, indicating standardisation in communication and procedures happening on the bridge. Verbal communication is generally preferred to non-verbal. Still, non-verbal communication is used to specify and support verbal communication e.g. to pinpoint dangerous elements in the environment or on the ECDIS. Such instances should have a high chance of joint vision (JV) that will be further investigated. Other cues, such as head movement or eye contact, are used to get attention or confirmation from another crew member. The communication patterns observed during the experiment have been initially organised in four recurring sequences (table 1).

2.7 Future Work

Further analysis of the notes will be followed an integrated with eye-tracking and video recording as well as speech analysis. Areas-of-interest will be used to analyse the eye-tracking data and JV can be identified as the overlap of the dwell time of both navigators. The communication will be analysed through the newly defined pattern set and categorised. Speech analysis and recognition (e.g. words per minute) will be used to support or identify other patters. Still, the content of the conversation will not be analyzed as the content should not correlate with the performance of the operator [20]. The RNoNA will analyze the collected team performance observations with respect to the scores for mission success, both for the overall mission and for each individual segment. It is of interest to the Navy to compare the SME ratings with the data presented by the eye-tracking analysis to identify how eye-tracking tools can assist in performance assessment of teams collaborating in a challenging maritime environment.

Table 1. Observed sequences incl. repeating patterns (N.: Navigator; A.: Assistant)

Briefing	**Initialize**
ECDIS gets inspected Situations are discussed Non-verbal actions to point out situations Set the system and settings e.g. AIS	Check status of everyone N. initialize and takes over the lead Everyone stays in their position Using non-verbal cues (e.g. pointing and look back) A. and N. look often outside
Prepare	**Turning**
A. provides coordinates from ECDIS, N. replies N. uses the Conn and checks other instruments. N. looks outside mostly A looks outside or on ECDIS A wants attention (by pointing or turning head) A. points out a situation (outside)	N. commands the bridge (actively walks around) The voice rises often A looks more often outside and at the N. N. looks together at ECDIS with A. N. mentions s.th outside (both look and discuss) Rarely A. points at the ECDIS (4th turn)
Arrive	
N. mostly stays at middle position Everyone looks mostly outside Non-verbal communication rises A. and N. still discuss situation on ECIDIS	

3 Conclusion

Even though communication frequency may not linearly relate to performance (e.g. an increase of communication may result in an inferior performance [3]), the definition of communication patterns will help to understand how communication can become more or less beneficial in an operational environment. The eye-tracking data should help to quantify the effect of communication on JV and the relation between workload (pupillometry) and other communication variables such as words per minutes. The first outcome of this research is the list of recurring communication patterns extracted from the observation notes. These patterns will be objectively verified through the analysis of the eye-tracking data and speech recordings. This effort should indicate whether such tools can be used to characterize communication in a high-speed navigational environment. Determining standards in communication and procedures could help to identify any abnormal behaviour at an early stage and aid the training process.

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