Validation of a Maritime Usability Study with Eye Tracking Data

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Abstract. The main objective of the navigation system on board a High Speed Craft (HSC) is contributing to safe operation, which is supported by a high degree of situation awareness for the navigator. On the modern HSC bridge, an increasing amount of displays and support systems has been introduced, with computers being networked and integrated information presented on Multi-Function Displays (MFDs). Eye tracking data in human-computer inter-action is a valuable tool to identify challenges with design and user interfaces, and to better understand the workload of the subject. This paper presents and analyse two eye tracking data sets collected to validate a mid-life update of a HSC navigation system, and outlines the challenges when collecting eye tracking data in an operational environment. Data collection with Eye Tracking Glasses (ETGs) is proven to be a valuable tool, but the quantitative data needs to be supported by qualitative data to be unambiguous.

Keywords: Maritime · High speed · Navigation · Eye tracking data
Eye tracking glasses · Navigation system

1 Introduction

High speed navigation in littoral waters is a challenging task. Both civilian and military High Speed Crafts (HSC) are operating in speeds above 20 knots (37 km/h) and some exceeding 60 knots, making the safe and efficient conduct of the passage crucial.

To support the navigation process, the bridge is equipped with MFDs to facilitate the information management in the navigation system for the navigation team [1]. The navigation system is integrated and networked together, and information is typically presented and integrated on a MFD on the Electronic Chart Display and Information System (ECDIS), radar application and application with information about the ship propulsion and technical systems (conning). The Situation Awareness (SA) of the navigator is crucial in order to facilitate for the safe and efficient navigation, and the navigation system aims to support a higher degree of SA [2].

Several studies have highlighted the challenge with information overload for the navigation team [3–8], and raises the question whether a bridge design and layout supports the safe and efficient navigation of the vessel.

To better understand the task of navigation and what the navigator is addressing during a passage, eye tracking data can be collected and analysed. ETGs can provide sufficient freedom of mobility for the test participants, and has shown good potential in better understanding the task of the (HSC) navigator [9, 10].

Eye tracking data can be collected by using ETGs, and the use of ETGs has shown good potential in maritime usability studies [11–13]. Previous studies highlighted design and Graphical User Interface (GUI) issues on board the Skjold-class Corvette (Fig. 1) bridge navigation system [9, 11, 14], and these were corrected in a mid-life update [15]. This paper presents a pre- and post-mid-life update eye tracking data set collected to validate and support the findings in the pre mid-life update study.

The research question in the article is if eye tracking data collected from ETGs can be used to validate a design-review of a maritime HSC bridge.

1.1   Decision Making in High Speed Navigation

HSC navigation is most commonly conducted in a navigation team, consisting of two persons, the Officer of the Watch (OOW) and the Navigator, which share the tasks given to achieve safe and efficient navigation. Dependent on the confinement of the waters, weather and speed, the navigation team workload is high [16]. Safe navigation means that no incidents or accidents occur, while efficient navigation means that the speed potential of the vessel is utilized [17].

Figure 1 shows the Royal Norwegian Navy Corvettes, with speeds exceeding 60 knots (110 km/h or 70 mph).

Fig. 1. Skjold-class Corvette

The conduct of a safe passage with a HSC is a complex task, conducted in a sociotechnical system as a navigation team [18]. To support safe and efficient navigation, the navigation team uses a methodology to aid the decision making process and increase the SA, known as the phases of navigation [1] or Dynamic Navigation (DYNAV) [19, 20]. The conduct of safe and efficient planning is shown in Fig. 2, and is an iterative process.
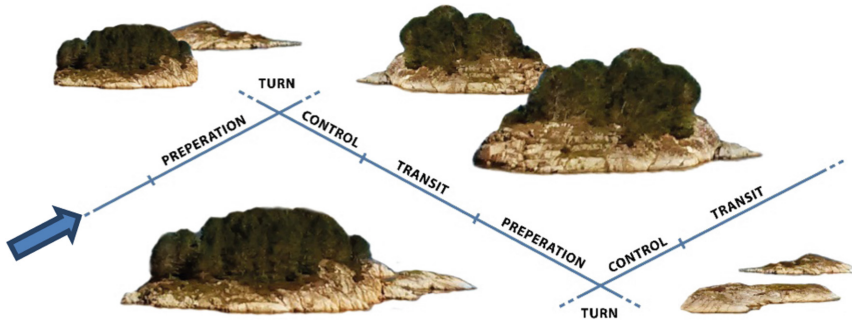

Fig. 2. Iterative process of (littoral high speed) navigation

In littoral waters there are multiple obstacles for navigation, making high speed navigation challenging. Each leg will vary in length, but as an example, a leg of one nautical mile (1 nm = 1852 m), will take 1 min to complete in 60 knots. In demanding waters, consecutive legs are often less than 0.5 nm in distance, making the decision process before the next leg less than 30 s.

In each phase of navigation, the navigator has a mental checklist to follow, and it is important that the navigators prioritize in order to have time to finish one phase before the next one starts, in order to maintain a high degree of SA. The navigator's SA consist of spatial-, task- and system awareness [6, 21], and the complexity of these factors affect the navigator's workload as shown in Fig. 3. Note that the bottom line in Fig. 3 is meant as examples, and is not complete.
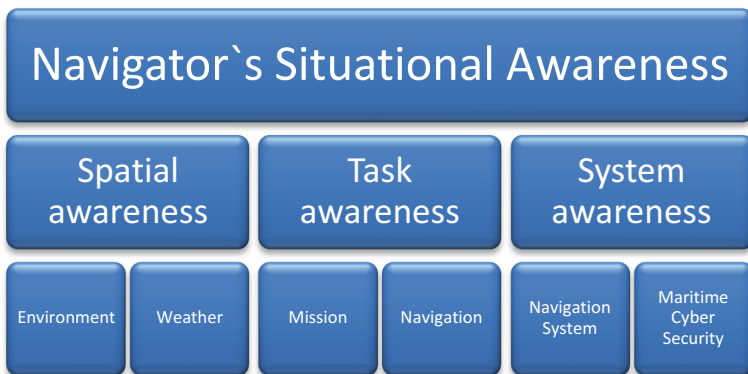

Fig. 3. Navigator's SA [21]

As navigation is conducted in a team, the communication skills is important to create and maintain a shared mental model in the navigation team, and the communication is mainly conducted in accordance with standard operating procedures. The integrated navigation information on the displays provide some of the basis of the navigation team shared mental model, however this information collection is non-verbal and could thus be interpreted differently by the operators [16].

1.2 Vulnerabilities in an Integrated Navigation System

Navigation systems on a modern HSC are networked, and the navigation sensors are integrated. The integrated information is presented on one or several MFDs, as shown in Fig. 4.
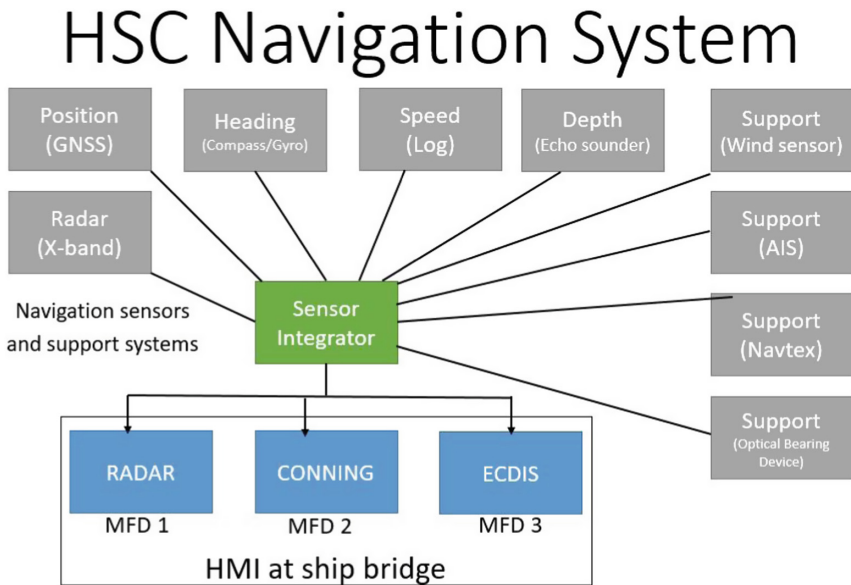

Fig. 4. Example of a HSC navigation system

The integration of navigation sensors in the navigation systems aims to contribute to improved SA for the navigator, and thus support the safe navigation of the vessel [2, 22–24]. This is partly conducted by presenting the near real-time position of the vessel on the ECDIS. The information from the position-, heading-, speed-, depth- and support sensors are integrated and presented on one of the MFDs on the ship bridge. The three main applications available for the navigation team is ECDIS, radar and conning.

The navigation system even on a relative small HSC vessel below 50 m is arguably a complex system in accordance to Redish [25], and there is a concern that the navigator does not hold a sufficient understanding of the navigation system they are

operating [26–28], known as system awareness in Fig. 3. This could lead to misinterpretation of information from the navigation system presented on the MFD.

Signal interference on the signal from a Global Navigation Satellite System (GNSS), intentional or un-intentional, can lead to Hazardous Misleading Information presented to the navigator [29]. There are several examples of jamming and spoofing of GNSS-signals [30–33], and the navigator needs to be aware of the vulnerabilities in the computer system in use [21].

1.3 Eye Tracking

Eye Tracking is the process of measuring the eye activities [34]. This could be performed by measuring either the point of gaze (where one is looking) or the motion of an eye relative to the head. An eye tracker is a device that can measure eye position and eye movement. ETGs is constructed in order to study human behaviour in real-world environments [35].

During the past years, eye tracking in Human-Computer Interaction (HCI) and usability studies/research has been more frequently used [36–41]. There has also been research and suggested frameworks for the use of eye tracking measurements when conducting usability evaluation at a ship's bridge [42].

Eye Tracking data from ETGs has been used to improve usability of bridge design [13, 43, 44], and the Graphical User Interface (GUI) and bridge layout of a HSC has been examined with ETGs in an earlier study [14, 15]. ETGs has been used as a tool to measure the efficiency of a navigator when conducting a passage [10], and in maritime bridge simulator assessments [45]. Nielsen and Pernice [40] find that the use of eye tracking data will aid the designers and software developers to better understand what people see and don't see, and ETGs has shown to be a useful tool in a framework to improve SA in demanding maritime operation training [12].

2 Methodology

The work presented in this article builds on earlier studies conducted prior to a mid-life update of the Skjold-class Corvette navigation system [9, 11, 14]. ETGs were utilized to better understand the visual attention of the navigator, in order to identify, and if possible correct, flaws in design and/or GUI. Tobii Pro Glasses 2 was used for the two data collections, and pros and cons with the use and different types of ETGs is laid down in earlier work [11].

2.1 Subjects

The participants were personnel in active service, mean age of 29 years (Standard Deviation (SD): 4 years), and a total of 13 subjects participated in the test conducting 19 runs. It would be beneficial with a higher number of test objects, but the amount of relevant personnel is limited. The RNoN has six Skjold-class in service, with two navigation teams on each vessel, thus 54.2% of available personnel participated in the data collection.

When recruiting personnel to the data collection, several challenges with the availability of relevant personnel was identified. The workload on personnel in active duty is high, and the data collection was not characterized as operational service, and therefore not given a high priority. This lead to challenges with the amount of participants, cancellations and time-constraints when conducting the data collection.

2.2   Apparatus

The data collection was conducted in the Navigation Simulator (NavSim) at the Navigation Competence Center at the Royal Norwegian Naval Academy. Earlier work has argued that the Skjold-class simulator at the NavSim provides eye tracking data with quality equal to live data [9].

The navigation bridge of the Skjold-class is shown in Fig. 5, and to better organize the eye tracking data, Areas of Interest (AOIs) of the bridge was defined. AOIs defines important regions in the visual scene, and further allows events such as dwells, transitions and AOI hits to be defined [35]. The AOIs are shown in Fig. 5, and is in accordance with the visual areas most commonly used by the navigator on board a Skjold-class Corvette.

Fig. 5. Skjold-class bridge layout with primary AOIs

The AOIs were defined by using experience from earlier studies, together with a pre-study conducted with three persons in three runs. This resulted in four main AOIs, which are divided into 7 AOIs in total. The AOIs are:

1. Outside (AOI_O): The surroundings of the ships, and are defined by the boundaries of the windows on the ships bridge.
2. ECDIS (AOI_E): The ECDIS information is presented on the MFD in front of the navigator.
   a. AOI_E also consists of the Route Monitor window (AOI_M) as a part of the ECDIS application [15].

3. Radar (AOI$_R$): The radar information, presented on the centre MFD on the ships bridge in Fig. 5.
   a. AOI$_R$ consist of the heading bearing (AOI$_H$) in the upper right corner of the radar application [11].
4. Conning (AOI$_C$): Consisting of information from the displays, consoles and autopilot related to the propulsion and steering of the ship.
   a. AOI$_C$ consist of the consoles for manoeuvring (AOI$_{CO}$) and the speed log display (AOI$_D$) [11].
5. White Space (AOI$_W$): The other areas than those defined by the AOIs [46].
   a. Both data sets white space was marginal, and has been left out of the graphics, which indicates that most fixations were within a defined AOI.
      i. AOI$_W$ pre-study data set: 0.22%
      ii. AOI$_W$ first data set: 0.15%
      iii. AOI$_W$ second data set: 0.26%

The navigations system (Sect. 1.2) consist of AOI ECDIS, Radar and Conning, and the eye tracking data analysis aims to provide a understanding of the use of these AOIs and thus an understanding of the system awareness which contributes to the Navigator's SA (Fig. 3).

2.3 Validation Procedure

The procedure and scenario for the pre- and post- data collection was identical. The scenario was set up in the simulator instructor software Polaris, and used in all the scenarios. The area of data collection is in Norwegian territorial waters, between Bergen and Floroe. The area, traffic, route and environmental conditions are identical in both the data collections throughout the 19 runs. The pre-planned route has a distance of 20.6 NM, and the average sailing time for each participant was 24.8 min (SD: 3.42 min). A total of 6 h and 12.4 min of eye tracking data has been analysed. The experience of the participant averages 1.9 years (SD: 1.75 years). The timeline for the project is shown in Fig. 6.
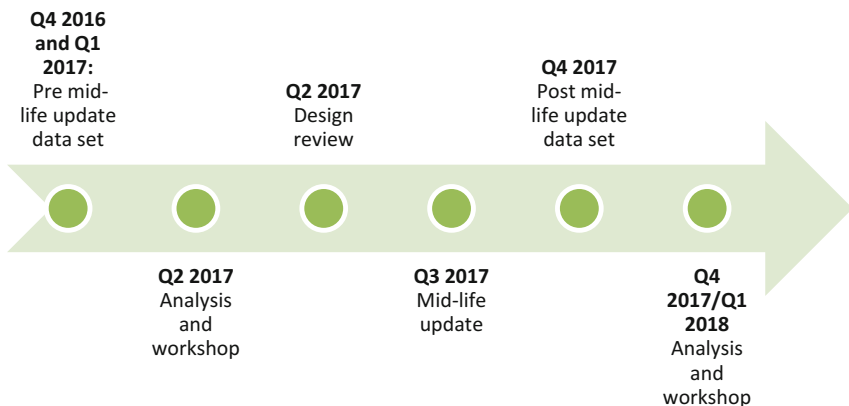

Fig. 6. Timeline process of validating HSC bridge design

The analysis was conducted in the manufacturers software, Tobii Pro Lab. Eye metrics data was captured, and further analysed in Microsoft Excel. In Excel sheets regarding fixations, duration, counts and events was analysed and visualized using diagrams (Figs. 9, 13 and 14). Visualization maps such as heat maps and scan paths were created in Tobii Pro Lab (Figs. 7, 8, 11 and 12). The visualizations maps provide a static overview of the visual attention of the navigator in the given period of time. The process of analysing and interpreting the eye tracking data can be challenging and time consuming, and a rule of thumb is one hour of analysis for every 10 min of eye tracking data.

2.3.1 Statistical Model

The statistical analysis has been conducted in four steps, where the statistical model is established and consist of a normality test, an F-test and a t-test to control if the values disprove the null hypothesis of similarity between the two eye tracking data collections within a significance level of 5%. The F-test is conducted to control the p-value for validation of similarity of the two collected data set. The t-test is conducted to control if the expectations values in the two collected data set are valid.

The generation of the analysis has been conducted in Microsoft Excel, by using the eye metrics data which is generated by the manufacturer software.

2.4 Technical Workshops

To better understand the Eye Tracking data and the analysis of it, workshops with Subject Matter Experts (SMEs) were conducted. This was facilitated through the creation of a Technical Group High Speed Navigation on the manufacturers equipment.

The working group consisted of SMEs, who are active navigators from the high speed navigation community in the RNoN. Representatives from the ECDIS manufacturer contributed together with HCI experts from the RNoN, which is supported by the call for more usability testing in complex systems [25].

The SMEs used the working group as a forum to express their opinions regarding the possibilities and the challenges with the existing navigation system. These opinions were correlated towards the presented eye tracking data and analysis, and discussed in the working group. System Problem Reports (SPR) and Engineering Change Proposals (ECPs) were produced where opinions from the SMEs and eye tracking data correlated. Amongst these were the three design issues described in Sect. 3.3, thus we investigated if eye tracking data collected from ETGs can be used to validate a design-review of a maritime HSC bridge.

The technical group conducted workshops both pre- and post-mid-life upgrade, and the feedback from the post mid-life update was correlated with the eye tracking data. The SMEs response to the revised design of the three main design issues was positive.

3 Results

3.1 Pre Mid-Life Update Data Set

The first data set consists of data from 10 participants, nine males and one female. Average age of participants 29 years (SD: 4 years). Average experience 1.6 years (SD: 1.6 years). The average time for conducting the passage was 24.5 min (SD: 3.9 min.

The first data set identified three main design issues, supported by earlier work [11]:

1. Poor availability of the presentation of heading bearing in radar GUI.
2. Challenges with the HCI with the distance measurement unit (Electromagnetic Log – speed log).
3. Sub-optimal GUI in route monitor window.

It is important to understand where the visual attention of the navigator is allocated during a passage. The visualization maps in the first data set is shown in Figs. 7 and 8.
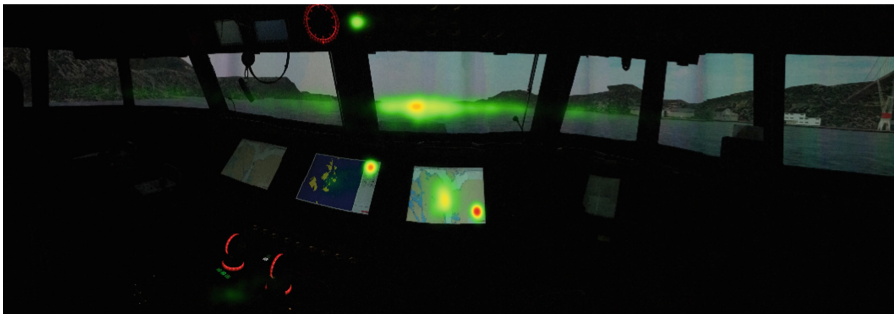

Fig. 7. Heat map from pre mid-life update data set

The heat map identifies the hot spots where the navigator addresses its' attention, and the three design issues is identified. Number 1 in the top right corner of the radar (centre MFD), number 2 in the top centre of the figure, where the speed log is placed. Design issue number 3 is the route monitor window in the lower right corner of the ECDIS GUI on the right side MFD (reference to Fig. 5).
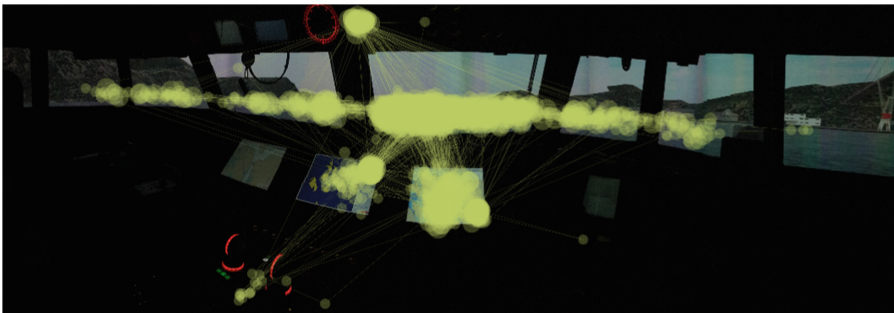

Fig. 8. Scan path from pre mid-life update data set

Analysing the scan path from the first data set, the three design issues are evident. Each fixation is represented by a circle, and the size of the circle represents the fixation time (larger circle, longer fixation).

The total time spent in an AOI can be an indication of the importance of the AOI. It could also indicate a design issue or high mental workload [35], and thus contribute to a decrease in SA for the navigator [40]. The total time spent in the AOI in the first data set is shown in Fig. 9.
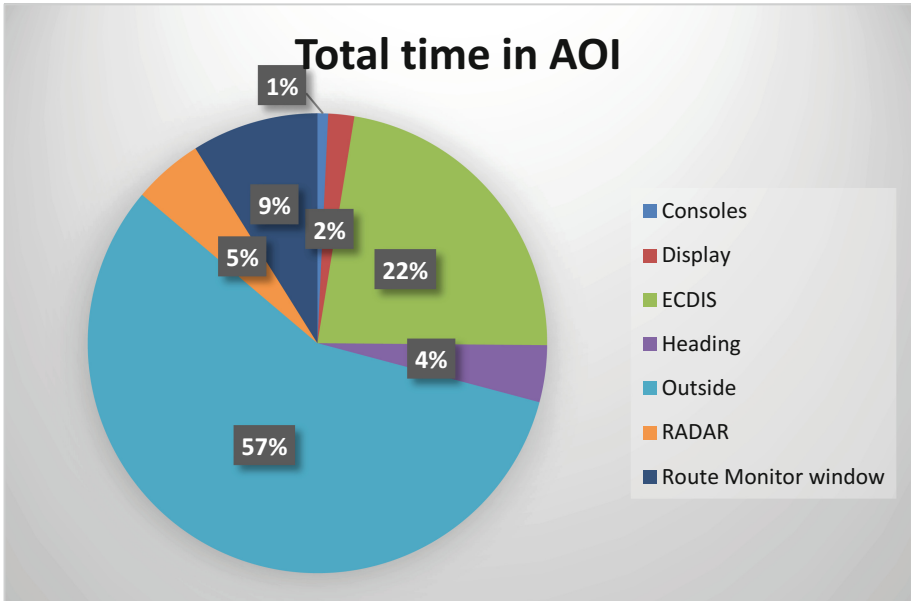

Fig. 9. Total time in AOI from first data set (pre mid-life update)

The pie chart provides valuable insight in the visual attention of the navigator [1], and the main objective is to provide more time for the navigator to control the surroundings to facilitate a higher SA (Fig. 3 – Spatial and Task Awareness). A suggestion of an optimal visual attention to AOI Outside is 80% in good visual condition conducting the passage in visual sailing mode [1], in order to support the navigators SA. The SD in AOI outside in the pre mid-life update data set is 8.3%.

3.2   Mid-Life Update Navigation System Skjold-Class Corvette

The three design issues were addressed during a design-review and mid-life update of the navigation system on board the Skjold-class Corvettes. The SPRs were discussed in the working group, and ECP developed for each of the design issues.

ECP for design issue 1 was moving the presentation from the top right corner of the radar GUI to a larger presentation in a new High Speed Craft Route Monitor (HSCRM) window. The final version of the HSCRM window is shown in Fig. 10, and the

heading bearing is presented with large fonts in the upper left corner of the GUI (#1). The HSCRM window is to be placed in the centre-top left corner of the ECDIS application, this in order to have a short visual passage from the display to the outside (surroundings) of the vessel, and contribute to a higher degree of SA by supporting the spatial, task and system awareness [15].

Fig. 10. HSCRM window from design review [15]

ECP for design issue 2 suggest moving the reset button for the trip meter from the overhead panel of the speed log [14], to the arm rest panel located on the left armrest of the navigator's chair (reference to Fig. 5). This implies the physical movement of the reset button from the speed log panel to within arm's reach of the left hand of the navigator. The display of the trip meter is co-located with other relevant information in the HSCRM window, and is shown on the top second line in Fig. 10 (#2). This makes the speed log display excessive, and the navigator only needs to address the HSCRM window.

ECP for design issue 3, a new route monitor window design, is shown in Fig. 10 and has been elaborated in earlier work [15]. The aim of this change was to sort and present the information needed for the navigator to maintain a high degree of SA. The presentation of this information is in line with the standard operating procedures on HSC in the RNoN [47]. A challenge identified in the workshops is that the HSCRM window will probably lay hold of relative more time from the navigator's visual attention, due to the relative large amount of information co-located in this GUI.

3.3   Post Mid-Life Update Data Set, Validating Design Updates and Measuring Impact

The second data set consists of six participants, all male. Average age of participants 29 years (SD: 4 years). Average experience 2.3 years (SD: 1.8 years). The average time for conducting the passage was 25.3 min (SD: 1.9 min).

The purpose of the design review was to free time for the navigator to control the surroundings of the vessel (AOI Outside), and contribute to a better SA for the HSC navigator.

In order to evaluate the end-state, a final eye tracking data set was collected (Fig. 6). Figures 11 and 12 shows the visualization maps for the validation data set.
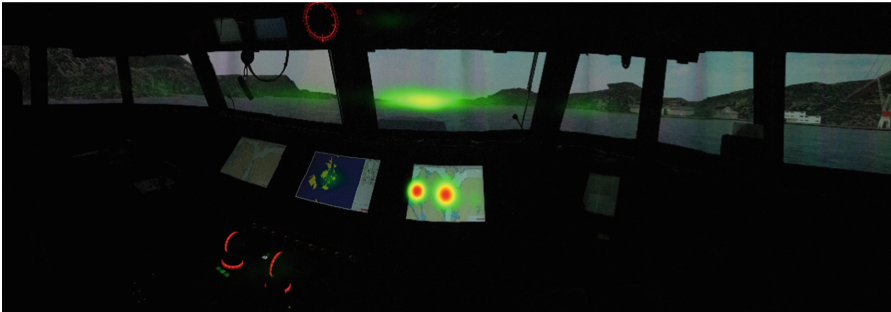

Fig. 11. Heat map second data set (validation)

When comparing the heat maps from the two data sets (Figs. 7 and 11), the heat map clearly identifies the three design flaws in Fig. 7, while these three areas are not present in Fig. 11. According to the heat map, more of the attention has been addressed to the ECDIS, Outside, Route monitor window and to the centre of the MFD with the radar application. There are fewer AOIs for the navigator to direct the visual attention towards, since AOI Heading, AOI Display and AOI Consoles is marginalized. This should in turn contribute to freeing time for the navigator to focus in more important AOIs, and contribute to increase the SA of the navigator. The eye tracking data visualization clearly indicates fewer AOIs in the new bridge design and GUI, more visual attention directed towards operational important information in AOI Outside, ECDIS and radar, which should contribute to safer operation.

Comparing the scan paths from the two data sets (Figs. 8 and 12), the second data set (Fig. 12) indicates a tidier scanning pattern, where fewer AOIs are visited. As shown with the heat map, less important AOIs such as AOI Heading, AOI Display and AOI Consoles are marginalized. This should contribute to a more efficient visual search for the navigator, and thus supporting an increase in the SA of the navigator. This finding supports the suggested Scan Pattern for the Maritime Navigator [1], which aims to streamline and optimize the visual search for the navigator. Note that the heat map in Fig. 11 shows inferior resolution inside the AOIs, compared to the scan path in Fig. 12. As an example the amount and placement of fixations inside AOI ECDIS becomes
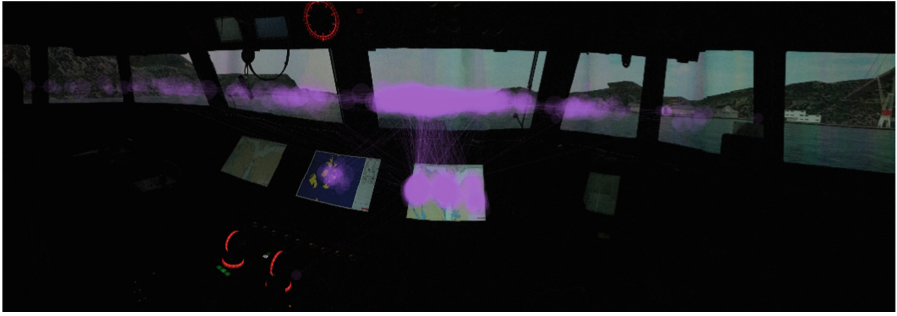
Fig. 12. Scan path second data set (validation)

more distinct in the scan path, than in the heat map. When analysing the heat map, be aware of the strength of the colour coding in the generation of the heat map can be adjusted in the manufacturer software [48], and is not uniquely. The increased resolution of the amount and placement of fixations in the scan path visualization, will support a better understanding of the eye tracking data.

The analysis of the eye tracking data from the post mid-life data set indicates that several of the AOIs have been marginalized in the mid-life update, shown in Fig. 13. AOI Console, Display, Heading and Radar has less than 1.5% of the total time. Since this was a passage conducted in daylight, it would be reasonable to suggest a vigorous increase in the attention to AOI radar during hours with reduced visibility or darkness. The total time in AOI for the second data set indicates an increase in the time spent addressing the ECDIS, and a retrogression in the accumulated visual attention in AOI Outside. One of the main objectives for the design review was to transfer more of the visual attention of the navigator to the actual surroundings of the vessel (AOI Outside).

4   Discussion

By comparing and analysing the visualization maps (Figs. 7, 8, 11 and 12), one could argue that the design changes conducted in the mid-life update has contributed to fewer areas for the navigator to focus on. Comparing the heat map (Figs. 7 and 11) indicates that the overhead displays, consoles and upper right corner in the radar (heading bearing) is removed as areas where the navigator focusses its' visual attention. Attention to these areas were identified as design flaws in the pre mid-life data set. The post mid-life update heat map (Fig. 11) indicates more visual attention to AOI ECDIS, and clearly indicates increased visual attention to the new HSCRM window located in the centre-left part of the AOI ECDIS as expected. The heat map also suggests more visual attention to the centre part of AOI radar, which shows an increased awareness from the navigator towards the operational valuable information provided from the radar (Fig. 3 – System awareness). By addressing attention to the centre of the radar, the navigator interprets the radar picture and evaluates and compares the surroundings of the vessel with a terrestrial mean. This will contribute to a higher degree of SA for the navigator, and thus supporting safe operation of the vessel.
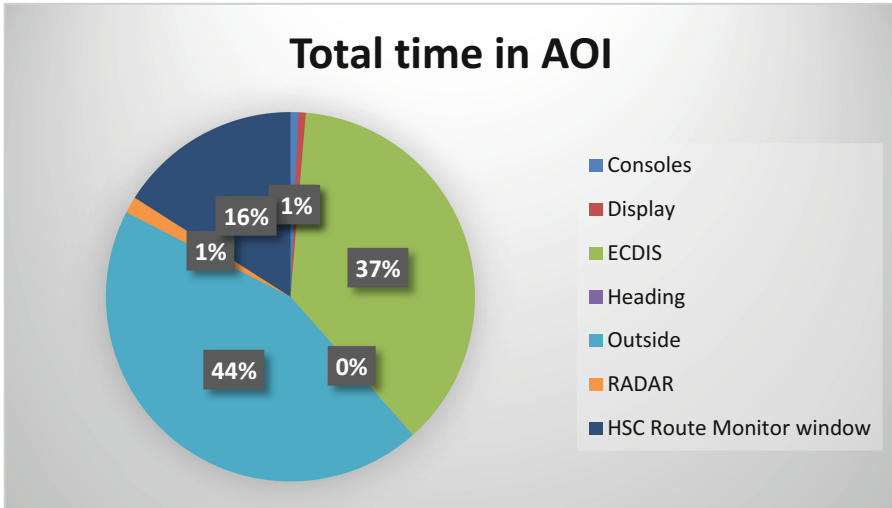
Fig. 13. Total average time in AOI post mid-life update data set

Analysing the scan path (Figs. 7 and 11), indicates a neater scan pattern for the navigator. The post mid-life update data set holds less scanning clutter, and this could contribute to a more efficient and less time consuming visual scan pattern for the navigator [1].
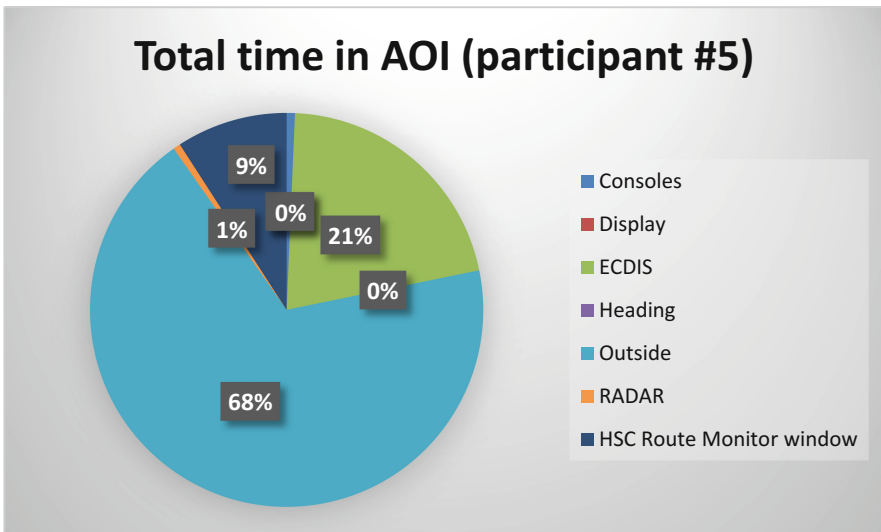
Total time in AOI (Figs. 9 and 13) shows an undesirable increase in the visual attention towards AOI ECDIS, and a decrease in the attention in AOI Outside. One could argue that an increase in attention towards AOI ECDIS will support increased SA (Fig. 3 - Task and System awareness) for the navigator as long as the chart is in focus, but the solution of the eye tracking data is not good enough to support the assumption that the visual attention is allocated to the chart alone. The design revisions aim was to support more attention towards AOI Outside, and the post mid-life update data set indicates the contrary. To better understand this finding, each of the participant's data set has been analysed, and there are discrepancies in the visual attention which are ambiguous and challenging to analyse.

When analysing the data individually, the difference from participant to participants becomes clear. If introducing experience and familiarization with the new design and software as a variable, it is a clear indication that the amount of time spent in AOI Outside is dependent on experience and familiarization. This is shown in Table 1.

When analysing the data from the participants in Table 1, the values gives an indication that the experience and familiarization time with the new SW, installed during the mid-life update, is a variable affecting the visual attention of the navigator. This is shown with participant 5 s time in AOI in Fig. 14, showing a high amount of attention towards AOI Outside, which is opposed to the accumulated visual attention in Fig. 13.

Table 1. Relation between experience and total time in AOI.

Participant	Total time in AOI outside (%)	Years of experience (years)	Time with new SW (months)
#1	43.52	1	2
#2	27.17	0.5	0
#3	46.24	4.5	0
#4	45.24	2.5	1
#5	68.49	5.5	4
#6	39.16	0.5	3

Fig. 14. Total time in AOI post mid-life update data set for participant #5

To better understand and analyse this finding, the most and least experienced participant of the subjects who participated in both data collections where analysed. This was the same persons in both data sets, and is shown in Tables 2 and 3.

Table 2. Comparison of the most experienced participant in the two data sets.

Data set/AOI (%)	Outside	ECDIS	Route monitor	Radar	Conning
Pre mid-life update	70%	14%	8%	3%	5%
Post mid-life update	68%	21%	9%	1%	1%

Table 3. Comparison of the least experienced participant in the two data sets.

Data set/AOI (%)	Outside	ECDIS	Route monitor	Radar	Conning
Pre mid-life update	47%	29%	10%	5%	9%
Post mid-life update	27%	49%	21%	1%	2%

Analysing Tables 2 and 3 can explain the deviation in the expected increase towards AOI Outside. Both experience and familiarization with equipment is known to be important variables when utilizing the navigation system [49]. Table 2 show how an experienced navigator with 4 months of familiarization on the new GUI shows good progression in utilizing the visual scan and direct the attention towards AOI Outside. Tables 3 indicates how an inexperienced navigator has challenges with operating unknown software, and must thus direct more attention towards the new design (the ECDIS and HSCRM window). Glover [50] presents the planning-control theory in visual representation, where he argues that human action is directed by a control system, while the perception is commanded by a planning system. This implies that a human (the navigator) take account for a wide variety of visual and cognitive information when conducting the planning of an action. This information is further integrated with memories of past experience, which could explain why experience is an important factor when using a system. This provides a link to how experience contributes to the navigator's SA.

Table 4 shows the higher SD in the post mid-life update. The SD could be a measure of the familiarity with the software and GUI. This is analysed as an indication of a higher familiarization with the software and GUI used in the pre mid-life update. All participants were familiar with the GUI in the pre mid-life update, since it had been in use for several years.

Table 4. Comparison of standard deviation in the two data sets

Data set/measure	Standard deviation in AOI outside
Pre mid-life update	8.3%
Post mid-life update	12.3%
Increase in % between pre- and post-mid-life update measures	48.2%

The importance of familiarization and experience is supported by earlier studies with eye tracking, and the findings in this study indicates the importance of both experience and familiarity with new software and design as factors [51–53]. It also indicates an important finding concerning operational use after post mid-life updates, which indicates that the low level of experience and low level of familiarization with new software decreases the visual attention towards AOI Outside. This could in turn contribute to a decrease in the SA of the navigator, and thus in the degree of safe operation. The importance of familiarization is thus supported and outlined by the findings in the two data sets [49].

The design of the method will contribute to less uncertainty when analysing pre- and post-mid-life updates of design. The pre mid-life update data set consist of 10 recordings and participants, while the post mid-life update data set consists of six recordings and participants. Five of the participants attended both data collections, and the two data sets where identical in conduct but not with regards to attendance of participants. With an increased amount and same number of participants in both data

sets, the analysis will be less ambiguous. It would strengthen the data set if the same participants took part in both data collections, and the design of the two data sets should be identical to avoid sub-optimal analysis of data sets. The findings in the data set does not support the hypothesis that the two data sets are similar within a statistical significant level of 5%, partly due to the low number of participant (F-value 0.45, p-value = 0.14). To achieve a p-value of less than 5%, with the assumptions of the same values as in the current data set, the amount of participants must be almost four times higher. This would be very difficult and time consuming to achieve in an operational environment with personnel in active duty.

Collecting eye tracking data in an operational environment, such as the bridge simulator, is challenging [54], and the ETGs and the manufacturer software is not mature to meet the demands of the operational environment in this study. It is also evident that data collection with personnel in active duty is challenging and changes in plan on short notice must be expected. Research will not supersede operational demand.

When comparing the analysis of the eye tracking data with the information collected from the SMEs in the working group, there are sufficient indications of an improvement in the mid-life update bridge design to support a higher degree of SA for the navigator. The qualitative measurements from the workshops is emphasised as an important support for the quantitative measurements, due to the ambiguities in the eye tracking data due to immature technology (ETG robustness and manufacturer software) and sub-optimal method design.

5   Conclusion

ETGs has shown a potential to support identifying design and GUI challenges that contributes to a decrease in the SA of the navigator, and in validation of design changes of ship bridges. This study shows that the quantitative data needs support from qualitative data to be unambiguous. The use of eye tracking data such as visualization maps provides a simple and intuitive measure for identifying changes in visual search pattern after a design alteration, but the process of analysing the data is time consuming. The eye tracking data is useful as a basis for the design-review, and as evidence and support for the discussions and conclusions in the technical working group. However, eye tracking technology used to collect data in an operational environment with ETGs, is in this work assessed to be immature.

The collected data set shows the uncertainties related to eye tracking data when the amount of participants is relatively low, and the challenges concerned with few possible participants when conducting studies in a narrow domain.

The importance of experience and familiarization with new design is salient, and this study shows that the participants must be given ample time to familiarize themselves with the new design and software to conduct a better and less unambiguous analysis of the eye tracking data. This finding is also important for the operational domain, concerning familiarisation with new equipment before operational use.

The method and procedure when conducting the data collection are imperative with regards to the quality of the data collected. The cost and effort of collecting an eye

tracking data set in an evaluation of a bridge design or software GUI, must be weighed towards the benefits, and the technology is at this time argued to be immature to collect eye tracking data from an operational environment.

If conducting maritime usability studies with data collected by ETGs, it is recommended to support the quantitative measurements with qualitative data for correlation and less ambiguity.

5.1   Further Work

Collect a new post mid-life update data set with optimal method design, in order to control the main objective of increased time in AOI Outside.

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