SHOW ME WHERE YOU LOOK AND I’LL TELL YOU IF YOU’RE SAFE: EYE TRACKING OF MARITIME WATCH-KEEPERS

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There is a common belief that experienced ship’s officers look out more through the window than novices who believe more in instruments. This pilot study focused on how the visual attention is shared between the window and the instruments available on the bridge. Using an eye tracker, eye movements were recorded from six scenarios in a ship simulator. The results show that eye tracker equipment can be used in a ship simulator, and provides information which can be highly relevant concerning safety aspects, bridge design and training programs.

Eye tracking, Ship simulator, Maritime safety, Training

1 Introduction

Experienced mariners worry that young navigators may over-rely on instruments and emphasise the need to also look out of the window, see Beer (2006) for a review of accidents in which inappropriate visual behaviour may be one cause. A proper lookout is for the safety of others, not only for the safety of your own ship. Regulations require that: A proper lookout shall be maintained at all times in compliance with the… International Regulations for the Prevention of Collisions at Sea, 1972, and shall serve the purpose of…detecting ships or aircraft in distress, shipwrecked persons, wrecks, debris, and other hazards to safe navigation (International Maritime Organization).

One way to understand how navigators think and reflect about navigation is to record their eye movements. Within air and road traffic studies have been performed to describe the visual behaviour of pilots and drivers to improve safety and cockpit design but also to improve training programs. Eye movement provides an on-line measurement of visual and cognitive processing of information (Liversedge & Findlay, 2000). Two parameters are usually employed: what the eyes are fixated upon in the environment and how long those objects are fixated. Several factors supposedly influence eye movements during the performance of the navigation task which is the focus here:

- Experience level: Novice drivers have a higher mental workload whilst driving than experienced drivers, because they have more limited mental resources in the task of vehicle control, and a poor mental model of what is likely to happen. This leads to a different (Falkmer & Gregersen, 2005) and less efficient (Underwood, Chapman, Bowden, & Crundall, 2002) visual inspection of the road.
- Mental load: An increase in mental workload reduces the ability to use and react to available visual information. It affects the field of view, and reduces the detection
capabilities in the peripheral area (Miura, 1987). More time is spent looking straight ahead, highly relevant for shipping, as keeping a safe lookout involves detecting all ships in the vicinity.

1.1 The navigation task
Navigation today is very different from the past. Navigators have become highly dependent on navigational aids such as radar and electronic sea charts. New technical instruments make navigation simpler and less time consuming, but, becoming dependent can be a risk and a potential cause for incidents. The overlap of available information between instruments and looking out is not complete. Some information which is visible outside is not available from instrument data and vice versa. The task on a ship’s bridge includes on a very basic level:

- Navigation: knowing where you are and where you are going.
- Anti-collision: keeping a good lookout and following the anti-collision rules, e.g., giving right of way to ships on the starboard (right) side.

For this task, several instruments are available as aids:
- Radar shows objects above the water surface such as other ships, leisure craft and land. However, radar is not a substitute for a visual lookout, as small objects may not be visible on the screen. Many radars today have ARPA (Automatic Radar Plotting Aid).
- A navigational chart is used to plan the voyage and to keep track of the ship’s position. It may be a paper chart, and/or an electronic chart, whereof the most advanced is known as ECDIS: Electronic Chart Display and Information System.
- A conning screen is often placed centrally. It may show position, speed, course, wind, drift information and autopilot and engine parameters.
- Most large merchant ships today have AIS - Automatic Identification System - a transponder which sends own ship’s identity and other information to nearby ships.

2 Objectives
This pilot study focused on how the visual attention of a bridge watch keeper is shared between the outside environment and the bridge instruments. There is a belief that experienced navigators look more through the window than novices who trust more in instruments. Moreover, it was a test of the eye tracker technique in a bridge simulator.

3 Methods
3.1 Material
Two maritime bridge simulators in Sweden were used, one at Chalmers University in Gothenburg and one at the Maritime Academy in Kalmar. The two are very similar and equipped with similar instruments, as detailed in Table 1. The bridges are designed with two workplaces so that navigators may use the “pilot – co-pilot” system. In front of the bridge, on a large screen of 270 degrees (most common, less or more exist), a projection of the environment is shown as if seen through bridge windows. The eye tracker is a helmet-based system called iVIew from SMI®.

3.2 Subjects and scenarios
Table 1 summarises information on the subjects and the scenarios. For each subject, 15-20 minutes was analysed. The first 5 minutes for each subject were considered a familiarisation phase, and therefore not analysed.
Table 1: Subject included in the study and their characteristics

<table>
<thead>
<tr>
<th>Subject</th>
<th>Degree of experience</th>
<th>Scenario</th>
<th>Simulator</th>
<th>Crew</th>
<th>Instruments available</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Experienced navigator</td>
<td>Navigation in fog</td>
<td>Kalmar</td>
<td>One co-pilot</td>
<td>ARPA, conning, centre console (CC)</td>
</tr>
<tr>
<td>2</td>
<td>Student</td>
<td>Navigation in Sydney fairway</td>
<td>Kalmar</td>
<td>Alone</td>
<td>ARPA, conning, chart, ECDIS, CC</td>
</tr>
<tr>
<td>3</td>
<td>Student</td>
<td>Ship to ship manoeuvre</td>
<td>Kalmar</td>
<td>Alone</td>
<td>ARPA, conning, CC</td>
</tr>
<tr>
<td>4</td>
<td>Student</td>
<td>Navigation</td>
<td>Gothenburg</td>
<td>One co-pilot</td>
<td>ARPA, conning, ECDIS, CC</td>
</tr>
<tr>
<td>5</td>
<td>Student</td>
<td>Navigation</td>
<td>Gothenburg</td>
<td>One co-pilot</td>
<td>ARPA, conning, chart, CC</td>
</tr>
<tr>
<td>6</td>
<td>Experienced navigator</td>
<td>Arrival Gothenburg harbour</td>
<td>Gothenburg</td>
<td>One co-pilot</td>
<td>ARPA, conning, ECDIS, CC</td>
</tr>
</tbody>
</table>

3.3 Definitions of analysed eye indicators
- **AOI - Area of Interest**: Where the subjects looked during the studied manoeuvre.
- **% of gaze**: Total visual time spent within an area of interest. Total time gaze is related to how the subject collects visual information in order to perform a task.
- **Mean glance duration**: Time from the moment at which the direction of gaze moves towards a target to the moment it moves away from it.
- **Scan path**: Differences in scan path could be attributed either to differences in experience or/and differences of scenario characteristics.
- **Number of glances per minute**: This shows how often the eyes shift target.

4 Results
4.1 Area of interest
First, areas of interest were identified for each scenario, i.e. areas the subjects looked at, and the respective percent of gaze within each area (Table 2).

Table 2: Percent of gaze in each Area of interest for the five subjects

<table>
<thead>
<tr>
<th>% gaze in AOI</th>
<th>ARPA</th>
<th>Conning</th>
<th>Centre console</th>
<th>Window</th>
<th>Chart</th>
<th>Electronic chart</th>
<th>ARPA 2</th>
<th>Colleague</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject 1</td>
<td>77</td>
<td>8</td>
<td>9</td>
<td>0,5</td>
<td>-</td>
<td>-</td>
<td>5</td>
<td>0,5</td>
</tr>
<tr>
<td>Subject 2</td>
<td>10</td>
<td>8</td>
<td>12</td>
<td>52</td>
<td>5</td>
<td>3</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Subject 3</td>
<td>37</td>
<td>22</td>
<td>11</td>
<td>30</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Subject 4</td>
<td>34</td>
<td>9</td>
<td>7</td>
<td>19</td>
<td>-</td>
<td>30</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Subject 5</td>
<td>70</td>
<td>3</td>
<td>8</td>
<td>16</td>
<td>1</td>
<td>-</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Subject 6</td>
<td>3</td>
<td>9</td>
<td>18</td>
<td>45</td>
<td>-</td>
<td>20</td>
<td>-</td>
<td>4</td>
</tr>
</tbody>
</table>

4.2 Mean gaze duration
Mean gaze duration for the six subjects is presented in Figure 1.
4.3 Scan path analysis

For comparison, two examples are presented; subject 2 (S2), an inexperienced cadet, and subject 6 (S6), an experienced navigator. In the following, Figures 2 and 3, grey arrows represent >4% of gaze, green arrows <4% gaze. The scan path of S2 seems disorganised, with glances to and from most instruments, and numerous glances to and from the window during the approach to Sydney harbour. The visual scanning pattern is based around the window, with few glances from and to ARPA. The paper chart takes a large place in his visual scan path, and glances to the chart mostly come from the window. We assume that S2 had a high workload with a lot of stress, since later during the run, S2 ran aground (please note that Figure 2 is not a photo of S2).

The scan path for S6 (Fig. 3) was well organised between the window, centre console, conning and ECDIS. An aspect which is not possible to show here is the low variation of gaze. S6 often focussed on one point within an area of interest.
4.4 Number of glances per minute
Number of glances per minute was: S1: 5, S2: 15, S3: 19, S4: 15, S5: 17, S6: 13.

5 Discussion
The number of glances per minute tends to be lower for experienced navigators (1 and 6), but the difference is small. This indicates a lower workload, as experience guides their search for information and situation parameters. S1 had a rate of 5 which seems in accordance with his well organised scan pattern. One might have expected tunnelling for S2, due to high workload. This is not evident; rather he seems to perform a frantic search, and half of the time is spent looking out of the window. S3 had a high rate, 19, which might not reflect the level of workload but a necessary change of his visual angle to see the other ship in the scenario. S4 and S5 had a similar rate of glances, 15 and 17 (same subject, different bridge set-up). A comparison indicates that when an electronic chart is unavailable, navigators shift their attention to the ARPA, rather than to the paper chart (only 1%). S6 was experienced and had a well organised scan path. At 13 glances/min, he moves his gaze slowly, which means that he knows what he is looking for. The area of interest varied between subjects depending on the scenario and their experience or strategy. Most of the measurements show a stable and reoccurring comparison between radar and window (not in harbour and not when berthing).

5.1 Limitations of the study due to methodological issues
This pilot study is based on six subjects which is a small sample. Some scenarios are difficult to study, as subjects can behave differently in a simulator compared to reality.

5.2 Safety aspects
From a safety point of view, a navigator looking both through the window and at the instruments is preferable to one just looking at instruments. It is interesting to note that S1 (well experienced) looked through the window even during navigation in fog. S1 navigated most of the time with the ARPA whereas S2 looked almost everywhere, at the paper chart and more than 50% of the time out through the window. Differences between S1 and S2 could be attributed to weather conditions, to their level of
experience or to their level of mental workload. S2 was judged to be under high mental workload, and his scan path indicates uncertainty about his position and navigation as his gaze moves between the paper chart and the window. S3, S4 and S5 had well organised scan paths and use similar amounts of time on ARPA, window and centre console. The two most commonly used information sources were the radar and the window. The gaze duration is relatively well distributed across instruments. We assume that subjects with co-pilots (1,4,5,6) were assisted with chart-related parts of navigation. Therefore the time spent on each instrument may be biased and not directly comparable between subjects. With more control over the scenarios, this can be corrected for.

So did we find that experienced navigators look out more? From our limited sample, we cannot say this. Here, it seems cadets and experienced navigators are very similar. It also depends on the task – navigation in fog naturally does not merit looking out very much. With an increased number of measurements, we expect to see differences, but they may have to be performed in realistic settings.

5.3 Future work:

Design issues: With more data we could search for scan path patterns to study how navigators gather information effectively. We would also use think-aloud methods, since the resolution of the eye tracking equipment does not permit analysis of exactly what subjects look at. This can be used to design instruments and optimal placement of information on screens and panels in relation to each other, the window and the task.

Education: More training will take place in simulators in the future. With further studies we expect to provide recommendations on a safe and effective way of looking during navigation. Similar studies have been performed for car drivers where recommendations are given to novices about where to look to collect relevant information.

6 Acknowledgements

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7 References


