

## Improved situation awareness in navigation using egocentric view 3-D nautical charts

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### Abstract

In spite of all electronic navigation devices on a modern ship bridge, bridge crews sometimes lose their orientation. Reasons for this might be excessive cognitive workload caused by fatigue, short decision times due to high speed or too many instruments to read and integrate. By tradition electronic chart displays and radar screens are displayed in north-up orientation. On south bound courses this necessitates mental rotations to align the chart with the real world. Research has shown mental rotations to take time and to be a possible source of errors.

In an information design research project on intuitive maps at Mälardalen University in Sweden, a 3-D nautical chart has been proposed allowing the bridge crew to access an egocentric bridge perspective of the chart. The cognitive workload is supposedly eased when mental rotations no longer are needed.

To test this hypothesis, a laboratory experiment was designed. Forty-five subjects each drove a vehicle through four different mazes using four different types of maps: a traditional paper chart, an electronic chart plotter in north-up mode, an electronic chart plotter in course-up mode and the proposed egocentric 3-D nautical chart. The experiment showed significant results suggesting that navigation with a 3-D egocentric display leads to faster decision making and less errors.

*Keywords: maritime ergonomics, vehicle ergonomics, cognition and human computer interaction*

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### 1. Introduction

In 1999 the Norwegian high speed ferry *Sleipner* lost orientation for some 20 seconds while going in full speed along her regular route between Stavanger and Bergen. The result was that she grounded on a rock and 16 persons lost their lives. Loss of orientation has been the cause of several accidents in recent years [1].

Onboard most ships navigation is by tradition aided by radar and chart displays presenting their world representations in an exocentric north-up perspective. To line up the chart or radar image with the navigators own egocentric surface view of the real world, s/he has

to mentally rotate the map representation twice: First the radar or chart image has to be rotated around the vertical z-axis to a course-up position (if the ship is on a southerly course this will mean a 180 degree rotation), then the image has to be rotated 90 degrees around the new y-axis (to "land the bird" and see the map from the surface). Mental rotations take time and can be erroneous, which has been shown by e.g. Shepard & Metzler [2] and Eley [3]. As vessels' speeds increase, decision time may be in short supply.

*Situation awareness* (SA) was a term used by Endsley and others in the 1980's to describe problems with mastering the ever increasing complexity in

aviation systems. Simply put, SA is the concept of *knowing what is going on* and how this will affect you now and in the future. Endsley defined it as “The perception of elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future” [4].

Looking at the SA of the geographical position, a navigator can be more or less certain of his position during a voyage. The area of uncertainty varies over time. The real position of the ship is more or less close to his believed position. The distance between the real position and some measure of his believed position varies over time. The acuteness of exact position knowledge may also vary during the voyage. In confined waters there will be a need for high position SA certainty and low SA error. In the open sea needs can be more relaxed.

In a research project, for a PhD in innovation and design at Mälardalen University, a new 3-D nautical chart is being studied with the purpose of allowing more direct understanding of the mapping between chart information and the environment. I call this “intuitive map reading.” The idea is that less cognitive workload is needed to resolve problems like “Where in the world/on the map am I?” “Where is there enough water for my ship?” “Which course must I steer to reach my destination /avoid dangers?” [5] (see Fig. 1 and 2).

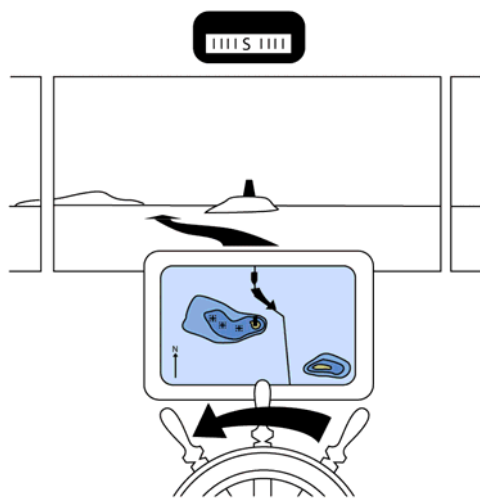


Fig. 1: Charts and radar displays are normally used in a north-up mode. On this south bound vessel, a desired action to pass on the east side of the beacon (to the right on the chart display) leads to a turn of the wheel in the opposite direction (port/left). This can be confusing.

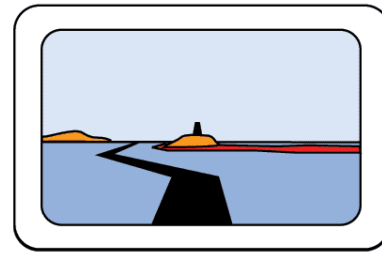


Fig. 2: A conning display showing a 3-D chart from an egocentric bridge view perspective would simplify decision-making in this situation.

In this paper I will present an experiment conducted to test the hypothesis that the problem of mental rotations could be resolved by allowing the navigator access to an egocentric, “bridge view” of the chart during *conning* (the actual driving of the ship).

In the laboratory experiment traditional electronic chart plotters in course-up and north-up modes were compared to traditional paper maps, and the suggested egocentric view 3-D chart.

Measuring situation awareness can be cumbersome. Several researchers have reflected on this [6,7,8]. Knowledge-based and verbalization self assessment methods might be distracting, intrusive into operator’s task or misleading. One can not be aware of what one is not aware of. Performance-based measurements are more unambiguous so the experiment was designed to measure two such parameters.

## 2. The Experiment

### 2.1. Hypothesis

My hypothesis was that navigating in an egocentric frame of reference is more efficient (faster due to quicker decision making and less erroneous) than traditional methods, i.e. electronic maps in course-up/head-up, north-up modes and traditional paper maps. A small maze, mimicking the confined waters of an archipelago, was used for the experiment.

### 2.2. Experimental Setting

A 6 by 6 m square was marked on the floor in a studio. The square was divided into an invisible 10 by 10 grid squares. Each square measured 0.6 by 0.6 m. Four landmarks in the form of one double and one single cardboard box pile, one paper cylinder and one chair were placed in the area as to serve as reference points. Four different archipelagos were designed. For

each archipelago I constructed one conventional 2-D map and one 3-D model. In figure 3 top, a photo of the experiment area, the four landmarks and a subject driving the vehicle, can be seen.

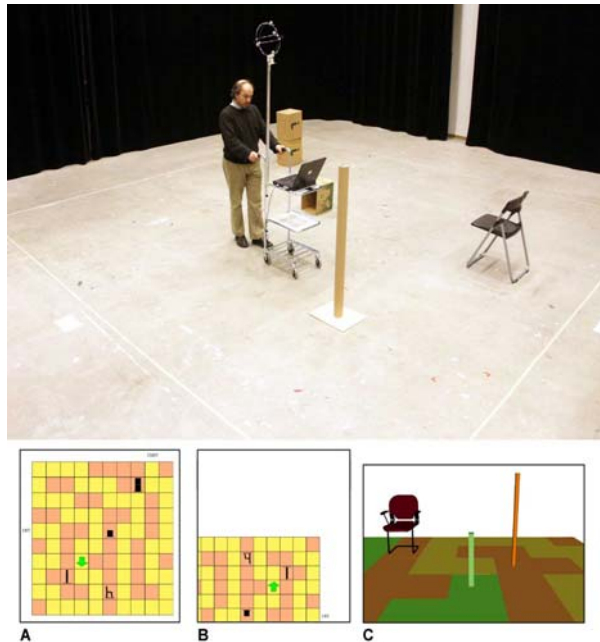


Fig. 3: Top, the laboratory archipelago, a 6 m by 6 m area with four landmarks and a subject driving the cart. Bottom left (A) the 2-D map in the north-up mode as it was shown on the screen of the laptop computer on the cart for the very position shown in the top picture. The middle (B) map is the 2-D map in course-up mode and right (C) is the 3-D map.

As a boat a small four wheeled cart covering a ground plane of 0.45 m by 0.38 m was used. All four wheels could rotate, making the cart easy to manoeuvre. The cart had a shelf where a laptop computer was fitted. The computer ran on batteries so no cords had to be attached to the cart during the experiment. The computer was fitted with a custom made real-time 3-D software application that was used to show both the 3-D egocentric chart and the 2-D exocentric north-up and head-up plotted charts. The application was also used to monitor and log time on track and the number of “groundings” made by the subjects.

The four archipelagos were constructed in the same grid. Each archipelago consisted of “deep water” and “shallow water.” The deep water areas had a light (yellow or brownish) colour on the maps and the shallow areas had a darker red or brown colour. If the

cart entered into the shallow areas a “grounding” were recorded.

It was possible to navigate through each archipelago on a track of deep water from an entry position to an exit. There was only one track so no decision making had to be made as far as which way to go. The subjects only had to translate the map to the real world. Each track through the archipelagos had about the same length and about the same amount of turns in different directions.

The subjects always used the four different tracks from 1 to 4 in that order, but the map type used for each track was randomized.

A Qualisys Medical infrared tracking system was used to detect the position of the cart in 6 DOF and send x, y and heading back to the laptop by wireless LAN as to mimic a GPS system. The uncertainty of the system setup was less than 2 cm. The update frequency of the tracking system was 50 Hz.

### 2.3. The four map types

The *paper map* was similar to map A, bottom left in figure 3, but without the position arrow. Subjects held the paper map in their hand and were allowed to rotate it or keep it north-up as they wished. They still had to drive the cart through the track using the other hand as the application logged their results. (This was really easy as the cart was light and easy to manoeuvre.) The other three map types were presented on the laptop screen of the cart.

The *north-up map* is shown as map A, bottom left in figure 3, the way it was presented on the laptop of the cart in the situation depicted in the photo, top. The map was fixed and the position of the cart was presented as a small green arrow that moved and rotated on the map.

The *course-up map* is shown in B, bottom middle in figure 3. It shows the same situation as depicted in the photo and in maps A and C. Here the green position arrow was fixed in the centre lower half of the screen and the map moved and rotated as the cart moved.

The *3-D map* is shown in C, bottom right in figure 3. A green rod fixed in the middle of the screen represented the position of the cart and the 3-D map moved and turned much as the VR landscape in a computer game. The screen dump in C represents the position of the cart in the photo.

## 2.4. Test subjects

Forty-five subjects were randomly selected from a population of available students, teachers and personal at the department of Innovation, Design and Product development at the university. 24 were male and 21 female. They had different navigational experiences. Some had very little or ordinary experience, some were active orienteer or amateur sailors; one was a schooled naval corvette navigator enlisted in the Swedish incident force.

The subjects were first guided through a practice session on a special trial track. When the subjects agreed on having understood the process the experiment started. Each subject drove the cart though all four tracks. The order in which the different maps were used was randomized. The instruction to the subjects was to drive the cart though the archipelago as fast as possible with as few groundings as possible.

After the four sessions a short interview took place. The subjects were asked about their previous navigation experience and they were asked to fill in a ranking form where they ranked the four map types after perceived user-friendliness. They also took a psychological figure rotations test, to try to establish some sort of objective measure of their spatial abilities.

## 3. Results

### 3.1. Main results

The results show that the use of the 3-D chart in an egocentric frame of reference was the “fastest” with a mean time on track for all 45 participants of 111 s, the head-up chart came second with a mean of 142 s, then the north-up map with 167 s and the paper chart with 230 s (see Fig. 4). In this test, decision making using the north-up map was 1.4 times faster than using a traditional paper map, the head-up map 1.6 times faster and the 3-D map 2.1 times faster than using the paper chart. When observing the experiment, it was evident that it was the decision making process – hesitating in a corner, deciding which way to turn – that was the major cause of time difference.

The number of “groundings” gave the same results: using the 3-D map resulted in the fewest number of groundings with a mean of 1.7 groundings for the whole group; the head-up map 3.6, north-up 4.2 and the paper map 8.2 (see Fig. 5). So navigation using a north-up map resulted in 0.5 times the number of groundings as compared to the traditional paper map, using the head-up map 0.4 times as many and using the

3-D map 0.2 times as many groundings as using the paper map.

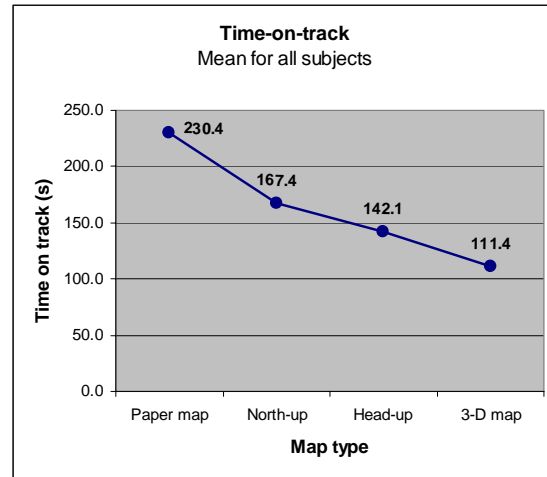


Fig. 4: The mean time (y-axes) for all subjects on the track split up on the four different map types (x-axis).

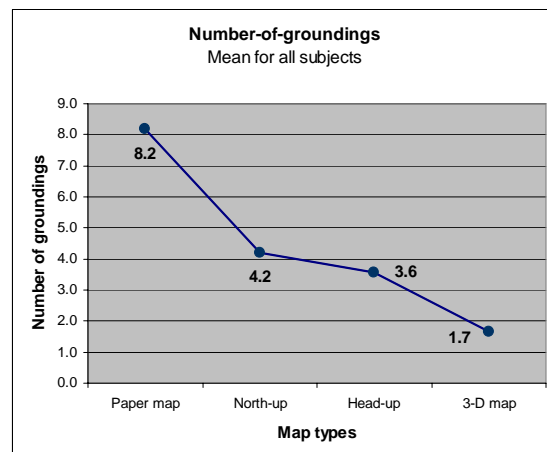


Fig. 5: The mean number of errors (y-axes) for all subjects on the track split up on the four different map types (x-axis).

The difference in time on track between the map types is statistically significant at the 1% level. ( $F(3,132,0.01) = 46.6, p < 0.01$ ). The same is true for the number of “groundings”. The influence of the map type on the number of groundings is statistically significant at the 1 % level ( $F(3,129,0.01) = 3.94, p < 0.01$ ).

After the test the subjects were asked to rank the perceived user-friendliness of the different map types

on a scale from 1 – 4, where “1” was the easiest and “4” the most difficult map to use. The 3-D map was classified as the easiest with a mean index of 1.1 followed by the head-up map with a mean index of 2.3. North-up had 3.2 and the paper map 3.3. (These are the black dots in Fig. 6.) Interesting to note is that the paper and the north-up maps were considered almost equally difficult to use while indexing the results for time-on-track in a similar manner (white dots), showed clearly better results with than the north-up map than with the paper map.

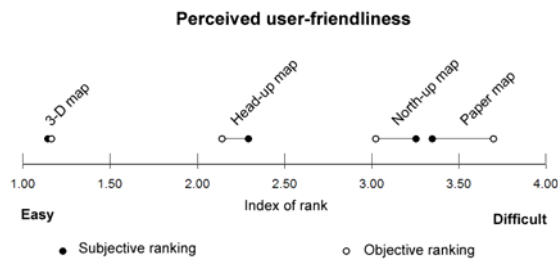


Fig. 6: Subjective ranking of user-friendliness. See the text for an explanation.

### 3.2. Results more in detail

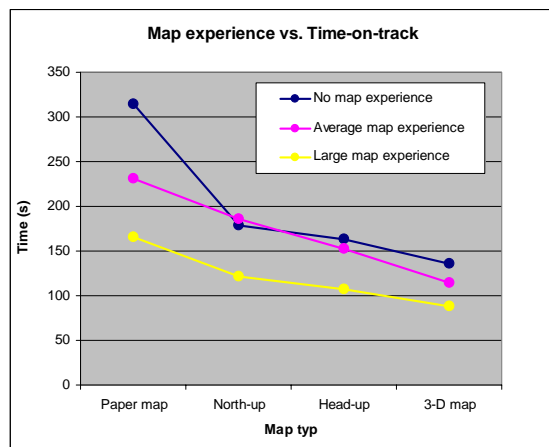


Fig. 7: Time-on-track split for three groups of experience in navigation. Dark blue (top) curve, “little” experience, light yellow (bottom) curve, “large” experience.

#### 3.2.1. Influence of experience

The subjects map experiences were classified into three groups: “large” (e.g. the subject had been competing in orientation, had long experience of

navigating leisure boats), “average” or “little.” The group with “large experience consisted of 12 subjects, the “average” group of 23 and the “little” group of 9. The mean values of time-on-track for each group are shown in Fig. 7. The results did not show a significant difference.

#### 3.2.2. Influence of gender

Splitting the test results for the 21 female and the 24 male subjects and looking at the mean value for *time-on-track* we see a small difference in the results favoring male navigation in the maze. The difference reached almost significance on the 5 % level for the paper map test for *time-on-track* ( $p = 0.051$ ) and *number-of-groundings* ( $p = 0.054$ ). For the 3-D map the sex difference was not significant,  $p = 0.119$  for *time-on-track* and  $p = 0.162$  for *number-of-groundings*. See Fig. 8.

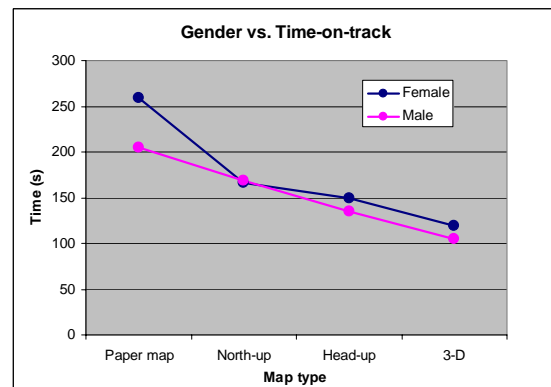


Fig. 8: Time-on-track split for male and female subjects. The dark blue curve is the female subjects and the light purple curve is the male subjects.

#### 3.2.3. Influence of age

A division into age groups was made to see if there was any difference in the results of navigation between people of different ages. Three groups were formed: age 16-29 (19 persons), age 30-49 (14 persons) and age 50-63 (11 persons). As far as navigating with the paper map there is a significant difference on the 5 % level between the age groups 16 – 29 and 50 – 63 for *number-of-groundings* ( $p = 0.031$ ) and very close to significance for *time-on-track* ( $p = 0.053$ ). See Fig. 9.

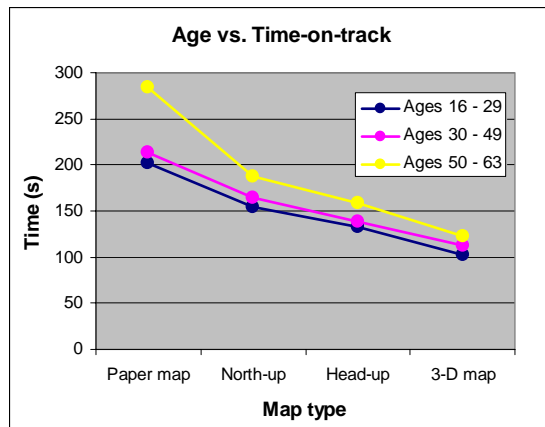


Fig. 9: Time-on-track split for subjects divided on three age groups.

#### 3.2.4. Influence based on spatial test score

All subjects were tested on the figure rotation test generally a part of a battery of tests used to judge spatial abilities. The results of the test were normalized into a *stanine* value 1-9, where 5 is the mean value for the normalization group. The mean value for this test group was 6.9. The test score for time-on-track was divided into three groups of stanine values 3-5, 6-7 and 8-9. The results are shown in Fig. 10.

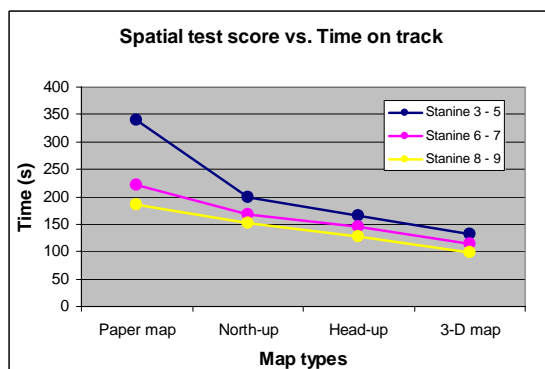


Fig. 10: Time-on-track for subjects split on three groups of different spatial ability according to results on the figure rotation test.

## 4. Conclusion

The results shows clearly that, at least in the laboratory archipelago, the 3-D map displayed in an egocentric frame of reference was more efficient than 2-D maps in head-up or north-up mode, or a traditional paper map. There was also a clear preference for the

3-D map before traditional exocentric maps.

Looking at the test results by splitting them into groups of different ages, gender, experience and spatial ability gave non-significant results which nevertheless support results presented in e.g. [9], that spatial ability generally decreases with age and favours males.

That experience influences the results is suggested, and also that map type influence both experienced and inexperienced the same.

That spatial ability, as measured by the figure rotation test, has something to do with the navigational skill is also suggested.

The tendency was the same for the number-of-groundings results. These results are omitted here for lack of space.

This project is aimed at nautical navigation but results may be equally important for navigation in for example cars. Future field experiments will show if the results will hold true in real world conditions.

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