The effect of a superimposed display on navigational performance

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Biography

Leo van Breda obtained a B.Sc. degree Electical Engineering in 1968, and joined TNO Human Factors Research Institute in Soesterberg, the Netherlands in 1971. He participated in human factors studies on the potential benefits of ship bridge automation. During a sabbatical leave at the Defence and Civil Institute for Environmental Medicine (DCIEM) in Toronto, Canada, he further specialised in the use of analysis techniques for human-machine interface design, with the emphasis on network modelling techniques for performance prediction. Since 1990, his main research activities concern vehicle control and tele-operation studies.

Peter O. Passenier is with the Information Transfer Group of the Department of Information Processing of the TNO Human Factors Research Institute. Before working at TNO, he studied electrical engineering at Delft University of Technology. After his graduation he joined the Control Laboratory at the Faculty of Electrical Engineering as a member of the scientific staff. In 1989 he obtained a Ph.D degree on the design of an adaptive track predictor for ships.

Abstract

A simulator experiment was conducted to investigate the potential benefits of a maritime Superimposed Information Display (SID). Participants were requested to cross a traffic separation scheme with a high-speed vessel. Two display types were used: (i) standard Automatic Radar Plotting Aid (ARPA) navigation display information with advanced collision-avoidance facilities; (ii) ARPA display information supplemented with a SID, presenting information projected over the outside world scene with a horizontal viewing angle of 100°. In the SID, a cursor was available to select possible (unidentified) objects in the out-of-the-window scene; the selected object's position was then calculated and included in the ARPA collision avoidance calculations. The participants were instructed to keep all traffic vessels as well as unidentified objects at a minimum safety distance of 1.0 nm. Task difficulty varied with the number of vessels in the traffic situation. Performance was assessed in terms of time to detect the unidentified object and in terms of violation of the minimum safety distance to any floating object. Results of the experiment indicate that there was a significant improvement in detection speed of unidentified objects when a SID was used. Further, it was found that unidentified objects were avoided more safely with a SID. Although the experimental results seem promising, many technical problems must be solved before SIDs may be successfully used in maritime applications

1 Introduction

Rapid developments in the field of maritime radar and display technology provide greater flexibility for display formatting. Integrated information presentation may enhance operator task performance since it is known that related information is better understood when it is presented in a single display.[1,2] For visual information this can be achieved by presenting radar information (target positions, collision-avoidance information) and vessel state information (speed, course, propulsion, future path) in a single representation. Simulation studies by Passenier, Van Breda, and Kerstholt,[3] and by Van Breda and Werkhoven,[4] performed as a part of the European project ATOMOS II (DGVII, Waterborne Transport), showed that navigational task performance improved when an integrated information display was used showing combined voyage planning, predicted path, collision avoidance (Predicted Capability Envelope, PCE) information, and vessel status information. Significantly fewer violations of the minimum safety distance with respect to other traffic vessels occurred; a factor of four in improvement was found compared with conditions with only standard ARPA radar information. In these earlier studies, the lookout function was conventional: The navigator observes the environment through the windows on the bridge and compares his observations with information presented on the navigation display. It may happen, however, that radar echos are not visible on the radar screen. Sometimes navigators are not able to detect targets due to bad environmental circumstances causing display clutter, or, it may happen that objects have bad radar reflective characteristics (e.g., small vessels without adequate radar reflectors, sailing boats, floating containers). In that case there is no ARPA radar plotting information available. Moreover, modern radar systems have no phosphor afterglow which decreases conspicuity of radar echos on the screen. Under these circumstances, detection is only possible through lookout. The research reported in this study addresses the support of this final aspect of information integration, i.e. integrating lookout related information with navigation information.

The present experiment focuses on the use of head-up (HUD) information to support the lookout function. In aviation, HUDs are commonly used to present aircraft state information in the visual field of the pilot.[5,6,7] Computer generated graphics, symbols, or text is optically projected onto a partially reflecting segment of the windshield directly in front of the pilot, which is focused on near-infinity to avoid accommodation. Projected HUD information in the direct line of sight allows the pilot to take in information without taking his eyes off the outside world scene. It is assumed that both images are more likely to share the spotlight of attention and are processed in parallel, hence, facilitating the ability to perform monitoring of both images concurrently. In this respect, Wickens and Long[8] emphasize that it is also important to present information as so-called conformal imagery, that is, the graphics should spatially overlie its outside world counterpart if properly aligned; it will move in synchrony and equal amplitude with that counterpart.

HUDs are primarily used in aviation, for presenting symbolic information about the current state of the aircraft (e.g., by presenting scales indicating attitude, altitude, and airspeed). Information is then provided concerning a process, independent of its location. In many military applications, however, the HUD is also used to present tactical information, where geographically-oriented information is shown as an exact visual overlay with objects in the background scene (e.g., a graphics symbol indicating the position of an enemy missile site on the top of a mountain). This kind of presentation improves the situational awareness of the pilot because tactical information and outside world information are integrated. In these options, the HUD is used as an *output device* for navigation support. Alternatively, it is possible to present a cursor symbol in the HUD which may be used to indicate an object in the external world scene. Cursor location information may then be transferred to the navigation system and used to determine the object's position in world co-ordinates, i.e. location information may be used to generate a radar echo at that position. In that case, the HUD is used as an *input device* to support navigation. The present experiment is focused on the use of HUDs for both input and output aspects.

For maritime application of HUDs, a number of problems must be solved. Existing aircraft HUDs have a limited field of view, while the costs are high. The design of HUDs for a larger field of view requires additional high costs. Another concern is the tendency that too much symbology is presented in the HUD, which may lead to display clutter.[7,9] It is recognised that there is a high risk that clutter perceptually masks critical information in the outside world. Display clutter is a factor that is likely to be even more important in HUD applications on board of ships. The HUD image may seldom be seen against a clear visual background, as is the case in aviation. The outside world scene observed from the ship's bridge is rapidly changing in colour contrast and is cluttered with moving and distracting patterns. Another problem to be solved is the effect of accommodation on visual attention, e.g., where in depth should HUD information be presented? It is clear that considerable research is needed to enable commercial applications of maritime HUDs.

The goal of the current experiment is to investigate whether a maritime HUD - we call this a Superimposed Information Display (SID) - as an addition to ARPA, supports the navigation task. In other words, to what extent are unidentified objects in the outside world detected faster, and how are these objects considered in the navigation task. In a ship manoeuvring simulator, participants were asked to sail a high-speed vessel across a traffic separation scheme. This task was considered highly demanding, since high-density traffic conditions may then be expected. It is essential that navigators keep a safe distance from any other ship while they maintain the initial course and speed as much as possible. It was also emphasized that a predetermined route had to be followed as much as possible. Two display conditions were investigated:

(i) navigating with the ARPA/PCE navigation display. In this baseline condition, integrated information was presented concerning voyage planning, predicted path, collision avoidance, and vessel status, enabling the navigator to select the safest course.[4] In the current configuration, PCE information was based on constant propulsion of the navigator's vessel;

(ii) navigating with the ARPA/PCE navigation display and additional SID. The SID, covering 100° horizontal field of view, presented basic radar plotting information as well as a cursor. The cursor could be used to initiate a radar target position for PCE, i.e., the cursor position was considered a radar echo to be included in the collision avoidance calculations.

Participants were instructed to keep a minimum safety distance of one nautical mile (nm) to all ships in the environment. Performance was assessed in terms of detection speed for unidentified targets, and safe and efficient navigation. Task difficulty was varied by manipulating traffic density which enables a systematic comparison between the display types under different task conditions.

It was expected that the use of SID information would lead to safer navigation, particularly in high-density traffic task conditions. Unidentified targets were expected to be detected in an earlier phase of the trial, and, fewer safety distance violations of unidentified targets were expected to occur compared to the baseline situation in which an ARPA/PCE navigation display was used without SID. Navigators were expected to assess dangerous situations more easily when position information of the unidentified targets was included in the PCE.

2 Method

2.1 Participants

Twelve maritime students (Rotterdam Shipping and Transport College, STC) participated voluntarily in the experiment. All students had completed the STC radar navigation course. They were paid for participation.

2.2 Task

Participants were required to sail a high-speed vessel (length 130 m; draught 20,000 dwt) in a simulator along a predetermined route across one lane of a traffic separation scheme. Traffic was approaching on starboard side from direction 50°. The participant's vessel initially started at about 1 nm outside the traffic lane, at an initial speed of 28 knots. A dusk situation was created in the simulator; illuminated vessels were clearly visible in the out-of-the-window scene. All traffic vessels were of the same type. Normal safety and navigation rules ('Rules of the Road') with respect to other vessels had to be followed. The participants were asked to cross the traffic lane and to follow the planned route as much as possible, while looking outside and considering all the available information. It was emphasized that there was a single unidentified target in the scene. As soon as this target was detected, a cursor in the outside world scene had to be manipulated and pointed to that target. Once this was done, a button for identification had to be pushed. For safe navigation, it was of primary importance that a 1 nm minimum passing distance to all (identified and non-identified) ships was maintained. In case of an estimated unsafe approach, a collision-avoidance manoeuvre could be initiated by re-planning the route, and following this re-planned route. It was not possible to alter the speed of the vessel. Each experimental trial lasted 15 minutes. Trials were performed under low and under high-density traffic conditions, that is, with 3 or with 10 traffic ships within 6 nm distance, respectively. There was no wind or current.

2.3 Apparatus

The experiment was carried out in the TNO Human Factors Research Institute (TNO-HFRI) ship manoeuvring simulator. This simulator consisted of an image generator for the external world scene, two additional image generators for modelling the wide-view SID system, a projection system, a mockup of an instrumented ship's bridge, and a computer system containing the hydrodynamic model of the vessel. The image generator was a two channel Evans & Sutherland ESIG2000 high speed graphics processor, providing synthetic video scenes for the simulator vision system. This processor is able to generate multiple channel high-resolution video images, i.e. 1500 to 2000 textured polygons and 800 x 600 pixel resolution per channel. The image update frequency was 30 Hz. For two channels, the total viewing angle was 103° horizontal and 42° vertical. SID information was generated by means of two Silicon Graphics Indigo systems. The SID resolution was 1024 x 768 pixels, covering the same viewing angle as the external world scene. All images were presented on a cylindrical screen by means of four Barco 800 video projectors. The viewing distance was about 3 m.

The mockup was a partially instrumented bridge of a high-speed vessel. Participants were seated at consoles equipped with navigation display and controls (see Figure 1). Details of the navigation display are explained in the next section. A Silicon Graphics Onyx system was used to generate navigation display information with 1280 x 1024 pixel resolution; a mouse was available for selection of the display setting. For course control, an autopilot system was installed. In case of a course change manoeuvre, a dial was used to select the new desired course first, then an 'execute' button was pressed to start the execution of the course change. The rudder limiter was fixed at 10°. The thrust of the vessel could not be changed. A joystick with additional push-button was used to manipulate SID information. Finally, an intercom system was installed for speech communication between experimenter and bridge mockup.

The hydrodynamic model of the vessel was based on a manoeuvring model of a 20,000 dwt catamaran. For the experiment, the model was simplified to a multi-variable model with which relevant manoeuvring effects could be reproduced.[10] For prediction calculations, the same model was used.

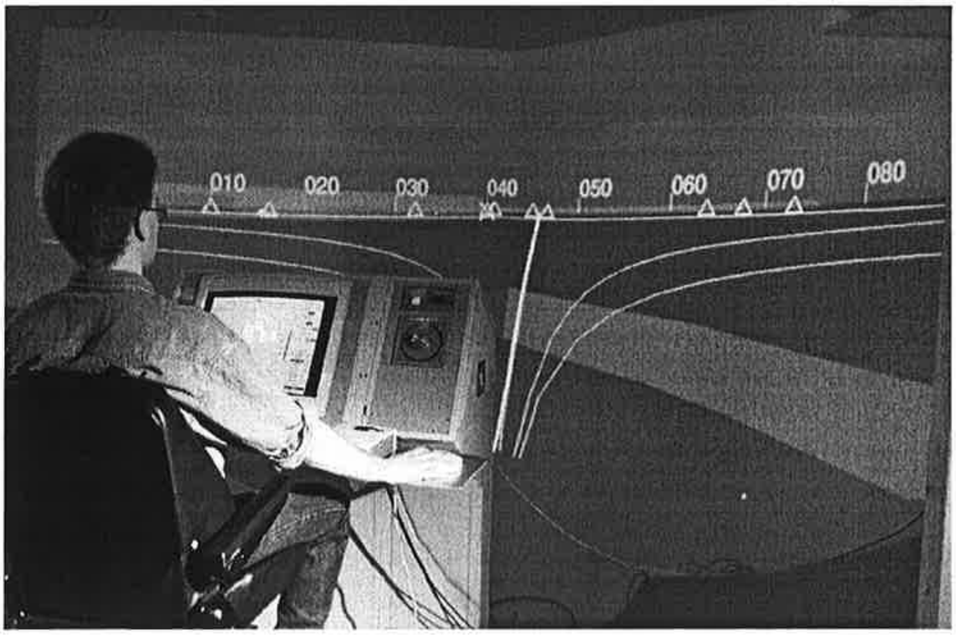

Figure 1. Overview of the bridge mockup in the TNO-HFRI simulator facility. A bridge configuration with HUD is shown.

2.4 Displays

Two display conditions were investigated: (i) navigating with the ARPA/PCE navigation display, and (ii) navigating with the ARPA/PCE navigation display and additional SID.

With the ARPA/PCE (no SID) display type, basic ARPA radar and collision-avoidance information was presented on the navigation display, in relative motion, north-up mode (Figure 2). The ship's fairway was visible as an electronic chart, with the predetermined route depicted as a solid green line. Other vessels were shown as targets. Along the right-hand screen edge, a menu for display interaction was presented, showing 'soft' push-buttons for the radar display setting to be activated with the mouse, and windows for general collision-avoidance information such as heading and speed of the participant's vessel, radar range, range ring distance, and vector length. Variable range marker (VRM) and parallel-index (PI) lines could be selected and manipulated. A cursor was always presented on the screen; range and bearing of its position were continuously presented in a separate window. This cursor could also be used to select targets for collision-avoidance information.

The selected target would start to blink amber while this target's range, bearing, speed, course, minimum passing distance (closest point of approach, CPA) and time to minimum passing distance (TCPA) were presented. Targets were always plotted in a selectable mode (i.e., true or relative vector mode). Along the screen edges, indicators for vessel's state variables were presented: actual heading, selected course, rate of turn, rudder deflection, log speed, revolutions of the propeller shaft, absolute wind and current data, and time of day. Interaction with the navigation display was performed by a separate mouse. The ARPA display type was considered the baseline task condition. In addition, PCE information was shown:

1) a solid line representing the vessel's predicted path over the next 30 minutes, given the selected radar range and heading set point of the autopilot (course controller);

2) a dotted line representing a trial value for a new heading setting, selectable by turning the selector of the autopilot;

3) areas representing the ‘no sail through' zones. For each predicted track it was calculated whether the minimum passing distance with any of the traffic vessels was less than 1 nm. A linear extrapolation technique was used, assuming a fixed speed and course of all targets (in accordance with conventional CPA calculations). The areas represent a passing distance less than 1 nm, the dark zones represent areas with a passing distance less than 0.5 nm.

For reference purposes, a cursor was presented in the outside world scene. This cursor could be manipulated to select unidentified targets.

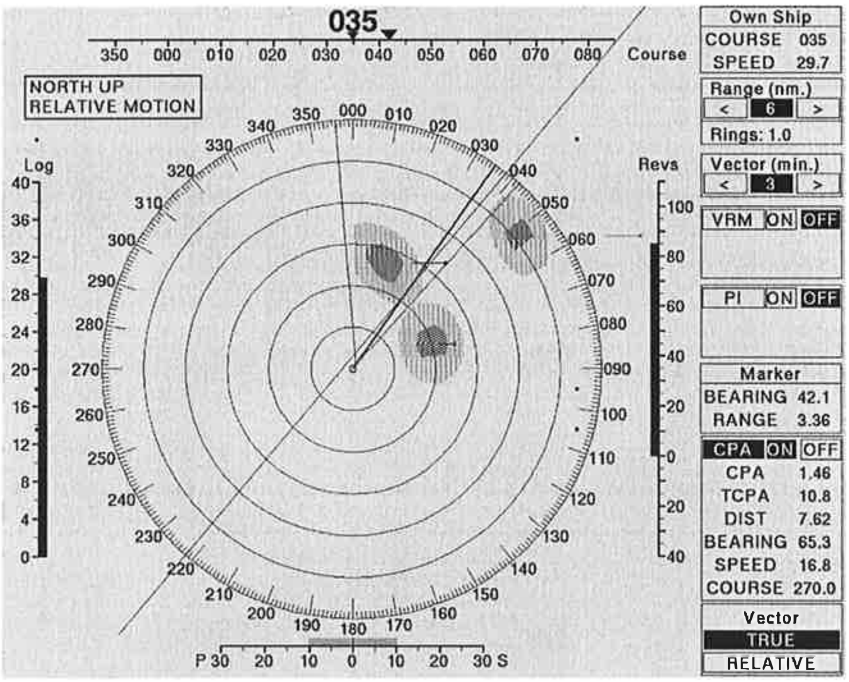

Figure 2. The ARPA/PCE navigation display representing basic radar and collision avoidance information, as well as PCE information.

With the ARPA/PCE + SID display type, the ARPA/PCE display type was used, with an additional SID (output device), showing basic radar plotting information projected over the out-of-the-window scene, i.e. a perspective representation of references for range and bearing of radar echo positions. The SID was also used as an input device, that is, a cursor (cross-symbol) was presented to be used for the selection of unidentified targets. The cursor could be manipulated over the SID (at sea surface level) by means of a joystick. By first positioning the cursor exactly on top of an object in the outside scene, and then by pushing a button, the object's position was fed into the computer system and transformed into world co-ordinates. This position information was then considered a (non-moving) radar echo by the ARPA/PCE. Subsequently, the cursor position appeared as a cross-symbol on the navigation display, together with related PCE collision avoidance information.

2.5 Scenarios

Participants were required to cross a traffic separation scheme. A single lane was crossed with traffic ships approaching from starboard 50°. The participant's vessel started at about 1 nm from the lane, with an initial speed of 28 knots. In the experimental set-up, vessels approaching from starboard side were scheduled such that close approach situations were possible. Low-density traffic scenarios included three other traffic ships plus one unidentified ship, high-density traffic scenarios included ten other traffic ships plus one unidentified ship. In order to make sure that the participant judges the traffic situation profoundly, scenarios were designed such that in 50% of the trials the unidentified ship left about half a mile additional space ahead for the participant to proceed; in all other trials there was not enough space left so that the participant had to alter course significantly and re-plan the route. During the experiment, scenarios were presented to the participants in balanced order. All traffic vessels followed the lanes and did not alter course or speed. There was no wind or current.

2.6 Training and instruction

Before starting the actual experiment, participants received basic information, describing the ship's manoeuvring characteristics. Subsequently, on the manoeuvring simulator, bridge equipment (navigation displays and autopilot console) was explained, after which participants were familiarized by means of a 20 minutes practice trial for each individual display type. On the basis of pilot studies, it was determined that this was sufficient to obtain a stable performance level of the participants. Additional practice trials were performed in case a participant expressed that there was not enough understanding of the navigation system and task. For the experimental trials, participants were instructed to follow the planned route across the traffic lane as accurate as possible while maintaining a 1 nm minimum passing distance to all (identified and non-identified) ships. It was emphasized that there was a single unidentified target in the scene, which after detection had to be tracked manually by means of the cursor in the outside world scene.

2.7 Procedure

The participants contributed to the experiment for half a day. In an introductory session, the participants were familiarized with the manoeuvring simulator, followed by the 20 minutes practice trials. Then the experimental trials started, presented in 3 blocks of 4; each block representing a display type, and each trial representing a different traffic scenario. Each experimental trial ended after 15 minutes. To avoid order effects, display types and traffic scenarios were presented in balanced order.

2.8 Performance measurement and analyses

The vessel's state variables, including position, heading, speed, rate of turn and rudder deflection, autopilot set point and propulsion set point, as well as the cursor positions, were sampled and stored every 1 second. Performance was recorded in terms of navigation safety, and was operationalised as the time needed to detect unidentified targets, and the violation of the minimum safety distance toward other ships. The time to detect an unidentified target was the time interval between the beginning of a trial until its proper selection by the participant. Safety distance violation was defined as the distance and time during which the controlled ship had been within 1.0 nm from any of the vessels, or from the unidentified target. Distance was calculated as the root mean square (RMS) distance error, expressed in nm.

The scores were subjected to an analysis of variance (ANOVA) and a Tukey test for a post-hoc analysis of differences, with display type and traffic density as fixed variables.

3 Results

All participants were able to perform the experimental trials. One trial was aborted because one of the participants did not follow the instructions. The results of this trial were excluded from the analysis.

3.1 Detection time

Figure 3 shows the mean detection time of an unidentified object as a function of display type and traffic density, averaged across participants. The ANOVA on the target detection time, with display type (ARPA/PCE no SID; ARPA/PCE + SID) and traffic density (low-density; high-density) as factors, showed a main effect of display type, $F(1,11)= 14.1$; $p< .01$. This means that the target detection time differed for the investigated display types. A Tukey post hoc comparison test indicated that detection time in display conditions without SID (average value of 100 s) differed significantly ($p< .01$) from the presentation conditions with a SID (average value of 26 s). No interaction was found between display type and traffic density, $F(1,11)= 2.17$; $p= .17$. Although Figure 3, particularly for the no SID condition, suggests an effect of traffic density on detection time, this difference appeared not to be significant.

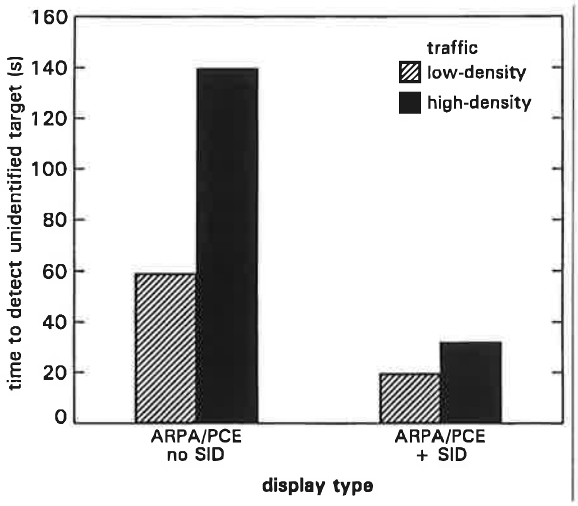

Figure 3. Detection time of an unidentified object as a function of display type (ARPA/PCE no SID; ARPA/PCE + SID) and traffic density (low-density traffic, high-density traffic), averaged across participants.

3.2 Minimum safety distance violation

Figure 4 shows two histograms, depicting the mean period of time that the minimum safety distance of 1.0 nm was violated, for the different display conditions and traffic densities, averaged over the participants. The horizontal axis is divided into intervals of 0.1 nm, starting at a distance less than 0.5 nm from the unidentified target, and ending up at the 1.0 nm minimum safety distance. The figure shows that a considerable amount of time was spent within the minimum safety distance of 1.0 nm when no SID was available, and, in some instances, participants were closer than 0.5 nm from the unidentified ship. With both ARPA/PCE/SID display types this was not the case; safety distance violations were negligible up to 0.7 nm distance. A Pearson Chi-square test indicated that the results in conditions without SID differed significantly from conditions with SID, $\chi^2(6)= 61.5$; $p< .001$ and $\chi^2(6)= 71.9$; $p< .001$, respectively.

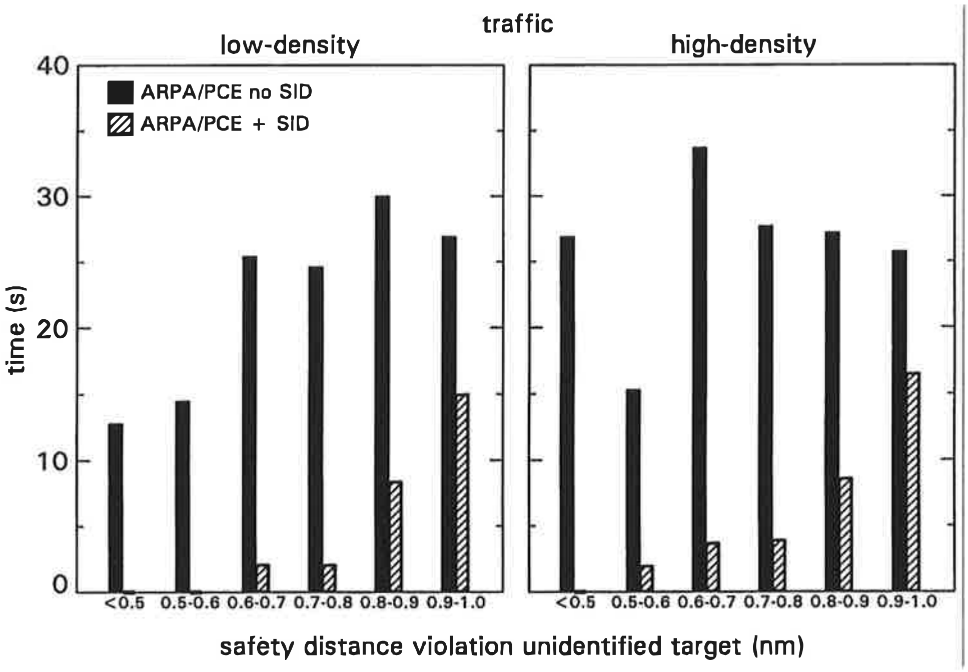

Figure 4. Period of time that the minimum safety distance of 1.0 nm was violated, as a function of display type (ARPA/PCE no SID; ARPA/PCE + SID) and traffic density (low-density traffic, high-density traffic), averaged across participants.

4 Discussion

The potential benefits of Superimposed Information Display (SID) information for ship navigation support were investigated in a simulator study, using manoeuvres in which a busy traffic separation scheme was crossed with a high-speed vessel.

As was expected, the results revealed that providing participants with a superimposed display yielded a reduction of the detection time of targets that were not visible on the radar screen (a factor of four on average). Further, somewhat surprisingly, no significant effect of traffic density was found on detection speed, although results did suggest an increase in detection time for high-density traffic situations. However, one has to consider that in the experimental task participants were told that there would be an unidentified vessel in the fairway during each trial. In real life situations, navigators are not in a constant 'state of alert'. The effects found in the current experiment are therefore considered to be a conservative estimate of differences between conditions to be encountered in real life situations

Results on the navigation task showed that the use of a SID increases collision-avoidance task performance. Providing the navigator with basic plotting facilities to track targets in the outside world and presenting this information on the navigation display is an effective way of integrating outside-view information with navigation information.

The potential benefits of the use of a SID on board ships are shown in this research. Note, however, that a number of questions remain unanswered. For instance, how should a wide-view SID be implemented on the ship's bridge, where the visual background scene is so clear and cluttered with moving objects? What is the minimum SID resolution that still guarantees accurate plotting facilities? What is the effect of accommodation on visual attention, e.g., where in depth should SID information be presented? What are the cost of such a SID system and are these affordable for merchant vessels? It is clear that considerable research is needed in these matters before a commercially-viable SID solution is found.

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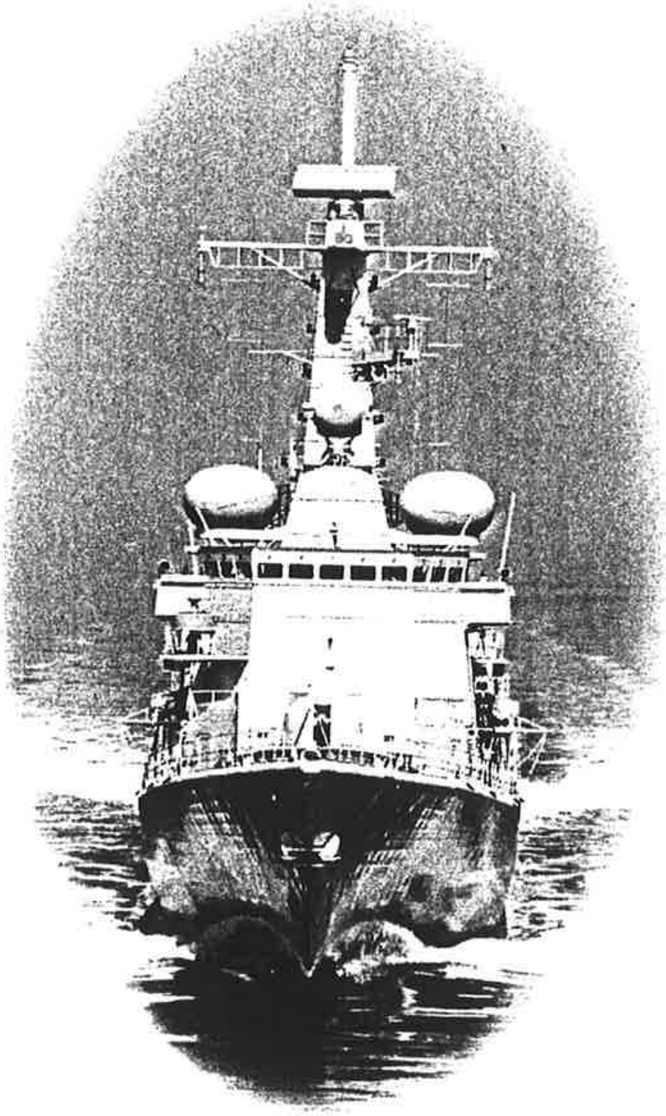

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