

THE USE OF ELECTRONIC CHARTS AND RADAR IN MARINE NAVIGATION

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Abstract

Mariners carried out simulated navigation exercises under three conditions: radar- electronic chart overlay, separate radar and electronic chart displays, or free choice of either the overlay or the separate display. Objective performance was measured by course track, distance from navigation hazards, and vessel speed. Mariners also completed self-ratings of performance and difficulty. There were no significant objective performance differences among the three conditions, but mariners rated their own performance as higher under the free choice condition. The exercises with simple chart displays were rated as producing better performance, less demand and less frustration than the exercises with complex charts.

Key words: Vision, decision, information display

L'USAGE DES CARTES ÉLECTRONIQUES ET DU RADAR LORS DU PILOTAGE MARITIME

Résumé

Des navigateurs marins ont complété quelques pistes de pilotage dans un simulator, sous trois conditions: soit radar et chart électronique surposés sur le même écran, radar et chart posés chaque à sa propre écran, ou libre choix entre surposition ou séparation. La performance des participants a été évaluée par une mesure intégrée d'erreur sur la piste de vaisseau, distance maintenu entre vaisseau et quelques hazards de navigation, et vitesse du vaisseau. Aucun différence significative a été trouvée entre les trois conditions, mais les officiers se regardent mieux leur performance sur la condition de libre choix. Les exercices avec de charts peu compliquée ont été évalué comme ayant produit un meilleur performance, moins de fardeau mentaux et moins de frustration que les exercices avec les charts plus compliquées.

Mots clés : Vision, décision, informatique

INTRODUCTION

The main goal of this study was to learn whether there was a difference between two ways of using marine electronic chart displays: with or without a radar overlay. Six mariners carried out nine simulated navigation exercises which were set under low-visibility conditions in the St. Lawrence Seaway, Halifax Harbour, and Come-by-Chance, Newfoundland. The exercises varied in the complexity of the chart display and in the number of other ships encountered. Each mariner ran each exercise under one of three conditions: radar-chart overlay only, separate radar display only, or free use of either the radar-chart overlay or the separate radar display. Performance was measured by how closely mariners kept to the prescribed course, how closely they approached hazards to navigation, and how fast they piloted their simulated vessel. Mariners also completed performance and difficulty self-ratings after each exercise.

Performance was almost identical under the choice, overlay or separate display conditions. Thus there is no reason to prefer one display condition over the others for navigation in pilotage waters. Mariners self-rated their own performance as higher under the choice condition. They rated the exercises with simple chart displays, which were harbour approaches or departures in open waters (Come-by-chance and the Halifax approaches) as producing better performance, less demand and less frustration than the exercises with complex charts that were set in Halifax Harbour and the St. Lawrence Seaway.

Based on earlier work carried out on the same simulator, navigation in piloting waters is more accurate with electronic charts than with conventional paper charts, and based on the new work reported here, the choice of electronic chart display mode: separate radar and chart, or radar overlay on the chart, can be left to mariners' discretion.

METHOD

The marine simulator at the CMS consists of a ship's wheelhouse installed on a six degrees-of-freedom motion platform, surrounded by a 360° visual projection screen, and operated by a Norcontrol computer system. For this study, the wheelhouse was equipped with a Norcontrol DB 2000 ARPA radar console and an Offshore Systems Limited ECPINS v.1.4 electronic chart display system. The ECPINS display system presents an electronic chart oriented to and coordinated with the ships' position as displayed by an "own ship" mark on the electronic chart. The chart orientation and scale can be varied. The system allows the user to superimpose a transparent radar overlay at the same position, scale and orientation as the chart. The radar display remains oriented to the chart display as the ship moves.

Nine navigation exercises were grouped into three groups of three each. Group RC contained the three exercises with high traffic density and high chart complexity, group Rc contained the three exercises with high traffic density and low chart complexity, and group rC contained the three exercises with low traffic density and high chart complexity. Each exercise displayed a pre-plotted course projected on the ECPINS display. The goal was to follow the course as closely as possible with due regard to the hazards to navigation, including oncoming and passing traffic. The navigating officer was free to vary the course and speed of the vessel at any time. The visibility on all exercises was reduced to 0.4 nm by simulated fog, and the exercise was run without simulated communication to other ships or shore stations.

The three display conditions were separate, overlay and choice. These terms refer to the way in which the radar display was used in association with the electronic chart display. In the separate condition, the radar display and the electronic chart display were always presented on separate but adjacent display consoles. In the overlay condition, the radar information was always displayed as a transparent overlay on the electronic chart, and both the radar and the chart were viewed on the ECPINS display. In the choice condition, the navigator could turn the transparent overlay off or on at will, and could move between the radar display and the ECPINS display at will.

Six licensed mariners, all men, served as experimental observers. Their professional experience ranged from eleven to 40 years. Four had worked at sea during the year preceding the study. All were associated with the CMS as instructors. Only one of them had previous practical experience with electronic chart systems.

Each mariner was given a preliminary training session consisting of a tour of the wheelhouse and its facilities as arranged for this experiment, plus a familiarization exercise of approximately 45 minutes' duration that preceded the experimental exercises. The training session consisted of an exercise (entrance to St. John's Harbour) that was not used during the experiment. During the training exercise the navigator used the electronic chart equipment in all three configurations; separate display, overlay display, and choice of displays. Mariners were briefed in advance about the purpose of the study (Appendix B), and were encouraged to contribute their own written comments on the self-rating data sheets (Appendix C) that they completed following each run.

Following the training session, each mariner was tested on nine experimental exercises. There were three exercises of each type (RC, Rc and rC). One exercise of each type was randomly assigned to the choice display condition, one to the separate condition, and one to the overlay condition, for each mariner. Each mariner completed the exercises in a separately randomized order. Each exercise was completed within a two-hour time period, which included a preliminary briefing on the exercise condition to be run (choice, overlay or separate), the exercise itself, and the post-exercise debriefing and self-rating. Mariners were never scheduled for more than two sessions per day; one in the morning and one in the afternoon. The study was completed between March 11 and March 24, 2000

RESULTS

Each set of response measures (objective measures, activity and self-rating) was analyzed separately using a two-factor multivariate analysis of variance, followed by two-factor analyses of variance on each single measure where appropriate. The analysis factors were display condition, exercise type, and their interaction. Mariners were treated as a random factor, and the interactions of mariners with each experimental factor and their interaction constituted the error terms for the analyses.

None of the objective performance measures differed significantly across the three display types. One objective measure did differ significantly when the differences were evaluated within each exercise type. Average cross-track deviation was significantly higher over all of the Rc exercises than over the other two exercise types, but the difference among exercise types was significantly reduced under the overlay display condition. Exercise Rc cross-track deviation under the overlay condition was not significantly different from the cross-track deviation recorded under the other two exercise types (RC and rC).

Average self-rated performance was higher in the choice display condition than the other two conditions. Multivariate analysis of the two mariner activity variables (displays and orders) gave a non-significant difference across display conditions.

All of the objective performance measures differed significantly across the three exercise types. All of the recorded values were greater for the Rc exercises, in which heavy radar traffic was encountered in coastal waters rather than the narrow confines of a harbour or seaway.

The three self-rating measures; demand, performance and frustration, all differed significantly across exercise type and a multivariate analysis of variance showed that the differences were significant. Demand and frustration were rated as significantly higher, and performance was rated as significantly lower, under the rC exercise conditions (little radar traffic on a complex chart), than either of the other two conditions. Rated performance was negatively correlated with demand ($r = -.40$, $p < .001$) and with frustration ($r = -.24$, $p < .05$), and frustration was positively correlated with demand ($r = .52$, $p < .001$), when the correlations were calculated across the 54 data points (nine exercises times six mariners) of the study. Neither the number of display manipulations, nor the number of rudder and engine commands, differed significantly across the exercise conditions.

Several mariners wrote that they preferred the separate radar and electronic charts, because, for example, "sailing with radar overlay through remarks and warnings printed on the chart was annoying and made it more frustrating." Another mariner said that "using e-chart without radar overlaid gives a better display, closer to using paper charts." On the other hand, a mariner commenting on a separate display condition said that "radar overlay would have reduced workload in this case as much attention had to be given to vessel being set down to port by winds." These comments relate to the determination of the ideal level of display complexity. Too much clutter makes the display unusable; but adding radar information to a chart display, which increases display complexity, would be useful if it allows the mariner to deal with all the relevant navigation information on the same spatial display.

DISCUSSION

Objective performance measures from an earlier CMS study (Mercer and Hong, 1994) show that electronic chart navigation with or without radar overlay is better than conventional paper charts and radar for navigation and piloting in confined waters and harbour approaches. Based both on the earlier CMS data and on the data from this study, there is no significant or important difference between objective performance using electronic charts with a radar overlay, and performance when the electronic chart and the radar display are presented on adjacent separate screens. If the electronic chart is reliable and complete then it will allow better navigation performance than a paper chart of the same area.

The only modification of this general conclusion compelled by the evidence reported here is that for the Rc exercise type (heavy radar traffic on simple charts), the overlay display condition reduced cross-track error, which was higher under the choice and separate display conditions, to about the same level as reported in the other two exercise conditions (RC and rC).

All of the objective performance measures as well as the self-ratings point to the Rc condition as being the least demanding. The Rc exercises (heavy radar traffic on simple charts) produced significantly larger cross-track errors, greater closest points of approach, and

higher speeds than the other two exercise types, and the Rc exercises were also rated lowest (but not significantly so) on demand and frustration. Rc was effectively tied for highest rating on self-rated performance (7.30, versus 7.39 for RC). As shown by the less tightly controlled navigation performance, the mariners tended to "cut corners" relative to the plotted course when the navigation situation was objectively simpler, the perceived workload was reported as lower, and self-rated performance was higher.

The significant performance and self-rating differences found as a function of exercise type point up the increase in attention and vigilance required when maneuvering in narrow channels with fixed and transient hazards that generate complex charts (e.g. the St. Lawrence Seaway and Halifax Harbour exercises in RC and rC) as opposed to making a harbour approach or departure in more open waters with simpler charts (e.g. the Come-by-Chance and Halifax approaches exercises in Rc). Open approaches are faster, require less attention to distance from navigation hazards, and do not demand as diligent a maintenance of the planned course. In spite of the "freer spirit" of the open approaches and departures found in the Rc exercises, the overlay display condition did reduce the cross-track deviation to approximately the same level experienced in the more demanding RC and rC exercise types. We conclude that the overlay condition, in which the navigator is forced to use the ECPINS with radar overlay and cannot look at a separate radar scope, coerces a more rigorous piloting discipline than would otherwise be observed when the navigator can avoid the information conveyed by the superimposition of chart and radar returns.

The rC condition (light radar traffic in a complex chart environment) was rated significantly as the most demanding and frustrating condition with the lowest self-rated performance. A possible explanation for this is that mariners feel anxious when restricted visibility (the operating condition for all of these exercises) is combined with few radar targets in a complicated navigation environment. The continued presence of radar targets in the RC and Rc conditions is a reassurance that another sensor is substituting for missing vision, and the fewer radar targets of rC may leave the mariner uncertain, frustrated and anxious about whether he will encounter targets that are not painted by the radar.

REFERENCE

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