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# Evaluation of symbol sets for naval tactical displays

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In conducting the research described in this report, the investigators adhered to the policies and procedures set out in the Tri-Council Policy Statement: Ethical conduct for research involving humans, National Council on Ethics in Human Research, Ottawa, 1998 as issued jointly by the Canadian Institutes of Health Research, the Natural Sciences and Engineering Research Council of Canada and the Social Sciences and Humanities Research Council of Canada.

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## Abstract

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The four experiments reported in this paper were conducted in support of the COMmand Decision Aiding Technology (COMDAT) (11bg) Technology Demonstrator Project (TDP) and the Halifax Class Modernization Command and Control System (HMCCS) programme. The first experiment assessed the relative visibility of the basic Naval Tactical Data System (NTDS) and MIL-STD-2525B (2525B) tactical symbols. Performance with the colour-coded versions of the two symbol sets was not significantly different. However, the air and subsurface symbols were less discriminable than the surface symbols. Recommendations for improving the discrimination of the different warfare area symbols are included.

One potential advantage of the 2525B symbols is the possibility of adding additional information about the track platform to the basic symbol shape. The remaining experiments assessed the visibility of the basic symbols with iconic information added and the visibility of the icons themselves. Adding iconic information did not have a large effect on the efficiency with which the basic symbols were located except when the icon shape replaced the symbol shape. Performance in locating and recognizing individual icons depended on their complexity and their uniqueness. It was recommended that only a small number of highly discriminable icons be used at any one time. The use of icons without the symbol frame should be restricted to non tactical information and such icons should probably not be colour coded. Further research is required to determine how to implement these recommendations.

## Résumé

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Les quatre expériences dont il est fait état dans le présent rapport ont été menées à l'appui du Projet de Démonstrateur de la Technologie (PDT) d'Aide aux Décisions de Commandement (COMDAT) (11bg) et du Programme de modernisation du système de commandement et de contrôle pour la classe Halifax (*Halifax Class Modernization Command and Control System Programme*, HMCCS). Dans le cadre de la première expérience, on a évalué la visibilité relative des symboles tactiques de base du Système de données navales tactiques (SDNT) et de la MILSTAND-2525B (2525B). Le rendement des versions codées en couleurs des deux jeux de symboles n'était pas très différent. Cependant, les symboles pour les entités aériennes et sub-superficielles étaient moins distinguables que ceux utilisés pour les entités de surface. Des recommandations pour l'amélioration de la discrimination des différents symboles utilisés dans les zones de guerre sont fournies.

L'un des avantages du jeu de symboles 2525B est d'offrir la possibilité d'ajouter à la forme de base du symbole de l'information sur la plate-forme de poursuite utilisée. Les autres expériences portaient sur l'évaluation de la visibilité des symboles de base lorsque de l'information iconique est ajoutée et sur la visibilité des icônes elles-mêmes. L'ajout d'information iconique n'avait pas un effet important sur l'efficacité avec laquelle les symboles de base étaient localisés, sauf lorsque la forme de l'icône remplaçait la forme du symbole. Le rendement en termes de localisation et de reconnaissance d'icônes individuelles dépendait de leur complexité et de leur unicité. Il est recommandé de n'utiliser simultanément qu'un petit nombre d'icônes hautement discriminables. L'utilisation d'icônes sans le cadre du symbole devrait être limitée uniquement à l'information non tactique et ces icônes ne devraient probablement pas comporter un codage en couleurs. D'autres recherches sont nécessaires afin de déterminer comment mettre en œuvre ces recommandations.

# Executive summary

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## Evaluation of symbol sets for naval tactical displays

Sharon McFadden; Jennifer Jeon; Annie Li; Annalisa Minniti; DRDC Toronto  
TR 2007-046; Defence R&D Canada – Toronto; January 2008.

**Introduction or background:** The research reported in this paper was conducted under the COMmand Decision Aiding Technology (COMDAT) (11bg) Technology Demonstrator Project (TDP) in support of the Halifax Class Modernization Command and Control System (HMCCS) programme. One of the goals for the COMDAT TDP is to develop improved Operator Machine Interface (OMI) guidelines. This includes selecting suitable symbol sets for naval tactical displays. In support of this work, four experiments were carried out to evaluate some of the design concepts for symbology laid out in MIL-STD-2525B. The first experiment compared the basic MIL-STD-2525B (2525B) tactical symbols with the Naval Tactical Data System (NTDS) currently used on tactical displays in the HALIFAX class frigates. The remaining experiments evaluated some of the icons specified in MIL-STD-2525B for representing platform information. The second experiment assessed discrimination of the basic symbol shapes, with and without the addition of icons, against a plain and a complex background while the third experiment assessed discrimination of the icons themselves. In the fourth experiment, participants searched for a specific target shape and then identified the icon superimposed on the basic symbol.

**Results:** The results of the first experiment indicated that the colour coded 2525B symbol set offered no advantage over a well designed NTDS symbol set if both were presented against a plain dark grey background. With both sets, the air and subsurface symbols were less discriminable than the surface symbols. A comparison of monochrome versions of the two symbol sets did indicate that the NTDS shapes are more discriminable than the 2525B shapes. However, visual search performance was similar with the colour-coded versions of the two symbol sets. In addition, iconic information can be added more easily to the solid shapes. Adding iconic information did not have a large effect on the effectiveness with which the basic symbols were located except when the icon shape replaced the symbol shape. Performance in locating and recognizing individual icons depended on their complexity and their uniqueness. It was recommended that only a small number of highly discriminable icons be used at any one time. The use of icons by themselves should be restricted to non tactical information and probably should not be colour coded.

**Significance:** The results of these experiments will be used to provide recommendation to the Navy on the selection of suitable symbology for naval tactical displays.

**Future plans:** It is recommended that a more discriminable method of representing a neutral contact be developed. The MIL-STD-2525B symbols for these types of contacts are unsuitable for use on electronic displays when presented at the recommended visual angle. Further research is required to evaluate proposed methods for improving discrimination between the air and subsurface symbols and to develop better guidelines for ensuring the effective discrimination of tactical (foreground) information and contextual (background) information.

# Sommaire

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## Evaluation of symbol sets for naval tactical displays

Sharon McFadden; Jennifer Jeon; Annie Li; Annalisa Minniti; DRDC Toronto  
TR 2007-046; R & D pour la défense Canada – Toronto; Janvier 2008.

**Introduction ou contexte :** Les recherches ici présentées ont été menées dans le cadre du Projet de Démonstrateur de la Technologie (PDT) d'Aide aux Décisions de Commandement (COMDAT) (11bg) à l'appui du Programme de modernisation du système de commandement et de contrôle pour la classe Halifax (*Halifax Class Modernization Command and Control System Programme*, HMCCS). L'un des objectifs du PDT du COMDAT est l'élaboration de lignes directrices améliorées pour l'interface opérateur-machine (IOM). Cela englobe la sélection de jeux de symboles appropriés pour les affichages navals tactiques. Quatre expériences ont été menées à l'appui de ces travaux afin d'évaluer certains concepts de symbolisation exposés dans la MILSTAND 2525B. Dans la première de ces expériences, les symboles tactiques de base de la MILSTAND 2525B (2525B) ont été comparés à ceux du Système de données navales tactiques (SDNT) actuellement utilisés dans les affichages pour les frégates de la classe Halifax. Dans le cadre des autres expériences on a évalué certaines des icônes dont l'utilisation est préconisée dans la MILSTAND 2525B pour la représentation de l'information sur les plates-formes. Dans la deuxième expérience, on a évalué la discrimination des formes de base des symboles avec et sans l'ajout d'icônes lorsqu'ils figurent contre des arrière-plans simples et complexes; lors de la troisième expérience on a évalué la discrimination des icônes elles-mêmes. Pour la quatrième expérience, les participants recherchaient une forme de cible spécifique, puis identifiaient l'icône superposée au symbole de base.

**Résultats :** Les résultats de la première expérience indiquent que le jeu de symboles 2525B codés en couleurs n'offre aucun avantage par rapport à un jeu de symboles SDNT bien conçu lorsque les deux sont affichés contre un arrière-plan gris foncé simple. Dans le cas des deux jeux, les symboles pour les entités aériennes et sub-superficielles étaient moins discriminables que les symboles représentant des entités de surface. Une comparaison des versions monochromes des deux jeux de symboles indique que les formes des symboles du SDNT sont plus facilement discriminables que celles du 2525B. Cependant, pour les versions codées en couleurs des deux jeux de symboles, le rendement de la recherche visuelle était similaire. En outre, l'information iconique peut être plus facilement ajoutée aux formes pleines. L'ajout d'information iconique n'avait pas un effet important sur l'efficacité avec laquelle les symboles de base étaient localisés, sauf lorsque la forme de l'icône remplaçait celle du symbole. Le rendement en termes de localisation et de reconnaissance d'icônes individuelles dépendait de leur complexité et de leur unicité. Il est recommandé de n'utiliser simultanément qu'un petit nombre d'icônes hautement discriminables. L'utilisation d'icônes seules devrait être limitée uniquement à l'information non tactique et ces icônes ne devraient probablement pas comporter un codage en couleurs.

**Portée :** Les résultats de ces expériences serviront à faire des recommandations à la Marine quant au choix du jeu de symboles convenant le mieux aux affichages tactiques navals.

**Recherches futures :** Il est recommandé d'élaborer une méthode de représentation des contacts neutres permettant une meilleure discrimination. Les symboles de la MILSTAND 2525B pour

trois types de contacts ne conviennent pas aux dispositifs d'affichage électronique lorsque présentés à l'angle visuel recommandé. D'autres recherches sont nécessaires afin d'évaluer les méthodes proposées d'amélioration de la discrimination des symboles utilisés pour des entités aériennes et sub-superficielles ainsi que pour élaborer de meilleures lignes directrices assurant une discrimination efficace entre l'information tactique (avant-plan) et l'information contextuelle (arrière-plan).

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# Introduction

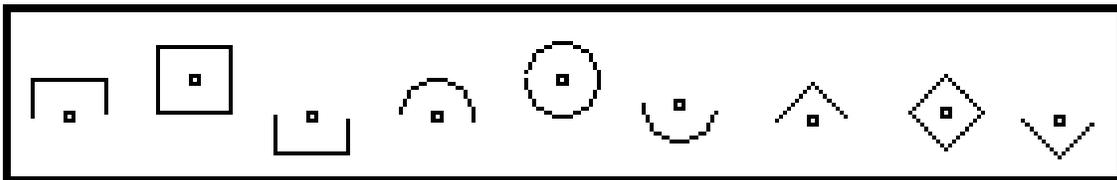
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The purpose of the COMMAND Decision Aiding Technology (COMDAT) Technology Demonstrator Project (TDP) is to research and demonstrate Multi-Source Data Fusion (MSDF) technologies and carry out human factors studies to support evolutionary upgrades to the Halifax Class Command and Control System (CCS) in the areas of battle space awareness. One of the goals of the human factors studies is to develop improved guidelines for designing the Operator Machine Interface (OMI) for naval command and control systems.

To support the development of improved OMI guidelines, a COMDAT OMI Style Guide (Unger Campbell 2004) was produced that distilled all of the accepted knowledge on the design of military tactical displays and adapted it for use with the CCS and the COMDAT Technology Demonstrator. In terms of symbology, the guide provided the designer with the option of using the Naval Tactical Data System (NTDS) symbol set currently on the CCS or adopting either North Atlantic Treaty Organisation (NATO) draft STANdardisation AGreement (STANAG) 4420 or Military Standard 2525B (MIL-STD-2525B). However, it cautioned that “Without further research only those elements of draft STANAG 4420 or MIL-STD-2525B that correspond to the current NTDS symbols should be used” (Section 15.1.6). The studies reported in this paper contribute towards the research required for improved guidance on the design and use of these alternative symbol sets for tactical displays.

## Background

Currently, the NTDS symbol set is used on Canadian Forces (CF) CCS displays (Figure 1). The shape of the symbol codes its affiliation or identification (ID) (friend-circle, hostile-diamond, unknown-square) while environment or warfare area is coded by the symbol's orientation (pointing up indicates air; pointing down indicates subsurface, and full symbol indicates surface). With the advent of colour coding, colour coded versions of these symbols, in which ID is redundantly colour coded, are sometimes used. As well, new symbols have been added to represent neutral targets and other variants of the symbols created in an effort to provide additional or more precise information to the operator about a contact or track.



*Figure 1: Basic shapes in the Naval Tactical Data System (NTDS) symbol set.*

Most of the additions were carried out in an ad-hoc manner as the need arose. Moreover, there is no standard version of the symbols especially across navies. Thus in the early 1990's, a NATO Working Group was tasked to develop a standard symbol set for naval tactical displays (draft STANAG 4420) that would take advantage of the capabilities of modern display technology and be consistent with human factor guidelines for displays (North Atlantic Treaty Organisation 1992).

The new shapes proposed by STANAG 4420 were based on the NTDS symbology. In fact the document indicated that a modified form of the NTDS symbology might continue in use for the representation of basic warfare area and ID information. To improve the visibility of the NTDS symbols on raster scan displays they recommended the use of two pixel wide lines. However, it is not clear from the draft document if the updated NTDS symbols would also be colour coded.

To accommodate additional platform information, it proposed solid versions of the NTDS symbols that could be overlaid with iconic information. As well, the number of ID categories that could be represented was increased to include assumed friend, etc, through the use of a dashed outline and a new symbol was added for neutral tracks. ID information was redundantly colour coded: red for hostile, blue for friendly, off-white for unknown and green for neutral. Military platforms all had these four basic shapes with amplifying information overlaid as icons or letter identifiers. Non-military tracks and weapons were represented by icons alone. Since STANAG 4420 was never ratified, the complete symbol set was never published. However, a U.S. evaluation of the proposed symbology includes a short description of draft STANAG 4420 and its development (NAVSPAWARSSYSCOM 1991).

As a precursor to ratification, the U.S. carried out a relatively extensive evaluation of the proposed design concepts (Kirkpatrick, Dutra, Lyons, Osga, and Puggi 1992b, NAVSPAWARSSYSCOM 1991). In it they compared the NATO symbols with the basic NTDS symbol set that was currently in use, a colour coded version of the NTDS symbol set with information tags, and a colour coded outline version of the NATO symbols. The information tags provided the same information as the icons in the NATO set. This allowed the investigation of the merits of design concepts such as colour coding, filled shapes, and iconic representation of amplifying information. In the evaluation, experienced operators carried out operationally relevant tasks including a recognition task (e.g. find all hostile air tracks), a scenario following task (e.g. engage hostile fighter approaching own ship) and a monitoring task (indicate new tracks). Tasks were carried out using a series of different scenarios and a simulated tactical display. For the recognition task, response times were significantly faster with the NATO symbols than the other three symbol sets and accuracy was significantly better than with the monochrome NTDS symbols. In the scenario following task, participants tended to perform better with the NATO symbols, but not significantly so. The use of operational tasks and participants who were familiar with NTDS symbology supported the potential benefit of the design concepts presented in draft STANAG 4420. However, the evaluation also pointed out limitations and recommended certain changes. For example, they found that it was impossible to produce dashed outlines that were clearly visible. They also recommended more systematic evaluations of factors such as symbol and icon discrimination, clutter, symbol size, and colour contrast.

Some of the evaluations proposed above were carried out as part of the same overall project. Separate studies looked at the effect of contrast, luminance, and saturation (Van Orden, Osga, and Lauben 1991, Van Orden and Benoit 1994), and symbol size (Laxar and Van Orden 1994). Although some results favoured the NATO symbols (Van Orden et al. 1991), with others there were no differences (Van Orden and Benoit 1994) and in at least one case the colour coded NTDS symbols proved superior (Laxar and Van Orden 1994). Since the studies varied in their methodology and conditions tested, it is difficult to draw definitive conclusions. However, overall there is some evidence that superior performance with the NATO symbols was due in part to the use of a grey background. In all of the studies where the NATO symbols proved superior or equivalent to the NTDS colour coded symbols, the NATO symbols were presented against a

medium grey background and the NTDS symbols were presented against a dark or saturated background. The grey background would tend to make the NATO symbols appear more saturated (e.g. redder) while the dark and saturated backgrounds would make the NTDS symbols appear less saturated (McFadden, Kaufmann, and Janzen 1994, Ware and Cowan 1982). When highly saturated NTDS symbols were used, the differences between the two symbol sets disappeared.

The symbol recognition and scenario following task made use of some of the icons available in NATO 4420, but there was no systematic evaluation of them. Another follow-up to the original evaluation (Kirkpatrick, Dutra, Heasley, Granda, and Vingelis 1992a) focused specifically on icon recognition. Seventy-four symbols composed of all the unique icons in the surface, subsurface, and air categories along with selected special point and miscellaneous symbols were tested. Participants were shown 74 sets of ten symbols composed of a target symbol and nine distractor symbols. The distractor symbols were selected from the test set and other special point symbols. The symbol sets were presented on a CRT with the name of the target symbol to be located at the top of the screen. Accuracy and response times were collected and confusion matrices generated. Symbols with zero errors tended to use two letter labels rather than icons although this was not universally true. Exceptions usually arose because the two letter code was inconsistent with the user experience. Icons that physically resembled the object also tended to have lower error rates. Unfortunately, the visual angle of the symbols was not indicated. Thus, it is not possible to determine if the symbol sizes were consistent with recommendations for tactical displays<sup>1</sup>.

Around the same time that NATO was developing its standard for naval tactical displays, the US was working on a common warfighting symbology standard to eliminate conflicts across the three environments. Initially, they based the design on the U.S. Army symbology set, but as a result of the evaluation of the draft NATO STANAG 4420 symbology, they adopted many of its design concepts. The main difference was the use of a yellow club or clover shape for unknown tracks instead of the square. A green square shape was used for neutral tracks. The most recent version of this standard is MIL-STD-2525B with Change 2 (Department of Defence 2006). To the best of our knowledge, no systematic evaluation of the 2525B symbols has been carried out beyond the development of recommendations for implementing the standard (NAVSEA Dahlgren 2006).

Overall, it would appear that the design concepts proposed in draft STANAG 4420 and incorporated into MIL-STD-2525B have merit. Operators experienced with the monochrome NTDS symbology set found the 4420 symbols easy to learn and use. There was little evidence of negative transfer from the NTDS symbols (NAVSPAWARSSYSCOM 1991). In subjective evaluations, operators responded positively to the 4420 symbology feeling that the colour coding and the availability of amplifying information on the symbol would be helpful. However, it was also evident from the results that the proposed symbols might not provide the anticipated level of improvement, especially if the alternative was a colour coded NTDS symbology set. Secondly, none of the studies evaluated all of the basic symbols in the two sets. Most of them used only the air symbols as targets and in some cases subsurface symbols were not even present on the display. With the move towards joint operations this is a serious deficiency. Earlier research with monochrome and colour-coded NTDS symbols had found that the air and sub-surface symbols were less discriminable from each other than from the surface symbols (Jacobsen, Neri, and

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<sup>1</sup> According to MIL-STD-2525B, tactical symbols should have a visual angle of between 30-40 minutes. However, they do not specify a viewing distance since that would be system dependent. Since draft STANAG 4420 was never promulgated, its recommended viewing angle is not known.

Rogers 1985). Moreover, there were problems with the icon set (Kirkpatrick et al. 1992a) and the use of a dashed outline (NAVSPAWARSYSCOM 1991). The MIL-STD 2525B symbol set also differs from the recommendation of 4420 to use solid versions of the NTDS symbol set to avoid negative transfer. The basic shape for the unknown symbol is a clover rather than a square. They use the square symbol for neutral tracks (Figure 2) and the different warfare areas are differentiated by whether or not the outline around the symbols is missing from the top of the square (subsurface), the bottom (air) or is complete (surface). Given the visibility problem with dashed lines, this is a potential concern. The 4420 proposal for unknown tracks indented the square at the bottom for air tracks and at the top for sub-surface tracks. Their neutral symbol was also a square with the indentation replaced by an equivalent protrusion. Since the 2525B symbology has never been systematically evaluated, the impact of these design decisions is not known.

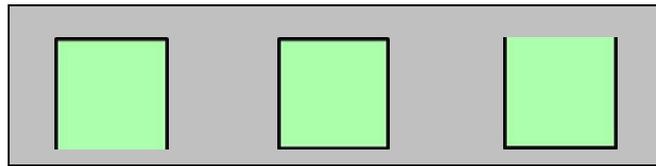


Figure 2: MIL-STD-2525B air, surface and subsurface neutral symbols

## Current research

The proposed research attempts to understand the relative strengths and weaknesses of the NTDS and 2525B symbol sets in order to recommend improvements to the design concepts laid out in MIL-STD-2525B. While it is clear from the previously cited studies that colour coding improves the visibility or discrimination of both symbol sets, it is not clear that the solid shapes are more conspicuous than the outline shapes especially if saturated colours and optimal backgrounds are used with the NTDS symbols (Laxar and Van Orden 1994, Van Orden and Benoit 1994). As well, all of the studies cited used the NTDS symbols with single pixel wide lines. As noted in draft STANAG 4420, the original NTDS symbols are potentially less conspicuous with raster scan displays as display resolution increases. The problem will likely get worse as high resolution LCD displays are introduced into military displays (Hollands, Parker, McFadden, and Boothby 2002). Thus, 4420 recommended using thicker lines. The relative ineffectiveness of the NTDS symbols when coded with less saturated colours is further evidence that the continued use of single pixel wide lines is not advisable. A potential problem with both symbol sets is the result reported above that the air and sub-surface symbols are less discriminable from each other than from the surface symbols. Moreover, in the studies by Van Order and Benoit (1994), the hostile symbol tended to be less visible than the friendly symbol. Given that hostile air symbols should be at least as conspicuous as all the other symbols, it is important to understand the extent and possibly the source of the above results.

For all of the above reasons, Experiment 1 assessed the relative visibility of each of the nine basic NTDS and 2525B shapes (see Table 1 in the method section) with and without the benefit of colour coding using a visual search task. Initially, we had planned to evaluate the 12 basic 2525B symbols. In pilot studies, it proved virtually impossible to discriminate the air, surface, and sub-surface neutral symbols (Figure 2). It was very difficult to determine whether or not a horizontal line was present at the top or bottom of the square when the symbols were presented at the

recommended visual angle on a high resolution display. Thus, the evaluation of the 2525B symbols was restricted to the nine basic symbols that corresponded to the basic NTDS set. As well, our evaluations were based on the symbol set as promulgated in MIL-STD-2525B (Department of Defence 1999). Recent changes to this standard were released in 2005 and 2006 after most of these studies had been completed. However, none of the changes in the revised standard resulted in significant changes to the symbols and icons evaluated in these studies.

In keeping with the recommendations of 4420, we constructed NTDS symbols with thicker lines. This also made it more reasonable to use the same chromaticities and background with both symbol sets. As Van Orden and Benoit (1994) point out, with moderately desaturated colours, it is possible to increase symbol luminance which improves contrast and visibility. It also allows more flexibility in the choice of colours.

Performance was assessed using a visual search task. Visual search is an important component of the tasks carried out by operators monitoring tactical displays. Moreover, there is a rich literature on the factors affecting visual search performance since it has been used extensively to measure performance in simple and complex displays (e.g. Teichner and Krebs 1972, Treisman and Gelade 1980, Wolfe, Cave, and Franzel 1989). A counting task was used over the more common yes/no task, because we have found that it provides a better estimate of the discriminability of different symbols (McFadden, Bauer, and McManus 1997). Time to locate multiple targets improved dramatically when the coding method supported the grouping of like objects across a spatial extent. Moreover, operators need to determine where the hostile contacts as well as if a hostile contact is present. Both requirements are represented in the counting task.

In a visual search task, participants usually search for a specific object (called the target) in a background composed of one or more 'distractor' objects. The distractors can vary both in number present (e.g. five) and in number of types (e.g. number of colours). In these experiments, there were always 50 objects on the display since we were primarily interested in evaluating performance on a cluttered display as opposed to looking at the effect of number of objects on visibility. Performance was measured when all the distractors were the same (one-distractor-type condition) and when distractors included all of the eight non-target symbols in the symbol set (2525B or NTDS) to which the target symbol belonged (eight-distractor-type condition). Thus, participants searched for instances of one the nine basic symbols, in either the 2525B or NTDS symbol sets, presented in a background composed of all remaining symbols in its set. The eight-distractor-type condition provides direct information on the relative visibility of the different symbols on a cluttered display. The results for the one-distractor-type condition were subjected to multi-dimensional scaling to assess the relative visibility of the members of each set and to understand the dimensions people are using to discriminate amongst the various symbols (McFadden et al. 1997, Tomonaga and Matsuzawa 1992).

One potential advantage of the 2525B symbol set is the possibility of adding more information about the underlying contact to the basic symbol shape. As with draft NATO STANAG 4420, 2525B specifies a large number of icons and modifiers that can be added to the basic symbol shapes for this purpose. In the initial evaluation of the 4420 symbols (NAVSPAWARSCOM 1991), operators responded positively to the augmented symbols because they reduced the requirement to hook or select the contact in order to get additional information about platform type. However, the icon shapes are often more complex than the basic symbol shapes and, since they fit inside the symbol, subtend a smaller visual angle. The same study expressed concern that

the operator's ability to discriminate or even recognize some symbols could be affected by factors such as display type and resolution and symbol size. Despite these concerns, there has been little direct evaluation of them beyond the follow-on study by Kirkpatrick et al. (1992a). It did not address the issue of visibility or increased display complexity with the augmented symbols.

Thus, Experiments 2 through 4 were carried out to gather additional data on the impact of augmenting the basic 2525B symbology with platform information. A total of 27 icons (9 air, 9 surface, and 9 subsurface), that are representative of the range of available platform types and that are likely to be encountered relatively frequently in CF naval operations, were used in these experiments. The 27 icons represent only a subset of the available platform types in MIL-STD 2525B. It would be very difficult to assess all of the icons and it is unlikely that all of them would be used in a naval context. The icons selected are typical of the platform types that could be encountered relatively frequently by the Halifax Class frigate. An additional criterion was that the icons represent the different ways that platform information is represented in 2525B. Thus, the chosen symbols (see Table 4 in Experiment 2) include iconic representations of a platform type (e.g. fixed winged aircraft, nuclear submarine), alphanumeric representation of a platform type, (e.g. BB for battleship), icon plus alphanumerics (e.g. rotary wing attack helicopter), and no frame (e.g. mine, decoy).

Experiment 2 assessed the impact of adding iconic information to the 2525B symbology. The task was identical to the eight-distractor condition in Experiment 1. Participants searched for examples of one of the basic colour-coded 2525B symbol shapes in a background composed of the remaining eight symbols. The displayed symbols were either the basic set used in Experiment 1 or the augmented set described in the previous paragraph.

Graphical icons are only one method of providing an operator with more easily accessible information about the tactical situation. Contextual information can be added to the background as well. This can range from adding graphical information such as range rings or air corridors, sensor information such as radar paints, and/or geographical information in the form of digital or vector maps. This contextual information may also impact the visibility of the tactical information about a track's ID and warfare area. To assess the potential negative impact of such contextual information on the visibility of the tactical symbols, Experiment 2 also compared performance with the basic and augmented symbols against a plain and a complex background.

Experiment 3 examined the relative visibility of the different augmented symbols. Participants had to search for a particular platform type in a background of the other nine platforms for that warfare area (the basic symbol was one of the alternatives). All of the symbols presented simultaneously had the same warfare area and ID or basic shape. It is unlikely that operators would want to search for a specific platform (e.g. locate all the helicopters). However, the more efficiently they are able to locate a specific icon, the more likely they will quickly recognize it when scanning a cluttered display. By understanding the characteristics of icons that are located efficiently, we can develop better guidelines for designing them.

Experiment 4 examined the participants' ability to classify the platform type on a cluttered display. A good icon should be both easily discriminated and intuitively interpreted. They were required to search for one of the basic symbol shapes and then identify its platform type. Since the participants were not initially familiar with the icons, they were given extensive training and provided with an information sheet that showed each icon and its label.

# Experiment 1 – Comparison of NTDS and 2525B symbol sets

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## Method

Experiment 1 examined visual search performance with four symbol sets – monochrome NTDS, colour-coded NTDS, monochrome 2525B symbols, colour-coded 2525B symbols. Participants counted the number of target symbols in a background of non-target symbols (distractors). The distractors were either all the non-target symbols in the target symbol's set or one of the non-target symbols.

## Participants

Ten participants (5 males and 5 females) took part. Their ages ranged from 21 to 50 with a mean of 32.8. All participants had normal or corrected-to-normal vision (based on self-report) and normal colour vision as assessed by the Ishihara Colour Plates (38 plate edition). Each participant signed an informed consent form approved by the DRDC Human Research Ethics Committee (HREC) before participating in the experiments (DRDC HREC Protocol L483).

## Conditions

Experiment 1 was a 4 (NTDS-monochrome, NTDS-colour, 2525B-monochrome, 2525B-colour symbol sets) by 9 (symbol label) by 2 (one- or eight-distractor-type) design. Each symbol set consisted of 9 different symbols: 3 warfare areas (air, surface, subsurface) by 3 different ID (friendly, hostile, unknown). Each target symbol was presented in a background composed of each of the other remaining symbols in its set for a total of 72 runs in each one-distractor-type condition (9 target symbols by 8 non-target symbols) and in a background composed of all the remaining symbols for a total of 9 runs for each eight-distractor-type condition. Thus, each participant completed 324 runs (81 runs by 4 symbol sets). Half the participants started with one of the NTDS symbol sets and half with one of the 2525B sets. As well, half of the participants started with a monochrome and half with a colour coded symbol set. Participants always completed both monochrome and colour-coded versions of a symbol set before moving on to the other set.

## Apparatus

Stimuli were presented on a 19" diagonal Hitachi Superscan 814 Monitor set to 1280 by 1024 pixels. All responses were collected via the numeric keypad on the computer keyboard. The chromaticity and luminance of each of the stimuli were measured with a Minolta CS100 chroma meter. The illuminance of the screen and keyboard were measured using a Hagner photometer in illuminance mode.

## Stimuli

The stimuli were modified versions of the 9 basic NTDS symbols and the equivalent 2525B symbols (Table 1). In both sets, geometric shape is used to code ID (diamond – hostile, square (NTDS) or club (2525B) – unknown, and circle – friendly) and whether the shape is closed (surface) cut off at the bottom (air) or at the top (subsurface) is used to code warfare area. The visual angle of each shape is also shown in Table 1. The symbol sets differ primarily in that NTDS uses outlines and 2525B uses filled shapes. The relative size of the symbols was based on the recommendations in MIL-STD-2525B for that symbol set and observation of operational displays for the NTDS symbol set.

The NTDS symbols were created using Corel Draw and saved in Windows MetaFile (WMF) format for importation into the experimental control program. The 2525B symbols were available in Corel Draw file format. Every effort was taken to make the symbols for each warfare area (e.g. the circle, square, and diamond) the same size. The small differences shown in Table 1 probably arose from display and software limitations.

Based on the results of pilot studies, some modifications were made to each symbol set. The lines that make up each NTDS symbol were made thicker for the reasons discussed in the introduction. The main modification to the 2525B symbols was the use of a completely closed outline for all symbols. The standard calls for no outline at the bottom of the air symbols and at the top of the subsurface symbols. However, as discussed, this additional cue to warfare area was not visible in the pilot studies. A closed outline was also consistent with NATO Draft STANAG 4420 (North Atlantic Treaty Organisation 1992). In addition, the outline was increased in thickness. In the samples supplied with MIL-STD-2525B (Department of Defence 1999), the outline was not visible on our monitors when the symbols were reduced down to the recommended size.

In the colour coded conditions, ID was redundantly colour coded. To avoid confounding the effect of colour coding with the effect of specific colours, the colours specified for the 2525B colour set were used with both colour sets. MIL-STD-2525B did not specify chromaticity coordinates or RGB values for symbols, but it does include a set of sample symbols. The default colours (RGB values) for these sample symbols were used. Table 2 shows the RGB values for all the stimuli used in Experiment 1 and the chromaticity coordinates and luminances for the Hitachi monitor.

Table 1: Colour-coded 2525B and NTDS symbol sets. The height and width of each symbol on the display in minutes of arc at a viewing distance of 60 cm is shown below the symbol.

Symbol Set	Warfare Area	ID and Size (minutes of arc)		
		Friendly	Hostile	Unknown
2525B	Air	 40 by 40	 40 by 40	 40 by 50
	Surface	 40 by 40	 50 by 50	 50 by 50
	Subsurface	 40 by 40	 40 by 40	 40 by 50
NTDS	Air	 20 by 46	 23 by 46	 20 by 40
	Surface	 46 by 46	 50 by 50	 40 by 40
	Subsurface	 20 by 46	 23 by 46	 20 by 40

Table 2: CIE 1931 Chromaticity coordinates (x,y) and average luminance (L in Cd/m2) of each of the symbols and backgrounds for the Hitachi 814 monitor.

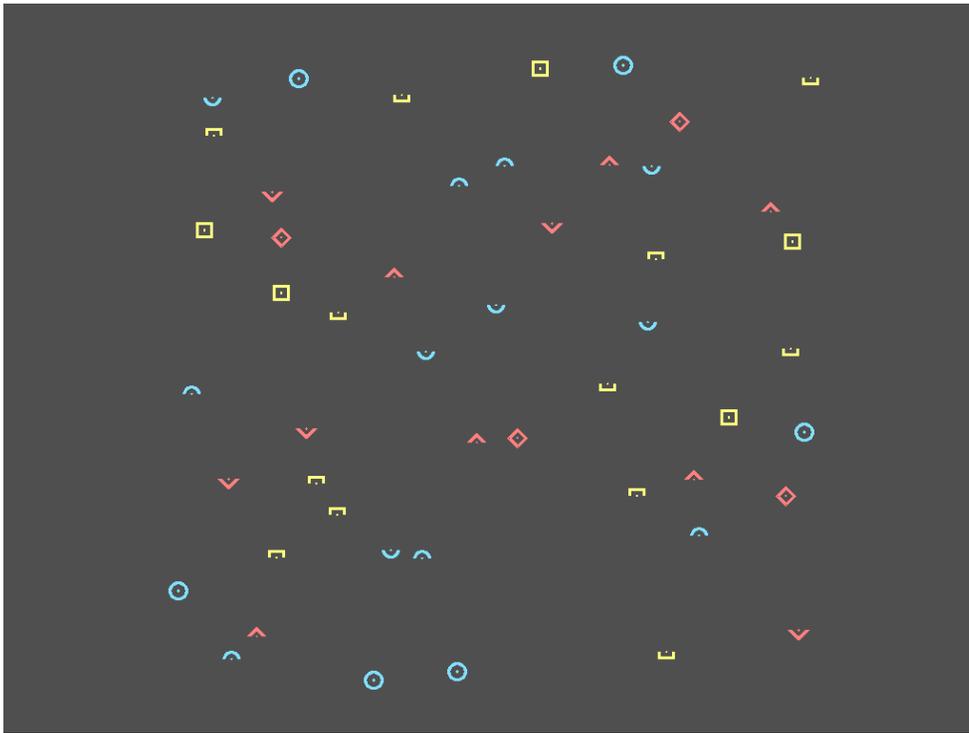
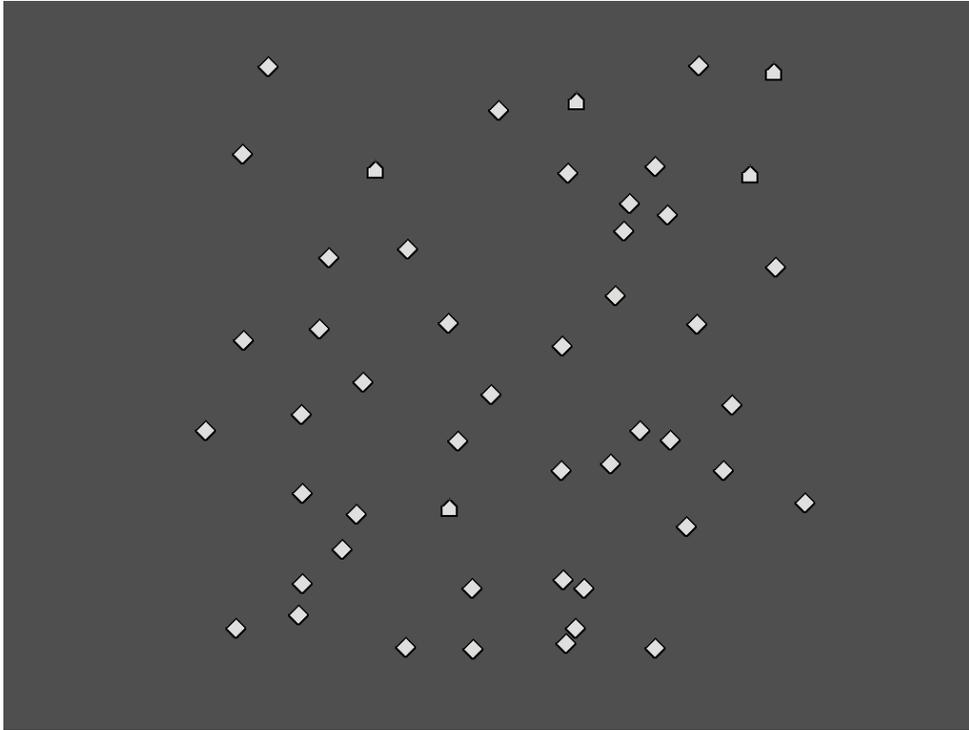
Symbol and background colours	Gun values			Chromaticity coordinates and luminances		
	Red	Green	Blue	x	y	L
Red (Hostile)	255	128	128	0.454	0.336	30
Blue (friendly)	128	227	255	0.207	0.262	54
Yellow (unknown)	255	255	128	0.372	0.467	83
Grey symbol	223	223	222	0.282	0.314	62
Monochrome background	79	79	79	Too low		3.2

## Display

On each trial, participants were shown a display containing 50 symbols randomly placed in the cells of an imaginary 8 (vertical) by 8 (horizontal) array presented against a monochrome dark grey background. The symbols were randomly offset between 0 and 90 minutes of arc in both x and y to make the display appear unordered and it usually resulted in a few of the symbols partially overlapping. The nominal size of the grid was approximately 23.5 by 23.5 degrees of arc at a viewing distance of 60 cm. The 50 symbols were made up of between 3 and 6 target symbols and 44 and 47 distractor symbols. In the single distractor conditions, all of the distractor symbols were identical. Figure 3 shows an example of a single and an eight-distractor-type display.

## Task

The participant's task was to count the number of target symbols on the display as quickly and accurately as possible and to indicate their response by pressing the appropriate number key.



*Figure 3: Examples of the displays presented to the participants. The top image shows a typical display in the 2525B, one-distractor-type, monochrome condition and the bottom image shows a typical display in the NTDS, eight-distractor-type, colour-coded condition.*

## **Procedure**

The whole experiment took a total of ten sessions, carried out on different days, with each session taking approximately 90 minutes including breaks to complete. Prior to starting the experiment, the participant read the general information sheet and signed the informed consent form. Any questions regarding the general design of the experiment was answered. Next the participant's colour vision was tested using the Ishihara Pseudoisochromatic colour plates. The participants then completed a set of practice runs to familiarize them with the task, the stimulus configurations, and the symbols. The practice sessions were identical to the test sessions except that only a small number of runs and trials per run were carried out.

The experiment was carried out under relatively low ambient illumination to maximize the visibility of the symbols. The light falling on the screen was approximately 7 Lux and the light falling on the keyboard 16 Lux. Participants were seated in an adjustable chair in front of an adjustable keyboard. The nominal viewing distance when the participants were seated properly in the chair was 60 cm. However, viewing distance was not controlled and participants were free to adjust their viewing distance if they wished. The viewing distance of operators using tactical displays would not be controlled and it was not required for the experimental conditions being manipulated.

At the start of each run, a screen specifying the target and distractor symbols for that run was presented. This screen remained on until the participant signalled with a keystroke to continue. On each of the 324 runs, 4 practice trials were presented (one with each of the different numbers of targets) followed by 12 experimental trials. The practice trials gave the participants a chance to become familiar with the target symbol for that run. The display for each trial remained on the screen until a response was made. Feedback in the form of a plus for a correct response or a minus for an incorrect response was given after each trial. The participant's response and the time taken to make that response were recorded. Participants were instructed to enter their count using the number keypad on the right of the keyboard, and to make their responses as quickly and accurately as possible. Also, they were advised not to lean forward but to sit comfortably and to keep the distance between the screen and their eyes relatively consistent. They were also encouraged to take breaks between runs especially if they felt fatigued. At the end of every six runs, a screen was displayed telling the participants to take a break. However, participants were free to take a break after each run.

The order of presentation of the different targets within a condition and the order of the conditions within a symbol set were randomized across participants.

## **Statistical analysis**

The results of interest were median response time per run for correct responses and counting accuracy per run. The median response time per run was used to control for outliers. Although response times were relatively normally distributed (usually skewness was less than 1.5 across conditions), using log response times did reduce skewness to less than 1 across all conditions. Thus log response times were used in all the analyses reported in the paper. Prior to conducting the main analysis, the effect of number of targets on response time was analysed to determine whether response time per trial or per target was the most accurate measure. The results indicated that response time did not increase as number of targets increased. Thus, response time per trial

was used in all subsequent analyses. Since there is often a trade off between response time and accuracy in visual search tasks, multivariate analyses of median log response times and accuracy were also carried out. The Wilks' Lambda statistic is reported for the multivariate analysis. For all statistical tests, a significance level of 0.01 was used. The Scheffe test was used for post-hoc analysis of the univariate analyses.

## **Results**

In terms of performance, our primary interest was in the data from the eight-distractor-type conditions. It is unlikely that operators would face a display with only two types of symbols. The one-distractor-type condition was carried out to better understand the dimensions participants were using to discriminate amongst the different symbols in each set. Thus, the two distractor-type conditions were analysed separately. Initially, a repeated measures analysis of variance was conducted on the eight-distractor-type data to determine the effect of symbol set. This was followed by separate analyses of the effect of symbol shape on performance for each of the symbols sets. Multi-dimensional scaling was used on the one-distractor-type data to examine the possible dimensions used in searching for the different targets within each symbol set.

### **Effect of symbol set and symbol shape on performance**

On average, there was a significant effect of symbol set on accuracy,  $F(3,27) = 33.1$ , and response time,  $F(3,27) = 71.9$  and overall  $F(6,52) = 40.3$ . A post-hoc analysis indicated that accuracy was significantly better with the colour coded NTDS symbols relative to the two monochrome symbol sets (Figure 4). In addition performance with the colour-coded 2525B symbol set was significantly better than the 2525B monochrome symbol set. Response times with both colour coded symbols set were significantly faster than with the monochrome symbols and response times with the monochrome NTDS symbols were significantly faster than with the monochrome 2525B symbols.

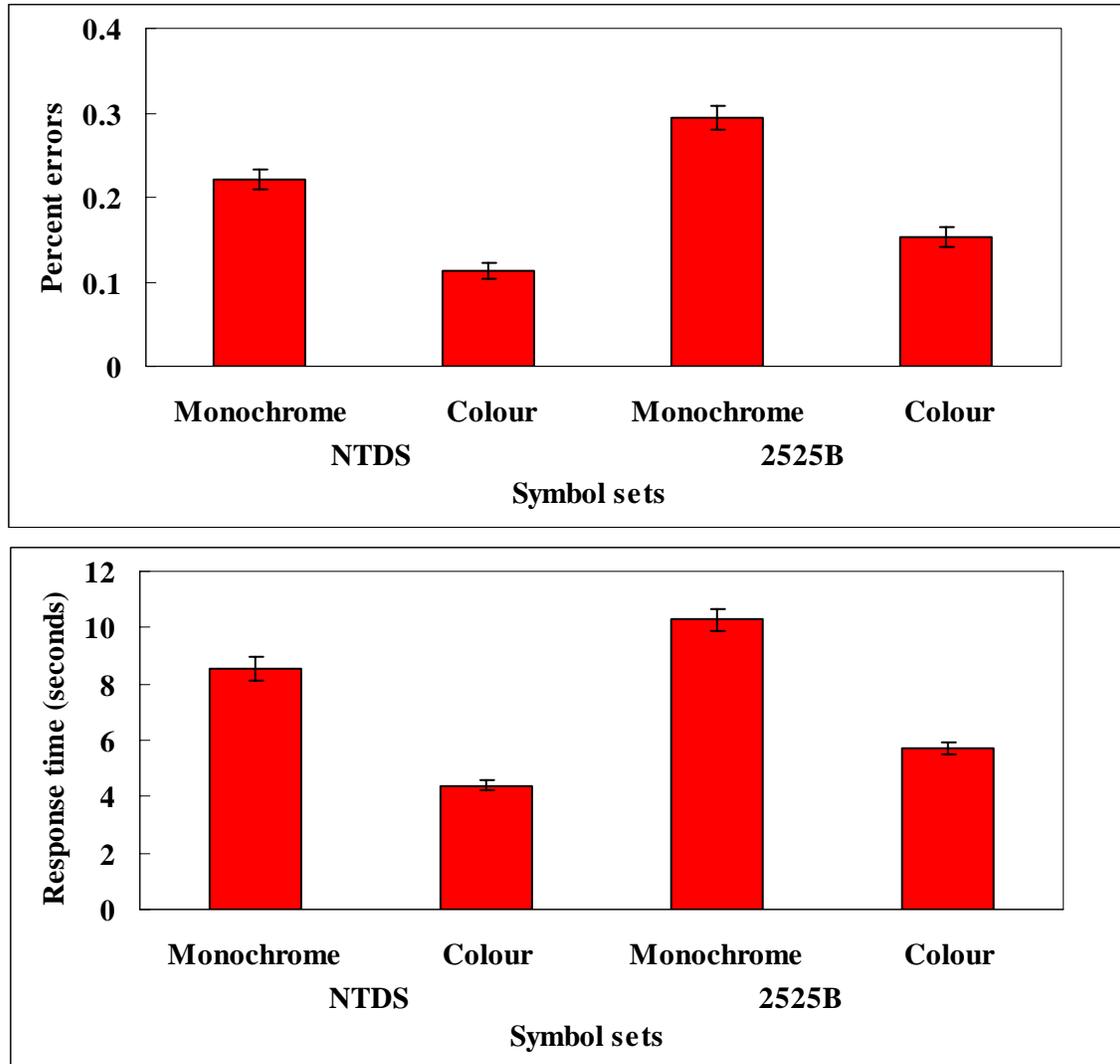


Figure 4: Percent errors and response times for each of the symbols sets in the eight-distractor-type condition. The standard error bars are also shown in this and subsequent figures.

The results of the analyses of variance for symbol shape for each symbol set are shown in Table 3. As can be seen, differences in accuracy were found only with the monochrome symbol sets. Post-hoc analysis of the effect of symbol shape on accuracy for the monochrome symbols showed that the surface friendly was significantly more accurate than the subsurface and air hostile symbols for the 2525B symbols and the surface hostile for the NTDS symbols.

*Table 3: Summary of repeated measures analyses of variance of symbol for each symbol set. Results for accuracy, response time, and a multivariate analysis of both measures are shown. Column 2 shows the univariate followed by the multivariate degrees of freedom.*

Symbol set	Univariate / multivariate degrees of freedom	F values (p < 0.01)		
		Accuracy	Response time	Multi-variate
Monochrome NTDS	8,72 / 16,142	9.9	19.6	21.6
Monochrome 2525B	8,72 / 16,142	7.2	20.2	10.3
Colour-coded NTDS	8,72 / 16,142	n.s*	46.8	23.3
Colour-coded 2525B	8,72 / 16,142	n.s	12.8	8.2

\*Not significant.

Symbol shape had a significant effect on response time and accuracy and response time combined for all four symbol sets. Post-hoc analyses of the effect of symbol shape on response time showed a similar trend to the accuracy results. As can be seen in Figure 5, response times were always shortest for the surface friendly. With the monochrome 2525B symbols, response times were also shorter for the unknown symbols. However, with the colour-coded 2525B symbols, the subsurface and air unknown symbols had significantly longer response times relative to the surface friendly and the surface unknown. With the colour coded NTDS, response times for the three surface symbols were significantly faster than all the remaining symbols. The trend was similar for the monochrome symbols except for the surface hostile which had a significantly longer response time than the other surface symbols. Overall, the effect of symbol shape is very similar for the two colour coded symbol sets. The primary difference is that response times for the surface symbols appear to be somewhat faster with the NTDS set.

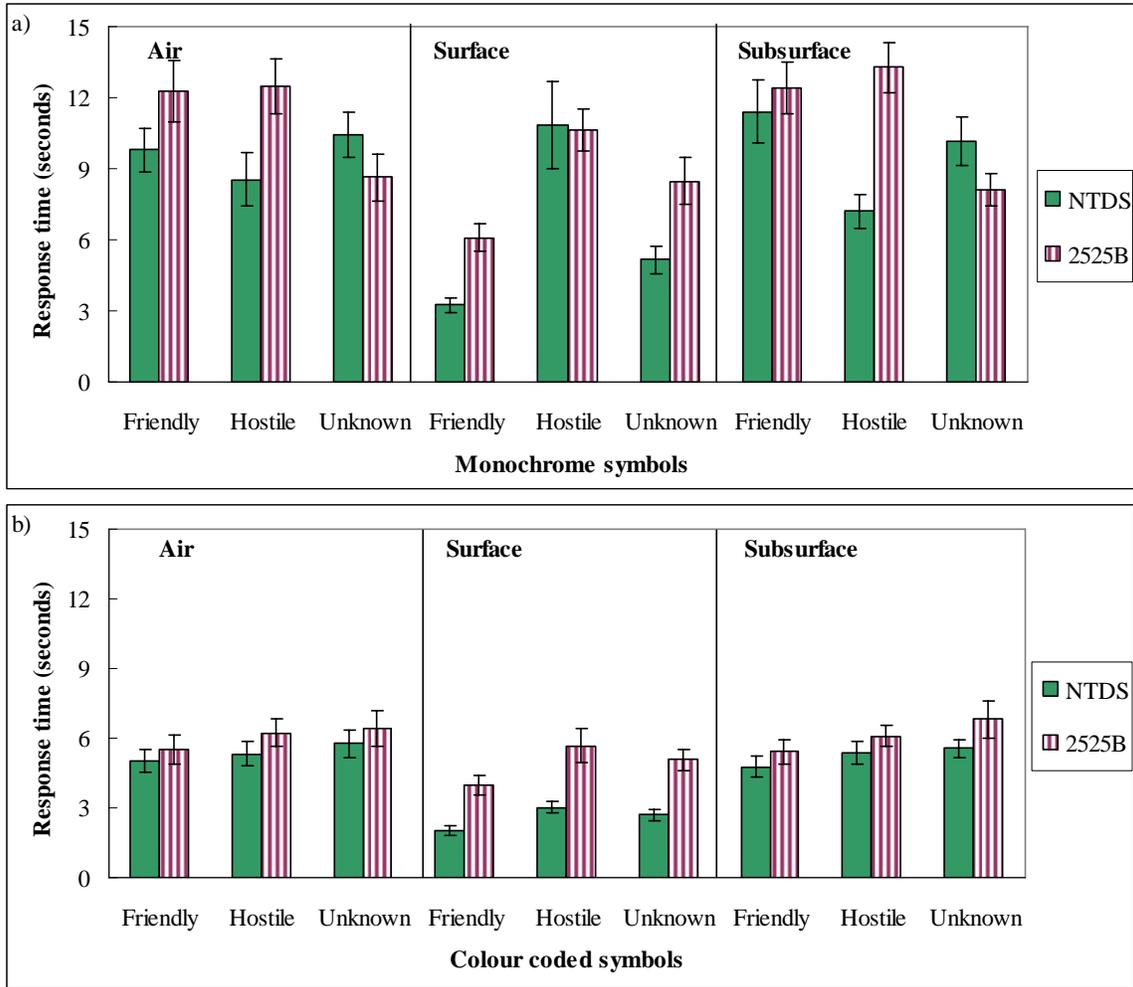


Figure 5: Average response time for a) monochrome and b) colour coded symbols with each of the symbols in each symbol set.

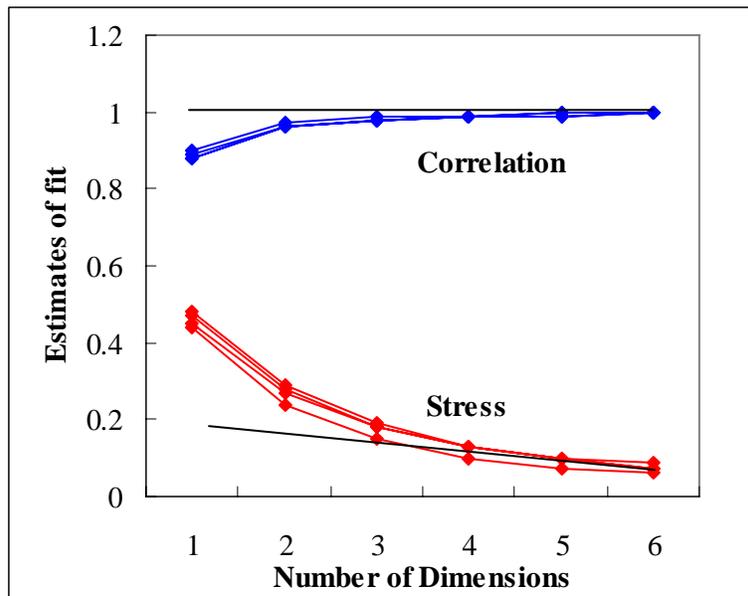
### Relative visibility of each symbol within the four symbol sets

The primary reason for including the one-distractor-type condition was to obtain a better understanding of how the choice of symbol shapes influenced discrimination of each symbol in the eight-distractor-type condition. As a first step, we carried out a Spearman rank order correlation for each symbol set to estimate the correlation between response times in the one- and eight-distractor-type conditions. In the one-distractor type condition, response times were averaged across all the runs with different distractor symbols for each target symbol. On average, we would expect the rank-order of response times for the symbols in the eight-distractor-type condition to be similar to the rank order of the average response time in the one-distractor-type condition if participants were using the same dimensions to find the target symbols under both conditions. Spearman rank order correlations ranged from 0.82 in the monochrome conditions to 0.9 with the colour-coded symbol sets.

Next, the underlying features that could have been used by the participants in the different symbol sets were examined using multidimensional scaling. A weighted Euclidean model was fit to the response times matrices for each symbol set using the MDS procedure in SAS<sup>®</sup> (SAS Institute Inc. 1992). The response times were treated as ratio data and a single partition was used. The analyses were carried out on a square (rather than a triangular) matrix because the matrices were asymmetrical.

Based on the design of the symbols, a two dimensional fit might be expected. One dimension would be ID which is represented by the basic geometric shape (and colour for the colour coded symbol sets) and the second dimension would be warfare area represented by whether the shape is whole or cut off at the top or bottom. Following the recommendation of Davison (Davison 1983), a separate solution was calculated for 1 to 6 dimensions. The MDS procedure provides several measures of the fit of the data to a particular solution. For a weighted Euclidean model, either the badness-of-fit criterion (or stress value) or the correlation between the data and the transformed distances can be used (Davison 1983). With the first measure, the lower the value is, the better the fit; with the second, the higher the value, the better the fit. Figure 6 shows the values determined for these two criteria as a function of the dimensionality of the solution for each symbol set.

The standard method for selecting the appropriate solution is a clear elbow or knee in the plot of fit versus dimensionality of the solution. The absence of a clear elbow and a relatively high correlation indicates a one dimensional solution. As can be seen in Figure 6, a three dimensional fit would seem to be most appropriate for these data.



*Figure 6: Two measure of fit for each symbol set for one to six dimension MDS solution. A straight line has been fit by eye to the higher dimension fit measures.*

The three dimensional solutions for the four symbol sets are shown in Figure 7 (monochrome symbols) and Figure 8 colour-coded symbols). In each case, the graph on the left shows

Dimensions 1 and 2 and the graph on the right Dimensions 1 and 3. Since the solutions are always constrained to fall within about plus or minus two, distances cannot be compared for the different symbol sets.

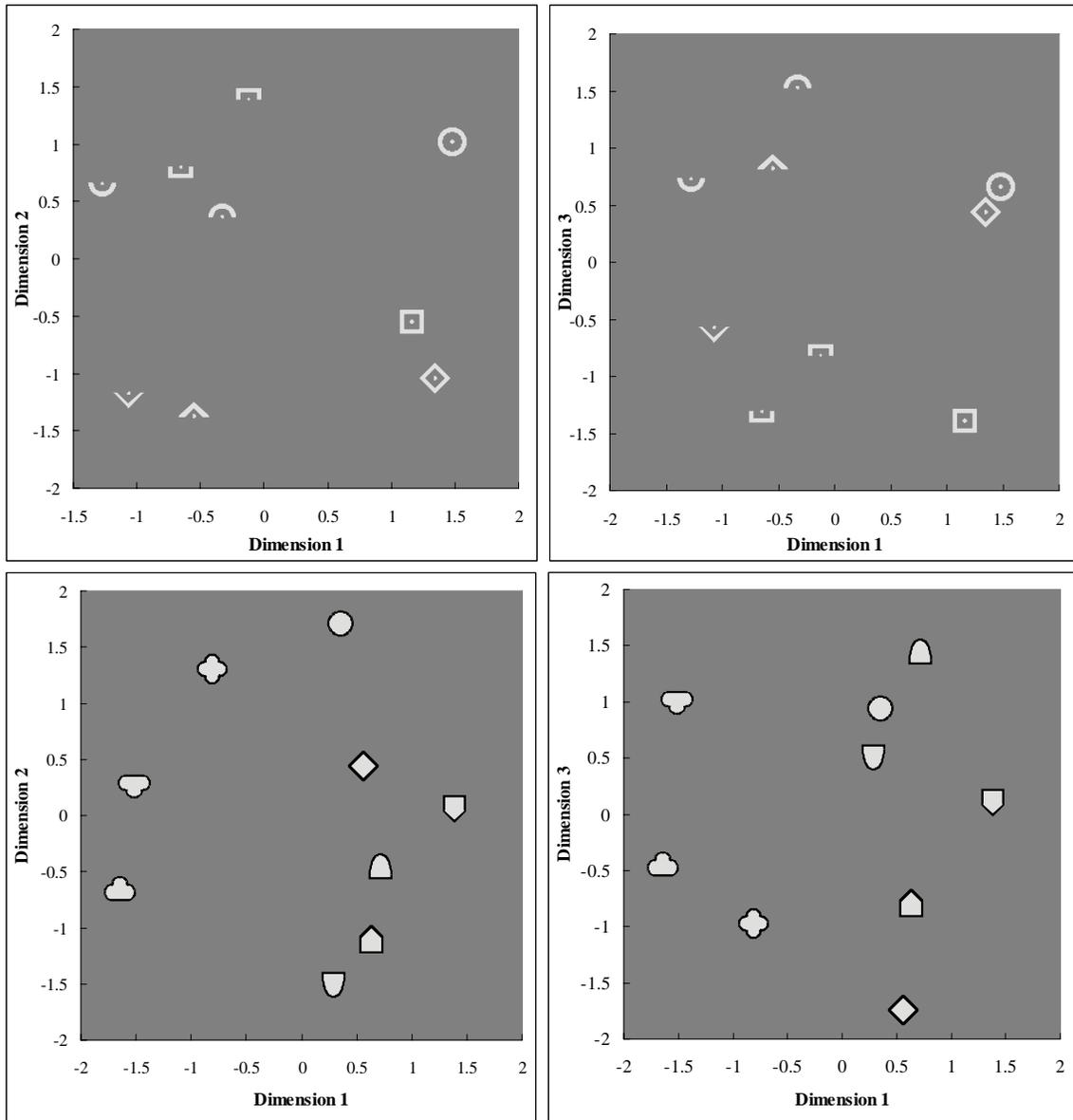


Figure 7: Three dimensional multidimensional scaling solutions for the monochrome NTDS (top) and 2525B (bottom) symbol sets.

For the monochrome NTDS symbols, Dimension 1 appears to differentiate the surface (whole shapes) from the remaining shapes. The separation between the remaining two warfare areas is relatively small but consistent along that dimension. Dimension 2 differentiates shapes with prominent right angles (hostile plus surface-unknown) from the remaining symbols and Dimension 3 differentiates the unknown shapes plus the subsurface hostile from the other

symbols. Of specific interest is the fact that the surface hostile is confused with both the surface-friendly and surface-unknown symbols in Dimension 1, with the surface-unknown in Dimension 2 and the surface-friendly in Dimension 3. This would account for the relatively high response times for this symbol in Figure 5.

For the monochrome 2525B symbols, Dimension 1 differentiates the unknown symbols from the remaining symbols. The remaining two dimensions do not appear as obvious as with the NTDS symbols even though the goodness of fit is similar. Certainly the dimensions do not correlate well with either ID or warfare area. Dimension 2 could be seen as differentiating the surface friendly and surface-unknown (circular shapes) from the remaining symbols while dimension 3 differentiates the surface hostile (the only symbol with strong angles) from the remaining shapes. The overall pattern of results suggests that the air-friendly, air-hostile, subsurface-friendly and subsurface-hostile could not be easily discriminated from each other. This is certainly consistent with the results of Figure 5.

The MDS solution for the NTDS colour symbols (Figure 8) is very similar to that for the monochrome NTDS symbols except that the dimensions are more clearly defined and the order of the dimensions has changed. Now, Dimension 1 differentiates the unknown from the friendly and hostile symbols and Dimension 3 the friendly symbols from the other two. Together, the symbols are clearly differentiated based on their colour coding and basic shape over Dimensions 1 and 3. Dimension 2 differentiates the symbols along warfare area lines. However, the order of the unknown air and subsurface symbols is reversed and they are relatively close together compared to the friendly and hostile symbols. This relative difference is consistent with the relatively poor performance of the air and subsurface symbols in Figure 5. As with the solutions in Figure 7, symbols with the same orientation do not necessarily group together.

The solution for the 2525B symbols is similar to that for the NTDS colour symbols except that Dimensions 2 and 3 are switched and symbols with the same colour are more tightly grouped. This would suggest that discrimination within a colour is poorer relative to the NTDS symbols. On the other hand, the pattern in Dimension 3 is consistent with warfare area. The similarities between the hostile and friendly symbols for air and subsurface have been overcome through the use of colour coding.

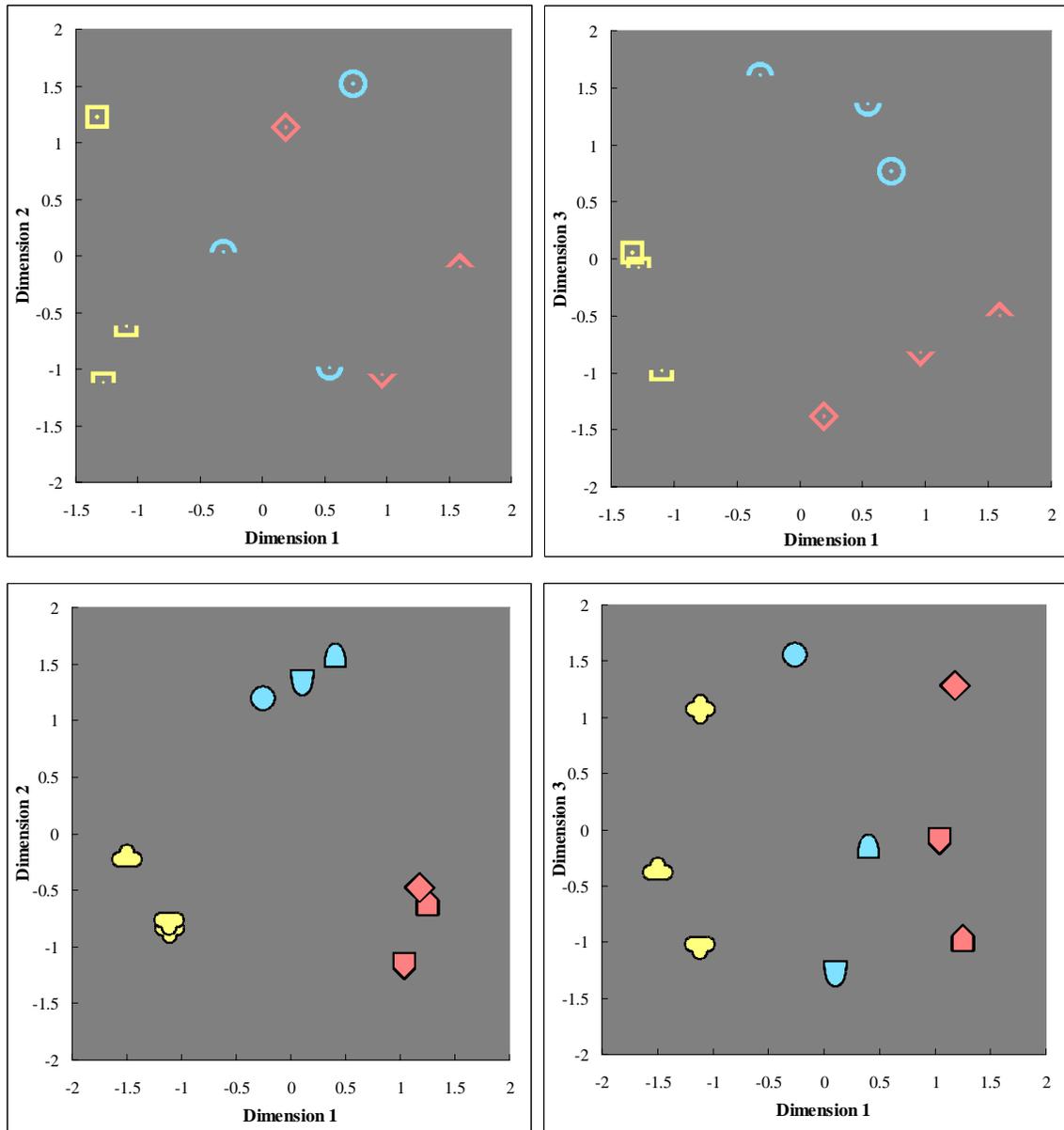


Figure 8: Three dimensional multidimensional scaling solutions for the colour coded NTDS (top) and 2525B (bottom) symbol sets.

## Discussion

The purpose of Experiment 1 was to conduct a more systematic comparison of the NTDS and 2525B symbol sets and to improve our understanding of the reasons for any differences in visibility. Thus, counting accuracy and response time for each of the 9 basic symbol shapes in the two symbol sets was measured in a background composed of all the other symbols in the set. In addition, response time and accuracy for each symbol when only one type of distractor symbol

was present was measured for each possible pair of symbols within each set. The latter data were subjected to multidimensional scaling in order to determine the dimensions people used to discriminate amongst the symbols.

As indicated in Figure 4, overall performance was very similar on the colour coded NTDS and 2525B symbols sets. Thus, when the symbols were presented on the same background, and the recommended form (North Atlantic Treaty Organisation 1992) for the NTDS symbols was used, the 2525B symbols showed no advantage over NTDS symbols. The use of the same background and thicker lines probably contributed to the visibility of the NTDS symbols. On the other hand, there would be no significant disadvantage in moving from a colour-coded NTDS to the equivalent 2525B symbol set.

Both symbols sets have problems that were not identified in previous comparisons of the NTDS and NATO symbols (Kirkpatrick et al. 1992a, Laxar and Van Orden 1994, NAVSPAWARSSYSCOM 1991) which primarily evaluated the air and surface symbols. When all nine symbols are presented simultaneously, performance with the air and subsurface symbols is considerably poorer than with the surface symbols. An examination of the multidimensional scaling solutions gives some insight into why this happens. The air and subsurface symbols are not clearly separated on any of the dimensions in Figure 7 or Figure 8. Most of the dimensions support the discrimination of the different ID dimensions. The exceptions are Dimension 1 in the solution for the monochrome NTDS symbols, Dimension 2 for the colour-coded NTDS symbols, and Dimension 3 for the colour-coded 2525B symbols. They separate out the surface symbols from the air and subsurface symbols. In the colour coded solutions, Dimension 2 (NTDS) and 3 (2525) also tends to separate out the air and subsurface, but the distances are smaller and less stable suggesting that orientation is not a strong cue.

The use of colour coding does improve discrimination of the symbols. A comparison of the monochrome and colour coded solutions indicates that colour coding reduces confusion across the different ID shapes. This is especially true for the 2525B symbols. In the MDS solution for the 2525B monochrome symbols, none of the dimensions discriminate between the air-friendly and air-hostile and the subsurface-friendly and subsurface-hostile symbols. The small differences in the shape of the four symbols (air-hostile, air-friendly, subsurface-hostile, and subsurface-friendly) are not particularly conspicuous when scanning a cluttered display.

The superior performance with colour coding is consistent with previous studies comparing the NTDS and NATO 4420 symbols (NAVSPAWARSSYSCOM 1991). It is hypothesized that people are able to use colour to reduce the search space (Hollands et al. 2002, Keillor, Thompson, Smallman, and Cowen 2003). This phenomenon is often referred to as pre-attentive processing (Treisman 1982). The result for the monochrome symbols suggests that symbol shape does not tend to be as effective in this regard. However, the superior performance with the surface friendly symbol (circle shape) across all four symbol sets and the unknown symbols in the 2525B monochrome symbol set indicates that shape can be effective if it is sufficiently unique. Moreover, the MDS analysis of the monochrome symbols suggests that size is an effective coding dimension. The difference between the surface and non-surface symbols is more distinct with the monochrome NTDS symbols compared to the monochrome 2525B symbols. The larger size of the NTDS surface symbols contributes substantially to their visibility and reduces the likelihood that they will be confused with an air or subsurface symbol. Unfortunately, reducing the size of some of the 2525B symbols would make them less suitable for adding icons.

Overall, these results underline the importance of making sure that critical dimensions can be easily discriminated.

There are several ways that the visibility of the air and subsurface symbols might be improved. One possibility would be to colour code warfare area as well as ID. However, this would potentially increase the complexity of the display. It would also reduce the ability of operators to group targets on the basis of ID. Since ID is the most critical dimension, every effort should be made to support the operator's ability to segregate the display along that dimension.

Another possibility, suggested by Smallman, St. John, Oonk and Cowan (2001), would be to remove the redundant shape coding for ID. Each of the warfare areas could then be given a unique shape. If such a solution were considered, careful consideration would have to be given to the choice of symbols to avoid interference with previous experience. As well, most human factors guidelines still recommend the use of redundant coding of colour-coded objects. Colour discrimination tends to be more susceptible to adverse environmental (bright sunlight) and technology (failure of one channel) effects and to individual differences (colour deficiency) than shape coding.

The method that has been explored most frequently is filtering. In its extreme form, an operator, monitoring only the air or subsurface picture, would have the option of removing the irrelevant symbols. A less extreme form is to use a combination of the two symbol sets. Such a concept was proposed and tested by Osga and Keating (1994). They investigated the utility of allowing operators to use different symbol sets including monochrome and colour coded NTDS and colour coded NATO symbols to create filters for different categories of tracks. Operators could define their own categories to support their watchkeeping tasks and assign a different symbol set to each category. They evaluated the number and types of filters that operators created, their performance in a dynamic scenario using the filters that had been created, and subjective opinion of the concept and suitability of the symbol sets. Most operators felt that the availability of the filters made the tactical picture much clearer by improving visual contrast for different types of tracks. In a follow-up study (Van Orden, Nugent, La Fleur, and Moncho 1999) participants searched for specific symbols in a display composed of symbols from either one symbols set (colour-coded NTDS) or two (colour coded NTDS and NATO 4420) or three (monochrome NTDS plus colour coded NTDS and NATO 4420) different symbol sets. Again, only surface and air symbols were used. The results showed no real advantage to the use of multiple symbol sets. However, the symbol sets were not used to differentiate the symbols along a dimension of interest such as warfare area.

A recent U.S. report (NAVSEA Dahlgren 2006) includes specific recommendations for implementing this concept using the 2525B symbols set. They recommend that operators have the option of using both solid and outline versions of the 2525B symbols. The solid versions would be used for the warfare area that is currently being monitored. This would avoid the potential differences in the basic unknown symbol shape between the NTDS and 2525B symbols. Although it is not explicitly stated, their outline symbols appear to use only single pixel wide lines. For the reasons discussed in the introduction, we would recommend the use of thicker lines.

# Experiment 2 – Impact of background and symbol complexity

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## Method

Experiment 2 examined the effect of symbol complexity and display background on performance in a visual search task. In this experiment only the colour coded 2525B symbols were used. The symbols were presented against either a monochrome grey background or a complex map background. Participants search for a specified symbol with a given ID and warfare area. The symbols presented were either the basic colour-coded 2525B symbols used in Experiment 1 or an extended symbol set that also provided platform information.

## Participants

Nine participants (4 males and 5 females) took part in Experiment 2. Their ages ranged from 19 to 51 with a mean of 26.1. All participants had normal or corrected-to-normal vision (based on self-report) and normal colour vision as assessed by the Ishihara Colour Plates (38 plate edition). Each participant signed an informed consent form approved by the Defence Research and Development Canada Ethics Committee before participating in the experiments (DRDC Ethics protocol #L563).

## Conditions

Experiment 2 was a two (simple or complex background) by two (basic or complex symbols) design. In the basic symbol conditions, the symbols were identical to those used in the colour-coded 2525B conditions in Experiment 1. In the complex symbol conditions, an extended set of 2525B symbols were used. This extended set provided information on platform type (e.g. battleship, civilian aircraft) as well as ID and warfare area. The symbols (basic and complex) were presented against either a monochrome grey background or a complex map background. Participants completed 9 runs, one with each basic symbol shape as a target, in each of the 4 conditions, for a total of 36 runs. The order of the four conditions was randomized across participants and the order of presentation of the 9 symbol shapes as target was randomized across conditions and participants.

## Apparatus

The stimuli were presented on a 19" (0.48 m) diagonal ViewSonic Professional Series P817 monitor set to 1280 by 1024 pixels. All responses were collected using the computer keyboard. Measurements of chromaticity, luminance, and illuminance were carried out with the same instruments as in Experiment 1.

## Stimuli

The stimuli were 30 hostile, 30 friendly, and 30 unknown colour-coded 2525B symbols. Table 4 shows the 30 hostile symbols. The friendly and unknown symbols were identical to the hostile symbols except for their colour coding (blue for friendly and yellow for unknown). As can be seen, the 30 symbols included 10 air, 10 surface, and 10 subsurface platform types. For the most part, platform type is represented by an icon within the basic symbol. In a few cases (mine and decoy), the icon is presented without the basic shape or frame as it is referred to in MIL-STD-2525B. The visual angle of the basic symbol was identical to those used in Experiment 1. For clarity throughout the remainder of the report, the term symbol will be used when referring to the basic symbol (as shown in Table 1) or the augmented symbols (symbol plus icon) and the term icon will be used to refer to the shapes that provide platform information.

As much as possible the icons were presented as supplied by MIL-STD-2525B. However, a few were modified because they were very difficult to discriminate when presented on our display. The decoy and mine icons were increased in size and outlined completely in a thicker black line as they were extremely difficult to see in their original format. Also the 'A' and 'K' in the rotary wing attack and tanker icons, the 'BB' for battleship and the 'WPN' for weapon were increased slightly in size. The visual angles of the basic symbols were identical to those used in Experiment 1 (See Table 1).

The RGB values of the stimuli in Experiment 2 were identical to Experiment 1. However, a different monitor was used so the chromaticity coordinates and luminance of the stimuli were slightly different. Table 5 shows the chromaticity coordinates for each of the basic shapes.

Table 4: The air, surface and subsurface hostile symbols used in Experiment 2.

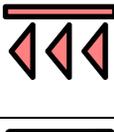
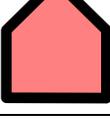
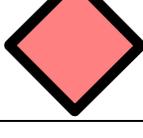
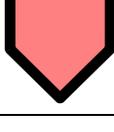
	Fixed Wing		Combatant		Sub
	F.W Attack		Carrier		Nuc Prop Sub
	F.W Tanker		Battleship		Con Prop Sub
	F.W Recon		Destroyer		Other Sub
	Rotary Wing		Frigate		Sub Station
	R.W Attack		Mine War Ves		Weapon
	R.W Tanker		Minesweeper		Torpedo
	Air Weapon		Patrol		Mine
	F.W Civil		Civ Fishing		Decoy
	Air No Icon		Surf No Icon		Sub No Icon

Table 5: CIE 1931 Chromaticity coordinates (x,y) and average luminance (L in Cd/m2) of each of the symbols and backgrounds on the ViewSonic Professional Series P817 monitor.

Symbol and background colours	Gun values			Chromaticity coordinates and luminances		
	Red	Green	Blue	x	y	L
Red (Hostile)	255	128	128	0.412	0.328	38
Blue (friendly)	128	227	255	0.212	0.266	63
Yellow (unknown)	255	255	128	0.358	0.444	89
Monochrome background	192	192	192	0.277	0.308	52

## Display

The display was identical to Experiment 1 with a few small exceptions. The symbols were presented against either a complex background (Figure 9) or a monochrome grey background with approximately the same average luminance as the complex one. In the basic symbol condition, the 3-6 targets presented on each display were identical. In the complex symbol condition, the target symbols could be any of the 10 platform types associated with that basic symbol shape. There were always multiple types of distractors and the distractors were the non-target symbol shapes. Thus in the basic symbol conditions, the distractors were the other 8 basic symbol shapes as shown in Table 1 and in the complex symbol conditions, they could be any of the remaining 80 symbols (8 basic non-target shapes by ten platform types).



## Statistical analysis

The data preparation and basic statistical analysis were identical to Experiment 1.

## Results

Experiment 2 examined the effect of adding iconic information (Table 4) and a map background on discrimination of the 2525B symbols. Counting performance with the basic symbols presented against a monochrome grey background was compared with the same symbols presented against a map background and with the complex symbols presented against both backgrounds. In general, counting performance was poorer with the complex symbols compared to the basic symbols and the effect was somewhat greater with a map background compared to the plain background (Figure 10). As shown in Table 6, there was a significant effect of symbol complexity and symbol on accuracy and response time and for both measures combined. However, there was no significant effect of background or interaction between background and symbol complexity.

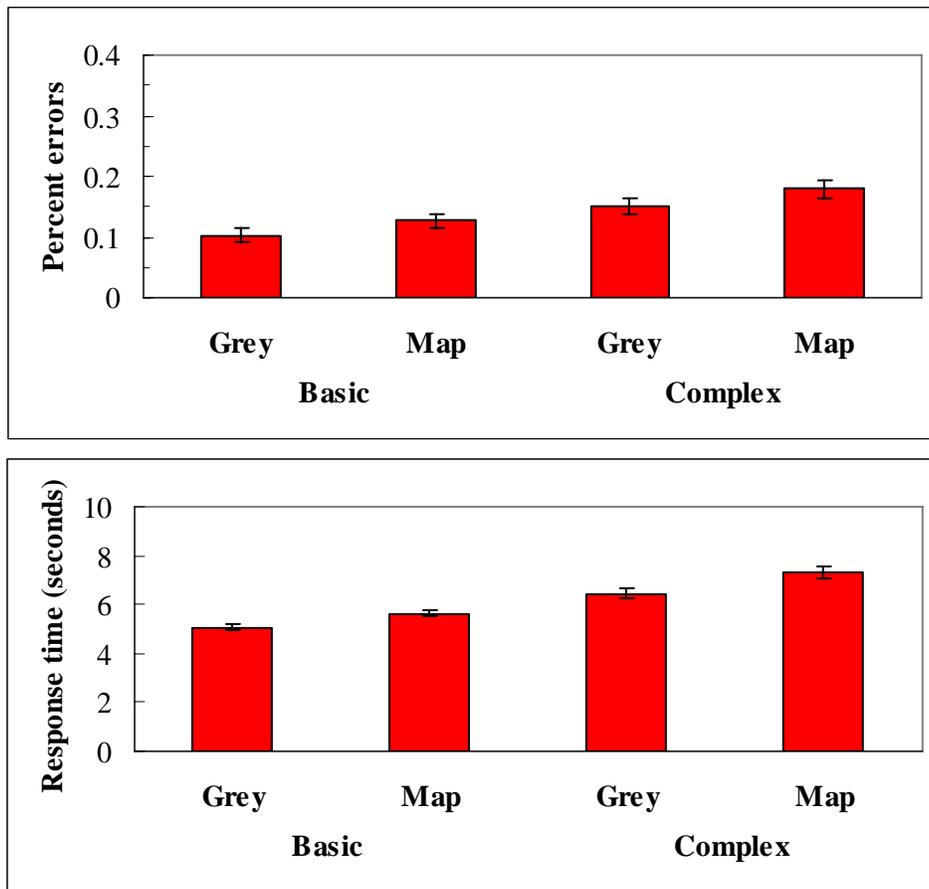


Figure 10: Counting accuracy and response time as a function of background and symbol complexity.

Table 6: Summary of repeated measures analyses of variance for accuracy, response time, and a multivariate analysis of both measures.

Source	Univariate / multivariate degrees of freedom	F values (p < 0.01)		
		Accuracy	Response time	Multi-variate
Symbol complexity	1,8 / 2,7	14.4	143.9	92.5
Symbol	8,64 / 16,126	6.2	42.6	13.8
Background by symbol	8,64 / 16,126	n.s.	3.9	3.1
Symbol complexity by symbol	8,64 / 16,126	n.s.	24.5	9.9

There was also a significant effect of symbol shape and a significant interaction between symbol shape and both background and symbol complexity. The overall effect of symbol shape was somewhat different than for Experiment 1. A post-hoc analysis of symbol shape showed that response time was significantly poorer with the subsurface symbols compared to the air and surface symbols (except for the air unknown) (Figure 11). A similar, but weaker, effect was also found with the accuracy data.

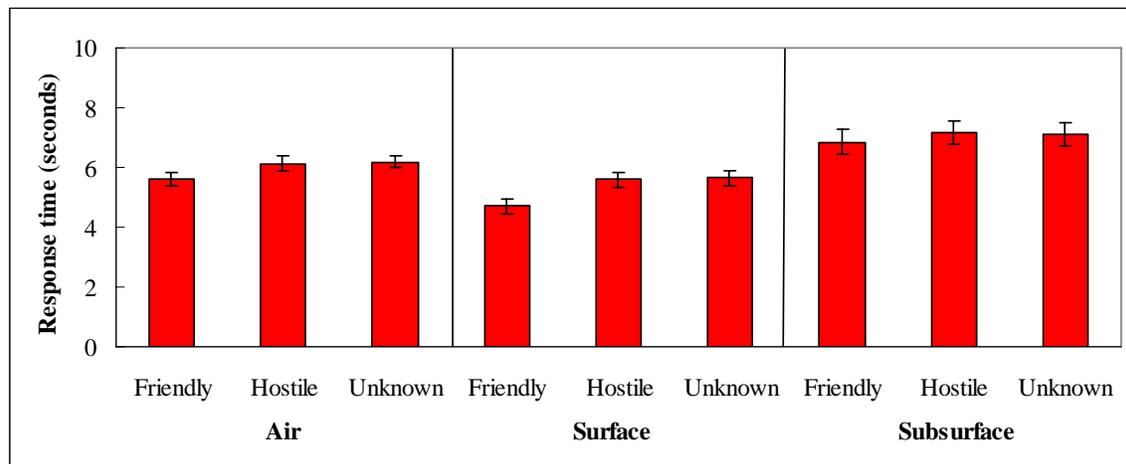


Figure 11: Counting response time as a function of symbol type.

An examination of the interactions between symbol shape and background and symbol shape and complexity indicated that most of it was due to poorer performance with the subsurface symbols in the complex symbol condition (Figure 12). As well, the addition of the complex symbols appeared to eliminate the difference in performance between the surface and air symbols.

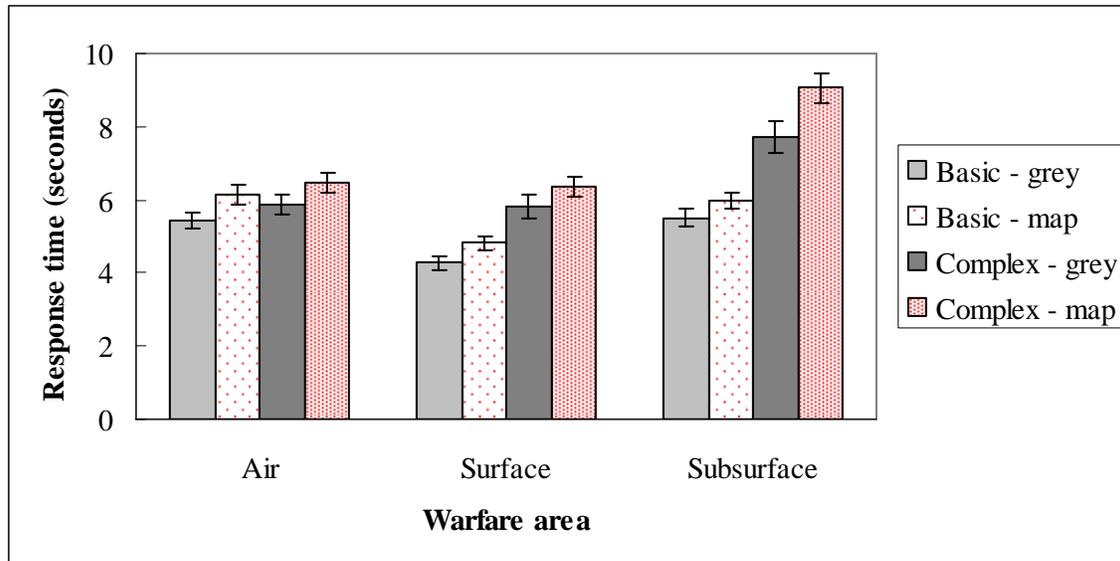


Figure 12: Response time as a function of background and symbol complexity for each warfare area. The results for accuracy were similar.

To evaluate these effects in more detail, a separate analysis was carried out for each warfare area (Table 7). It supported the effects observed in Figure 12. With the air symbols, there was no effect of either background or symbol complexity on accuracy, response time, or the two measures combined. In contrast, performance was significantly poorer with the surface and subsurface complex symbols compared to the basic symbols. As well, accuracy was significantly lower against the complex background with the subsurface symbols. The significant interaction between background and symbol for response time with the surface symbols is shown in Figure 13. As can be seen, the basic hostile surface symbol was adversely affected by the map background relative to the friendly and unknown symbols.

Table 7: Summary of repeated measures analyses of variance for accuracy, response time, and a multivariate analysis of both measures for the surface and subsurface symbols.

Source	Univariate / multivariate degrees of freedom	Warfare area	F values (p value < 0.01)		
			Accuracy	Response time	Multi-variate
Background	1,8 / 2,7	Surface	n.s.	n.s.	n.s.
		Subsurface	20.0	n.s.	17.1
Symbol complexity	1,8 / 2,7	Surface	12.3	194.8	85.8
		Subsurface	35.1	202.5	148.7
Background by symbol	8,64 / 16,126	Surface	n.s	09.5	n.s
		Subsurface	n.s	n.s	n.s

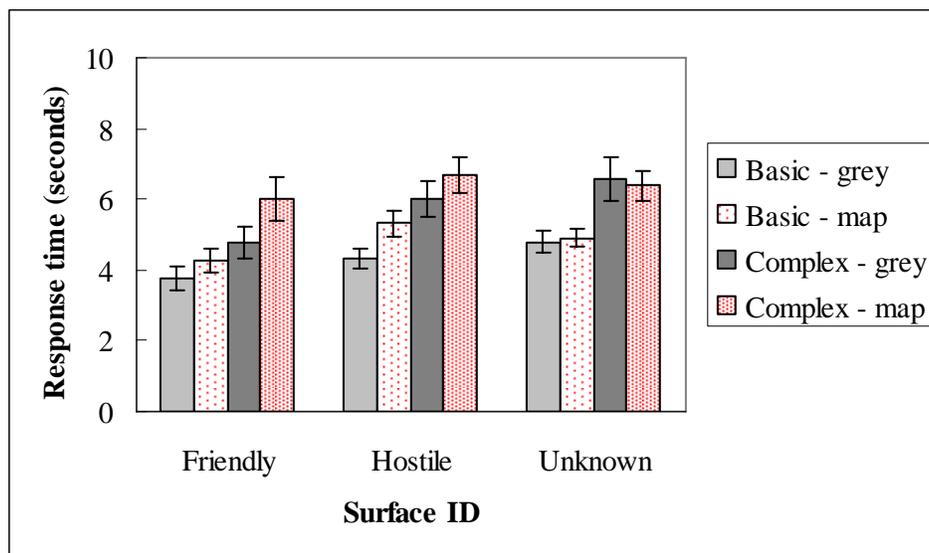


Figure 13: Response time as a function of background and symbol complexity for the surface ID symbols in the counting task.

## Discussion

Experiment 2 looked at the impact of adding icons on the detection and discrimination of the basic symbols. In most cases if the icon was presented on the symbol, its presence had relatively little impact on the participant's ability to count the number of instances of a specified symbol on the display. Poorer performance primarily occurred with the subsurface icons and was probably due to the inclusion of the mine and decoy icons in that set. They were not presented against the basic symbol. Although the colour was the same, participants had to search for up to three

different shapes on a given trial. There was also some evidence (Figure 12) that the visibility of the surface symbols was poorer with the complex symbols. Without the icons, the surface symbols were usually significantly more discriminable than the air and subsurface symbols. When the icons were present this was no longer the case. More research is needed to understand why this occurred. It could be due to the presence of similar icons against the different shapes or to a reduction in the colour coded area. Whatever the reason, it does suggest that any effort to improve discrimination amongst the basic symbol shapes could be negated by the addition of icons.

## **Presence of a complex background**

As discussed in the introduction, the addition of background information is becoming more common on tactical displays. The results of Experiment 2 suggest that adding such information may have unexpected consequences even when existing guidelines are followed. The major impact was with the subsurface symbols. Performance was significantly degraded with the addition of a complex background. Although results for individual icons are not available, it is likely that the poorer performance was primarily due to the inclusion of the mine and the decoy. Even with the thicker outline, subjectively, they were not as easy to find on the display. It may be that they were more easily confused with the different objects in the background. Another possibility is the fact that these shapes include critical elements with relatively high spatial frequencies. The minimum contrast for detecting an object increases rapidly as its spatial frequency increases above 6 cycles per degree (Campbell and Robson 1968, McFadden 1994). These results also suggest that outline symbols such as the NTDS symbol set would suffer substantially as the complexity of the background increased.

One way of improving the visibility of complex icons such as the mine and decoy is to make them either black or white, depending on the average luminance of the background. This is the practice followed in the specification of colours and symbols for electronic charts (International Hydrographic Organization 1997). It recommends the use of simple geometric shapes, which have a relatively low spatial frequency, for critical information. More complex symbols are usually black or white to maximize their contrast and legibility given that they have a lot of high spatial frequencies. This would restrict the use of icons without a frame to objects that did not have an ID. Unfortunately, whether or not an object has an ID is often a function of the taxonomy that is being used to organize the symbology (Harrison 2006). For example, in the taxonomy used for MIL-STD-2525B, ID is defined at a very high level. Thus, even inanimate objects such as oil platforms are given an ID.

The current study is only a start at evaluating the impact of complex backgrounds. Current guidelines usually recommend minimizing the use of colour and patterns (Osga and Kellmeyer 2000, Unger Campbell 2004). However, there is very little guidance on foreground versus background colours or the interaction between different categories of information. These results suggest that properly designed symbols are relatively resistant to the addition of colour coded backgrounds and other static information. However, the results for the hostile surface symbols (Figure 13) provide a caveat to that conclusion. Further research is required to better understand the factors that lead to interactions between different elements in a complex display. The background used in this study was a typical electronic chart background. The background colours conform to the standard (International Hydrographic Organization 1997) which requires the use of desaturated background colours. Other static information and non critical information are

coded in black or grey to reduce their interference with more critical symbology. Thus, it is very important that these results not be used to justify the use of backgrounds that do not conform to these guidelines. Even with good design, the critical nature of information on a tactical display makes it imperative that operators have the option of removing all non critical background information and dimming critical contextual information.

## **Experiment 3 – Icon discrimination**

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### **Method**

Experiment 3 assessed participants' ability to discriminate the different platform icons. Since the basic shape delineated warfare area, only discrimination of icons within each platform area was assessed. To avoid interactions with symbol shape and colour, the icons were always presented against the hostile symbol shapes.

### **Participants**

The same participants that completed Experiment 2 took part in Experiment 3.

### **Conditions**

Experiment 3 was a three (air, surface, and subsurface) by ten (platform icon) design. The participants searched for a specific platform icon in a background composed of the 9 other platform icons for that warfare area. Participants completed 30 runs, one for each platform icon. The participants completed all the runs for one warfare area before continuing on with the next set. The order in which warfare areas were presented was randomized across participants and the order in which icons were presented was randomized across participants.

### **Apparatus**

The apparatus was identical to Experiment 2. However, a sheet showing Table 4 was located on a document holder to the right of the monitor.

### **Stimuli**

The stimuli for Experiment 3 were the 30 hostile symbols shown in Table 4.

### **Display**

The display was identical to Experiment 2 with a few exceptions. The symbols were only presented against the monochrome grey background and only the hostile symbols were used. The target symbol was always one of the thirty symbols shown in Table 4 and the distractors were the other platform types for that warfare area. Thus, if the target was the helicopter, the distractors would be the other nine air platforms.

### **Task**

The participants' task was identical to Experiment 2 except that they were required to count the number of occurrences of a specific platform type.

## Procedure

The procedure was identical to Experiment 2. Experiment 3 was carried out following completion of Experiment 2.

## Statistical analysis

The data preparation and basic statistical analysis were identical to Experiment 1.

## Results

Experiment 3 assessed how discriminable the 10 icons in each warfare area were from each other. Participants searched for a specific icon or platform type in a background composed of the remaining icons for that warfare area. All of the icons on a given display appeared against the same basic symbol shape to avoid having to search across different coloured symbols. There was a significant difference in overall response time across warfare areas,  $F(2,16) = 23.4$ , with the post hoc analysis indicating that the time to count the surface symbols was significantly slower (11.0 seconds versus 10.0 and 9.0 for the air and subsurface warfare area respectively). However, there was no significant difference in accuracy. Since the individual icons were not comparable across warfare areas, a separate analysis was carried out for each warfare area. For all three warfare areas, there was a significant effect of icon (Table 8) for accuracy, response time and the two measures combined. As shown in Figure 14, count times were usually fastest for the basic symbols. The only icons with similar response times were the civilian fishing trawler from the surface icons, the mine and the decoy from the subsurface icons, and the civilian aircraft and missile from the air icons. The results in Figure 14 were supported by the post-hoc analysis. The basic symbol was located significantly faster than all the complex symbols and in turn the civilian aircraft and missile were located significantly faster than the other air icons. With the surface symbols the basic symbol and the civilian fishing trawler were located significantly faster than the remaining surface icons. Finally the basic symbol, decoy and mine were located significantly faster than the remaining subsurface icons. The fastest response times were similar to those for the basic symbol in Experiment 1. Accuracy results were similar although the differences between specific icons were not significant in most cases.

*Table 8: Summary of repeated measures analyses of variance for accuracy, response time, and efficiency for the air, surface and subsurface icons.*

Source	Univariate / multivariate degrees of freedom	Warfare area	F values ( $p < 0.01$ )		
			Accuracy	Response time	Multi-variate
Icon	9,72 / 18,142	Air	4.5	56.4	17.2
		Surface	8.6	207.3	38.0
		Subsurface	3.2	61.9	17.9

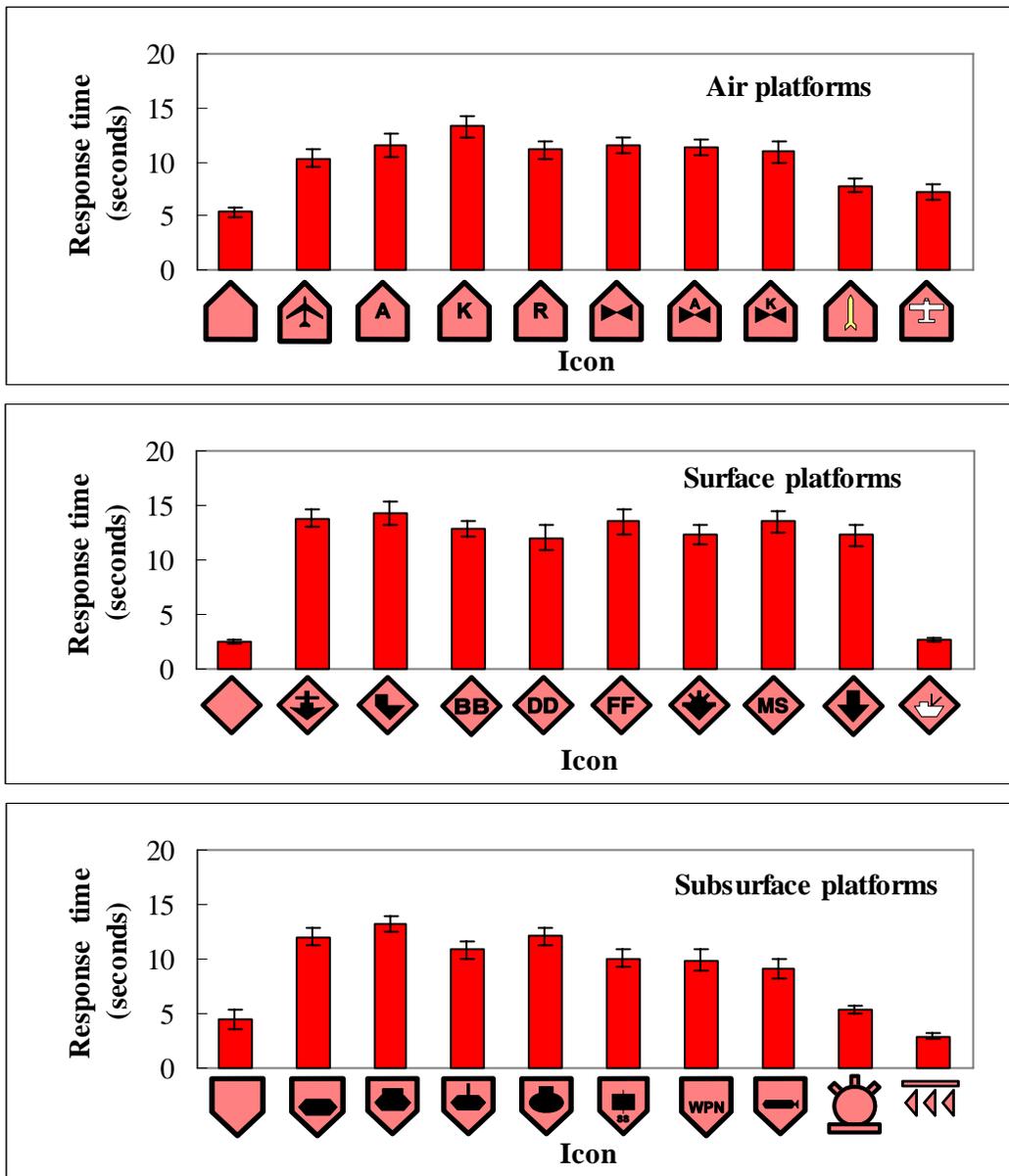


Figure 14: Counting response time for each of the complex symbols associated with the air, surface and subsurface warfare areas.

## Discussion

Experiments 3 examined the discriminability of the different icons using a counting task. On average, counting performance with the icons was similar to what was found with the monochrome 2525B symbols. This suggests that most of the shapes were not distinctive enough to support pre-attentive processing. However, some of the complex symbols were located as

rapidly as the colour coded 2525B surface symbols in Experiment 1. Thus, it is possible to create perceptually distinct icons. In most cases, the best icons differed in colour (basic symbol or no icon, missile, civilian aircraft, and tanker) or basic shape (decoy and mine) from the remaining icons or symbols. As in Experiment 1, the value of this coding seemed to depend on its uniqueness. The speed and accuracy with which the missile and aircraft were detected was somewhat poorer than the civilian tanker which was the only light coloured icon in the set of surface icons. Overall these results support the possibility that icons could be designed that would allow operators to scan the display for operationally significant platforms. However, the number of such icons that could be generated is probably relatively small. For example, the use of a combination of shape and alphanumeric icons did not seem to reduce the search space for the air icons. These results also suggest that improper use of these perceptually distinct features in coding icons could have a negative impact on performance. In MIL-STD-2525B the general practice is for military platforms to be black, civilian platforms white, and missiles yellow. This has the advantage of reducing the search space as described above. However, since there are usually more military than civilian tracks, it does not necessarily reduce the space a significant amount. Moreover, the fact that counting performance for the white civilian aircraft and yellow missile were slower than for the civilian trawler suggests that the yellow and white were not that discriminable and this coding decision could lead to the missiles being lumped with the civilian platforms. There is also the possibility that the use of perceptually distinct icons would interfere with grouping the symbols on the basis of ID or warfare area as was suggested in Experiment 2 for the surface symbols. However, further study is required to provide a definitive answer on these issues.

## Experiment 4 – Icon classification

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### Method

Experiment 4 examined participants' ability to quickly and accurately associate a label with each of the icons. The icon shape should either intuitively suggest the platform type being represented or operators should be able to easily learn the platform type represented by a particular icon.

### Participants

The participants were identical to Experiments 2 and 3.

### Conditions

Experiment 4 was a three (air, surface, and subsurface) by ten (platform icon) design. Participants searched for one of the nine basic 2525B symbol shapes and then identified the platform icon of the target symbol. The target symbol was presented in a background composed of a randomly selected subset of the remaining 80 symbols (eight basic shapes by ten platform types). The basic symbol shape was constant across a run, but the platform icon varied randomly from trial to trial. Participants completed nine runs composed of 10 practice (one example of each platform type) and 30 test trials. The order in which the basic symbol shapes were presented was randomized across participants.

### Apparatus

The apparatus was identical to Experiments 2 and 3. However for Experiment 4, participants were assigned one of three different keyboards<sup>2</sup>. The participant's assigned keyboard was attached to the computer at the beginning of each of his or her sessions. Each keyboard was modified by affixing the keys with labels showing the terms listed in Table 4. The labels were printed in 11 point Times Roman font for a nominal visual angle of about 17 to 20 minutes of arc. They were placed on the 10 number keys, and the alphabetic keys in the second and third rows plus the ';'. Labels for each warfare area were placed on different rows that were also labelled with the warfare area. Three different orders for the location of the warfare area (first, second, or third row) and the placement of the labels within a row (see Table A2) were generated to control for bias and the different orders were affixed to the different keyboards. A sheet showing Table A1 was located on a document holder to the right of the monitor.

### Stimuli

The stimuli used in Experiment 4 were the 90 symbols used in Experiment 2. During the training sessions the symbols were presented at a visual angle of approximately 2 degrees of arc at a viewing distance of 60 cm to ensure that the details of each icon were clearly visible.

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<sup>2</sup> The modified keyboards were used for Experiments 2 and 3 as well. However, participants used the number pad for those experiments.

## **Display**

Two different displays were used in Experiment 4 – one for the first four training sessions and a second for the final training session and the experimental session. The display in the experimental session was identical to the complex symbol condition in Experiment 2 except that there was always one target symbol and 49 distractor symbols. For the training sessions, only a single symbol was presented on each trial. The monochrome grey background presented in Experiment 2 was used in both the training and test sessions.

## **Task**

During the training phase of Experiment 4, participants were shown a single symbol on each trial. They were required to press the key containing the label associated with that symbol. In the experimental session, participants were required to locate one of the 9 basic symbol shapes and then identify the icon superimposed on that shape. The participant indicated the platform by pressing the key labelled with the identifier that he or she had learned to associate with that icon during the training sessions. Participants always had Table A1 available to assist them if they forgot the keyboard label associated with an icon.

## **Procedure**

The basic procedure was identical to the previous experiments. However, the training sessions were carried out in parallel to Experiments 2 and 3. During each training session, participants completed 9 runs of ten trials each. On each trial within a run, they were shown a different complex symbol from the set of ten complex symbols associated with a basic shape and were required to select the appropriate label for the icon within the complex symbol on the keyboard. During the first three training sessions, the three ID symbols associated with one warfare area were completed before presenting the ID symbols from a second warfare area. The order in which the warfare areas were presented was varied across days. During the fourth training session, the basic symbol shape randomly varied from run to run. During session 5, the participants completed a practice session that was identical to the test session, except that it had fewer trials, followed by the test session. No immediate feedback was given during either the training or the test sessions in Experiment 4 because of limitations in the experimental control software. However, participants were given feedback on their overall accuracy after each training session.

## **Statistical analysis**

Data preparation for response times was identical to the previous experiments. However, no multi-variate analysis was carried out as accuracy was close to 100% across all conditions.

## **Results**

In Experiment 4, participants searched for a basic symbol shape and then identified the icon associated with the shape. Their responses and response times were recorded. Prior to this experiment, participants completed five training sessions to learn to associate each icon with a name and also the location of those names on the keyboard. All the participants averaged better

than 95% correct and average response times dropped from 4 seconds to 2.2 seconds across the five training sessions. Over the last two training sessions, response time ranged from 1.2 to 3.6 seconds across participants.

A between/within ANOVA showed no effect of keyboard or icon. There was a small, but significant interaction ( $F(58,174) = 1.7$ ). The fastest response times on each keyboard tended to be associated with those icons that were at the ends of the keyboard. Mean response times ranged from 2.1 to 2.4 seconds across the three keyboards.

Collapsing across keyboards, response time did vary significantly ( $F(8,27) = 6.2$ ) across the icons in the training sessions. However, there were no significant differences between specific icons in the post-hoc analysis. This is not surprising given the variability in response times as a function of keyboard location for specific icons. Response times ranged from 1.7 seconds for the submarine station to 4 seconds for the rotary wing tanker icon.

Since observers had to search for the basic symbol shape, an overall analysis of symbol shape was carried out as well as an overall analysis of icon shape for the data in the test sessions. In addition, icon shape was analysed as a function of warfare area since we were primarily interested in the discrimination of the complex symbols within each area. As in the training sessions, accuracy was quite high. It ranged from 95 to 99% correct across symbol shape and from 91 to 100% across icon shape. These differences were not significant.

Analysis of the response times did show an overall effect of symbol ( $F(8,64) = 11.2$ ) with the post hoc indicating that responses to the surface friendly were significantly faster than to the air and subsurface hostile and unknown. There was also a significant effect of icon ( $F(9,72) = 7.5, 0.01$ ), but the post hoc analysis showed no significant differences amongst individual icons. The analysis of icons within a warfare area showed a significant effect of icon for all three warfare areas (air:  $F(9,72) = 8.6$ , surface:  $F(9,72) = 3.1$ , subsurface:  $F(9,72) = 5.5$ ). As indicated in Figure 15, the post hoc analysis showed that rotary and fixed wing tanker icons took significantly longer to identify than the fixed wing and rotary wing icons. For the subsurface icons, the post hoc analysis indicated that responses to other-sub were significantly slower than responses to the torpedo icon. Standard errors are somewhat larger than in the other experiments. This is probably due to variability in response times across keyboards and across participants.

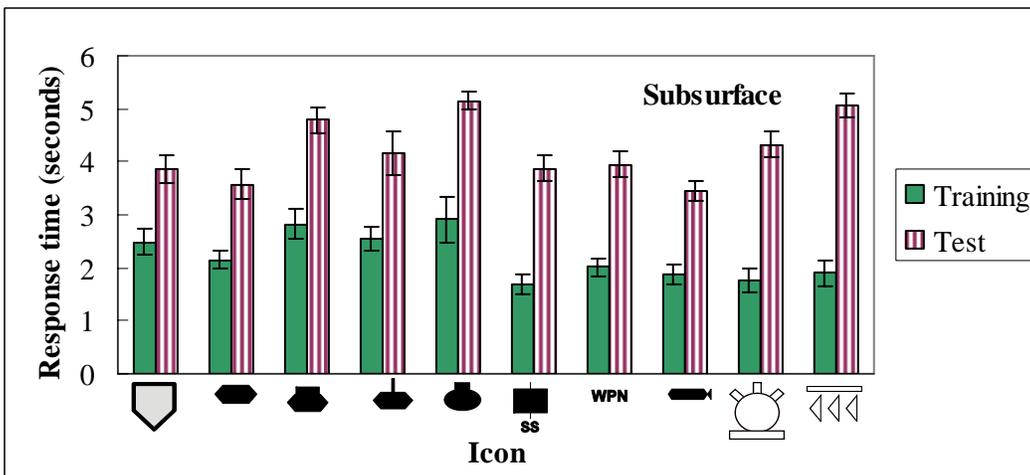
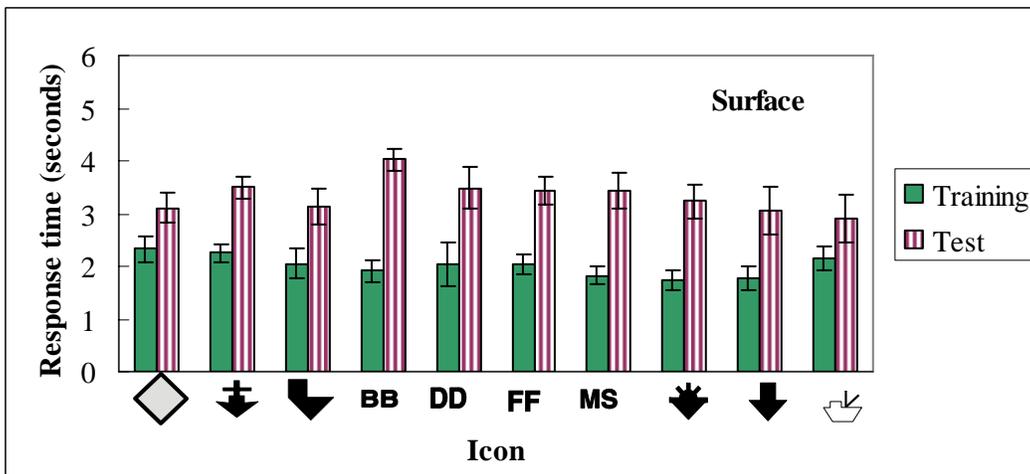
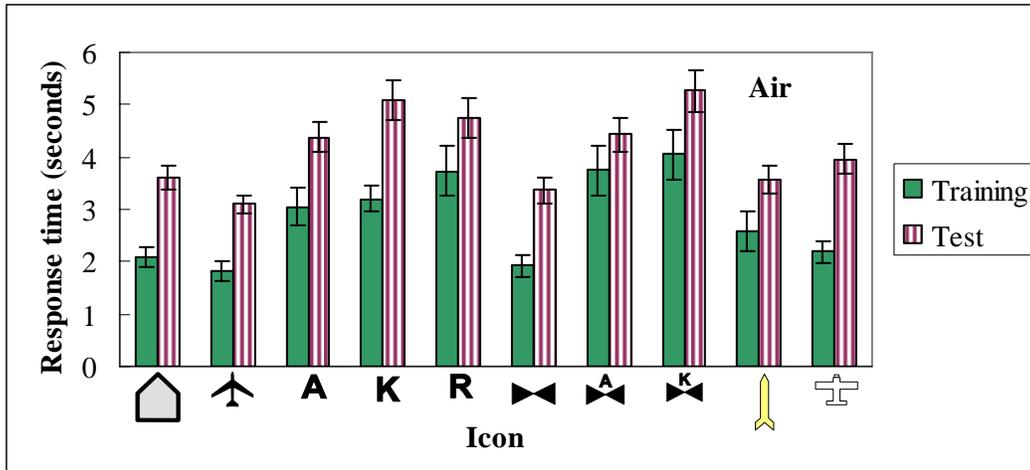


Figure 15: Response time for each of the icons associated with the air, surface, and subsurface warfare areas in the last two sessions of the training runs and in the test session. The icons for each warfare area appeared against the three ID symbols.

## Discussion

Experiment 4 examined the intuitiveness of the different icons using an identification task. Participants search for a basic symbol shape and then identified the icon presented in or in place of the shape. Although many of the icons were difficult to discriminate, participants were able to identify them accurately and relatively quickly in Experiment 4. Participants identified an icon by pressing the key labelled with the name of the icon. It is recognized that this was a somewhat inefficient method of collecting responses. It was unlikely that participant would memorize the location of all the labels within a row in the training time provided. Thus, response times reflect both the time to locate the icon label as well as the time to identify the icon. However, it is possible to get some estimate of the time required to locate the label from the initial training sessions. Those results suggest that it took about 2 seconds to locate the label on average. Symbols with longer response times were either less intuitive or more difficult to discriminate. Since the symbols were relatively large, it is unlikely the longer times were due to legibility.

The response times in the test session reflect the above factors plus the time to locate the basic symbol as well as legibility problems due to the reduction in size of the complex symbol. Since the response times were averaged over the three ID shapes in each warfare area, differences in the increase in response time across the icons within a warfare area should be due to differences in discriminability.

Taking the above corrections into account, the longest identification times were found with the air alphanumeric icons. Interestingly, participants did not have a similar problem with the surface alphanumeric icons. One possibility is the use of the 'A' and 'K' by themselves and with the rotary wing symbol made interpreting those icons more difficult. That would not explain the long response time for the fixed wing reconnaissance icon. An examination of Table A2 suggests another possibility; the labels for these icons were relatively similar. They all had either F.W. or R.W. Thus at least part of the increased response time probably resulted from the choice of labels.

Best performance overall occurred with the surface icons. Average response time tended to be less than four seconds and there was no difference across icons. The use of relatively distinct icons and relatively equal numbers of alphabetic and shape icons possibly compensated for any reduction in legibility with reduced size. After the label issue has been taken into account, the same could probably be said for the air icons. The exceptions are the fixed wing and rotary wing tankers. The most likely reason was the use of the letter K for tanker. All the other alphabetic icons used the first letter of the platform – a more intuitive choice.

The largest increase in performance between the training and test runs occurred with the subsurface icons. Icons were used for most of the platform types and their shapes were similar. This potentially made the different icons less discriminable when they were decreased in size in the test conditions. The differences in response time between the training and test runs for the mine and decoy probably occurred for a different reason. The mine and decoy were very distinct, but only if the participant knew that they were looking for them. As in Experiment 2, the symbol that participants were searching for could have any one of three shapes. Thus, the results with the mine and decoy substantiate the explanation for the subsurface results for Experiment 2.

The above observations are tentative at best given the relative crudeness of the response method and the use of relatively naïve participants. Overall, they do suggest that a relatively small set of

carefully constructed icons can be accurately interpreted relatively quickly, but that discrimination and identification would likely decrease rapidly if the set size increased substantively. Thus, it will be important to work with operators to determine the kinds of platform information that should be represented with icons and what kinds of platforms are likely to be encountered in different scenarios. That information could then be used to optimize the legibility and discriminability of the most relevant icons.

## General discussion

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The four experiments reported in this paper were carried out to improve our understanding of the relative strengths of the NTDS and 2525B symbol sets and to develop some guidance on the use of iconic information on a tactical display. The results indicate that the effective design of complex symbols that are discriminable and intuitive is not easy. Considerably more systematic research is required and the current results should be treated as preliminary at best.

### Design of the basic symbol shapes

The shapes of the NTDS and 2525B symbol sets were designed to discriminate the symbols along the dimensions of warfare area and ID. The results for Experiment 1 suggest that this goal was not achieved. Specifically, the different warfare areas are not equally discriminable and the most critical warfare area, air, is not the most discriminable. Moreover, this problem is worse with the 2525B symbols where the symbols are the same size. As discussed previously, efforts to improve discrimination along the warfare dimension (e.g. by using colour) may have undesirable side effects. Thus, it is probably better to look at ways of allowing operators to customize their displays to support their critical tasks. Even here, it is important to carefully evaluate proposed concepts. For example, in their investigation of variable coded symbology, Van Orden et al (1999) discovered that poor performance was linked with the use of both white and grey symbols on the same display.

Discrimination is especially poor with the neutral symbol proposed in MIL-STD-2525B. As discussed earlier, it was impossible to discriminate amongst the neutral symbols for the three warfare areas. A possible alternative, proposed in draft STANAG 4420, was a notched square. The notch was at the bottom for air platforms and the top for subsurface platforms. The U.S. Navy implementation Guide (NAVSEA Dahlgren 2006) recommends the use of the notched symbol, but only when the basic symbol is used without iconic information. If operators are simply examining specific symbols, the icon shape is a useful cue about the track warfare area. However, if operators are scanning a display looking for new tracks or changes in tracks, the results for Experiment 3 suggest that searching for icons associated with a specific warfare area is often slow and inefficient. A more efficient strategy would be to use the basic symbol shape to reduce the size of the search space and then examine specific icons within that space. The notched symbols are better for this purpose than the simple square specified in MIL-STD-2525B.

### Use of complex symbols

The primary benefit expected from providing iconic information on the tactical display is a reduction in the requirement to select a symbol in order to get amplifying information about a specific track (NAVSPAWARSYSCOM 1991). In order to achieve this advantage, the icons need to be legible, intuitive, and discriminable. Although icons are widely used, both in electronic systems and in the environment, there is little evidence that these criteria are ever fully met. To start, icons are rarely as intuitive as their designers expect (Smallman, St. John, Oonk, and Cowen 2000). Legibility and discriminability are usually compromised by the need to make them

relatively small to avoid clutter and overlap. Recent research has suggested that icons should subtend at least 45 minutes of arc (Lindberg and Näsänen 2003). With tactical displays, there is the additional constraint that the addition of platform information should not impact the visibility of the other information encoded in the symbol. Experiment 2 addressed this final requirement while Experiments 3 and 4 primarily examined legibility and discriminability. Since the icons represent tactical platforms and we were using non-military participants, it was not possible to investigate intuitiveness directly although the results did provide some evidence of its importance.

Experiments 3 and 4 examined the discriminability of the different icons using a counting and an identification task respectively. As discussed previously, the results suggest that it is possible to design icons that would allow operators to scan the display for operationally significant platforms. However, the number of such icons that could be generated is probably relatively small and the indiscriminate use of these perceptually distinct features in coding icons could have a negative impact on performance.

The effective location of the mine and decoy in Experiment 3 suggests that the use of icons without a frame (not superimposed on a basic symbol shape), would be another method for highlighting operationally critical platforms. Their unique shape made them highly conspicuous. However, the results for Experiments 2 and 4 indicate that this could interfere with the operator's ability to monitor all of the tracks for a particular warfare area or with a specific ID. Thus, the decision to use an icon without a frame has to be carefully considered. STANAG 4420 restricted the use of icons without a frame to objects that did not have tactical significance. However, this is often difficult to determine and could be risky. Even a seemingly innocuous pleasure boat can become a hostile contact. Moreover using unique shapes for non critical tracks would be at odds with highlighting operationally critical platforms. In general, it is possible that the effective use of icons without frames is context dependent. Further research is required to determine how to use them effectively.

It should be noted that the above recommendation tends to be at odds with current developments (Department of Defence 2006). In general, there seems to be a move towards the use of larger numbers of icons to represent the known characteristics of specific platforms. This leads to very complex icons and a corresponding decrease in legibility. The basis for this decision is not clear. It may be that even if only a small percentage of the icons are readily identified, average response time is reduced relative to selecting or hooking each track and reading the platform information. Another possibility is that most of the research investigates only a subset of the icons or does not employ time-sensitive tasks. It is important to test how quickly operators locate specific icons under operational conditions as well as how intuitive the icons are. Thus, further research is needed to systematically evaluate the operational values of these complex icons.

## Recommendations

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Based on the results of the experiments reported in this paper, it is recommended that the following work be undertaken;

1. Implement a modified form of the 2525B symbol set for representing contacts on tactical displays especially if complex backgrounds are being considered or if is desirable to provide iconic information about platform type. Necessary modifications include:
  - a. Replacing or redesigning the current neutral symbol;
  - b. Outlining the symbols in a solid line at least two pixels wide to ensure their visibility against complex backgrounds;
  - c. Restricting the use of icons without frames to objects that are not tactically significant.
2. Conduct further research to evaluate proposed methods for improving discrimination between air and subsurface symbols. These studies must include time sensitive tasks.
3. Conduct further research to evaluate proposed guidelines for complex backgrounds and symbols that will minimize the impact of the backgrounds on the visibility of tactical symbols.
4. Conduct analysis and research to develop more effective symbol taxonomies.
5. Conduct analysis and research to develop guidelines for icon construction that:
  - a. Maximize differences amongst icons that are likely to be presented simultaneously;
  - b. Ensures operationally critical icons are unique;
  - c. Minimizes the effect of the icons on the visibility of other information represented by the symbols.

## Conclusion

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Four experiments were carried out to investigate the impact of moving from the NTDS symbol set to the MIL-STD-2525B symbol set for representing tracks on naval tactical displays. Experiment 1 assessed the visibility of the basic Naval Tactical Data System (NTDS) and MIL-STD-2525B (2525B) tactical symbols. Experiments 2 through 4 measured the discrimination of the basic symbols with iconic information added and discrimination of the icons themselves. In addition, Experiment 2 investigated the effect of presenting the basic and complex 2525B symbols against a complex background. The results for Experiment 1 indicated that the colour coded 2525B symbol set offered no advantage over a well designed NTDS symbol set if both were presented against a plain dark grey background. However, the results for Experiment 2 suggest that colour-coded solid shapes outlined in black are probably more visible than colour coded outline shapes when presented on complex backgrounds. In addition, iconic information can be added more easily to the solid shapes. For the most part, adding iconic information did not affect how quickly and accurately the 2525B symbols were detected except when the icon shape replaced the symbol shape. Accuracy and response time in detecting and recognizing individual icons depended on their complexity and their uniqueness. It was recommended that only a small number of highly discriminable icons be used at any one time. The use of icons by themselves should be restricted to non-tactical information and probably they should not be colour coded. It was also recommended that a more discriminable method of representing a neutral contact be developed and tested. The MIL-STD-2525B symbols for these types of contacts are unsuitable for use on electronic displays when presented at the recommended visual angle. Further research is required to evaluate proposed methods for improving discrimination between the air and subsurface symbols and between tactical (foreground) and contextual (background) information.

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## Annex A Symbol sheet and keyboard layout

Table A1: Symbol sheet used in Experiment 4

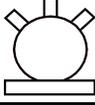
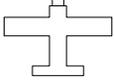
	Fixed Wing		Combatant		Sub
<b>A</b>	F.W Attack		Carrier		Nuc Prop Sub
<b>K</b>	F.W Tanker	<b>BB</b>	Battleship		Con Prop Sub
<b>R</b>	F.W Recon	<b>DD</b>	Destroyer		Other Sub
	Rotary Wing	<b>FF</b>	Frigate		Sub Station
<b>A</b> 	R.W Attack		Mine War Ves	<b>WPN</b>	Sub Weapon
<b>K</b> 	R.W Tanker	<b>MS</b>	Minesweeper		Mine
	Air Weapon		Patrol		Decoy
	F.W Civil		Civ Fishing		Torpedo
	Air No Icon		Surf No Icon		Sub No Icon
					
					

Table A2: Location of labels on the three keyboards used in Experiment 4

Keyboard 1									
F.W. Attack	R.W. Attack	Air No Icon	Air Weapon	R.W. Tanker	F.W. Tanker	F.W. Recon	Fixed Wing	Rotary Wing	F.W. Civil
Battle ship	Mine sweeper	Combatant	Frigate	Civ. Fishing	Carrier	Mine War. Vess.	Surf No Icon	Destr-oyer	Patrol
Sub	Sub Station	Torpedo	Con Prop Sub	Mine	Other Sub	Decoy	Nuc Prop Sub	Sub Weapon	Sub No Icon

Keyboard 2									
Combatant	Frigate	Civ. Fishing	Battle ship	Mine sweeper	Destr-oyer	Patrol	Carrier	Mine War. Vess.	Surf No Icon
Nuc Prop Sub	Sub Weapon	Sub No Icon	Other Sub	Decoy	Con Prop Sub	Mine	Sub	Sub Station	Torpedo
F.W. Tanker	F.W. Recon	Fixed Wing	Rotary Wing	F.W. Civil	F.W. Attack	R.W. Attack	Air No Icon	Air Weapon	R.W. Tanker

Keyboard 3									
Con Prop Sub	Mine	Sub	Sub Station	Torpedo	Nuc Prop Sub	Sub Weapon	Sub No Icon	Other Sub	Decoy
Fixed Wing	Rotary Wing	F.W. Civil	F.W. Tanker	F.W. Recon	Air Weapon	R.W. Tanker	F.W. Attack	R.W. Attack	Air No Icon
Carrier	Mine War. Vess.	Surf No Icon	Destr-oyer	Patrol	Battle ship	Mine sweeper	Combatant	Frigate	Civ. Fishing

## **List of symbols/abbreviations/acronyms/initialisms**

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CF	Canadian Forces
CCS	Command and Control System
COMDAT	COMmand Decision Aiding Technology
DRDC	Defence Research and Development Canada
HMCCS	Halifax Class Modernization Command and Control System
ID	identification (especially Standard Identification)
MIL-STD-2525B	Military Standard 2525B
MSDF	Multi Source Data Fusion
NATO	North Atlantic Treaty Organisation
NTDS	Naval Tactical Data System
OMI	Operator-Machine Interface
STANAG	STANdardisation AGreement
TDP	Technology Demonstrator Programme

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The four experiments reported in this paper were conducted in support of the COMmand Decision Aiding Technology (COMDAT) (11bg) Technology Demonstrator Project (TDP) and the Halifax Class Modernization Command and Control System (HMCCS) programme. The first experiment assessed the relative visibility of the basic Naval Tactical Data System (NTDS) and MIL-STD-2525B (2525B) tactical symbols. Performance with the colour-coded versions of the two symbol sets was not significantly different. However, the air and subsurface symbols were less discriminable than the surface symbols. Recommendations for improving the discrimination of the different warfare area symbols are included.

One potential advantage of the 2525B symbols is the possibility of adding additional information about the track platform to the basic symbol shape. The remaining experiments assessed the visibility of the basic symbols with iconic information added and the visibility of the icons themselves. Adding iconic information did not have a large effect on the efficiency with which the basic symbols were located except when the icon shape replaced the symbol shape. Performance in locating and recognizing individual icons depended on their complexity and their uniqueness. It was recommended that only a small number of highly discriminable icons be used at any one time. The use of icons without the symbol frame should be restricted to non tactical information and such icons should probably not be colour coded. Further research is required to determine how to implement these recommendations.

Les quatre expériences dont il est fait état dans le présent rapport ont été menées à l'appui du Projet de Démonstrateur de la Technologie (PDT) d'Aide aux Décisions de Commandement (COMDAT) (11bg) et du Programme de modernisation du système de commandement et de contrôle pour la classe Halifax (*Halifax Class Modernization Command and Control System Programme*, HMCCS). Dans le cadre de la première expérience, on a évalué la visibilité relative des symboles tactiques de base du Système de données navales tactiques (SDNT) et de la MILSTAND-2525B (2525B). Le rendement des versions codées en couleurs des deux jeux de symboles n'était pas très différent. Cependant, les symboles pour les entités aériennes et sub-superficielles étaient moins distinguables que ceux utilisés pour les entités de surface. Des recommandations pour l'amélioration de la discrimination des différents symboles utilisés dans les zones de guerre sont fournies.

L'un des avantages du jeu de symboles 2525B est d'offrir la possibilité d'ajouter à la forme de base du symbole de l'information sur la plate-forme de poursuite utilisée. Les autres expériences portaient sur l'évaluation de la visibilité des symboles de base lorsque de l'information iconique est ajoutée et sur la visibilité des icônes elles-mêmes. L'ajout d'information iconique n'avait pas un effet important sur l'efficacité avec laquelle les symboles de base étaient localisés, sauf lorsque la forme de l'icône remplaçait la forme du symbole. Le rendement en termes de localisation et de reconnaissance d'icônes individuelles dépendait de leur complexité et de leur unicité. Il est recommandé de n'utiliser simultanément qu'un petit nombre d'icônes hautement discriminables. L'utilisation d'icônes sans le cadre du symbole devrait être limitée uniquement à l'information non tactique et ces icônes ne devraient probablement pas comporter un codage en couleurs. D'autres recherches sont nécessaires afin de déterminer comment mettre en œuvre ces recommandations.

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COMDAT; Navy; MIL-STD-2525B; NTDS symbols; operator-machine interface; symbols; icons; tactical symbology; multi-dimensional scaling





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