BUILDING SITUATION AWARENESS: IMPACT OF SYMBOL TYPE AND READOUT LOCATION

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ABSTRACT

For many of their tasks, Navy CIC operators sequentially select or otherwise browse tracks or contacts of interest. Both the symbology used and the design of the text readouts associated with selected tracks can impact performance. A set of four tasks was used to quantitatively compare operator performance with three different symbol sets - colorized Naval Tactical Data System (NTDS) symbols and modified MIL-STD-2525B symbols in a top-down plan view display, and realistic 3D icons in a perspective view display. For the 2D displays, two locations for text readout were assessed - adjacent to the track in question and in a fixed location. The 3D displays were found to provide no benefit for altitude estimation tasks, and comparison of results across tasks indicates that realistic aircraft symbols in a 3D display are harder to search than are 2D symbols. Including within the symbols more information of relevance to the operator improved response times by 40% to 60% in two different tasks. No consistent differences in performance were found for text readout location.

BIOGRAPHICAL SKETCHES

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INTRODUCTION

Although the majority of tactical displays currently fielded on or planned for US Navy surface combatants make use of color-coded symbology, there is still significant variability in their implementation. Some displays will use a color-coded version of current Naval Tactical Data System (NTDS) symbology, some will use realistic 3D icons, and some may use MIL-STD-2525B symbology. Both the 3D icons and MIL-STD-2525B symbols provide more information within the symbols themselves than does NTDS symbology, bringing a potential for better operator performance.

Prior research has demonstrated that both speed and accuracy can be improved with MIL-STD-2525B or similar symbology over color NTDS (SPAWAR, 1991; Nugent, 1994; Pharmer, Campbell, and Hildebrand, in press). Realistic 3D icons have been well-received by Naval operators from their introduction to ships (Kramer, Hontz, and Broyles, 1995). Research has shown that they have an advantage over basic 2D symbols in determining aircraft altitude (Smallman, Schiller, and Mitchell, 1999). However, 2D symbols such as those in MIL-STD-2525B are identified faster, searched faster, and cause less confusion than realistic 3D icons (Smallman, St. John, Oonk, and Cowen, 2000; Smallman, Oonk, St. John, and Cowen, 2001).

This experimental effort was triggered by the need to determine how high-volume track loads impact the comparative advantages of 2D and 3D symbols and displays. Also, although more information may be inherent in a symbol than in current NTDS symbology, not all information required by the operator can be presented this way. This set of experiments also sought to examine the impact of different layouts for text readouts.

Versions of NTDS symbology, MIL-STD-2525B symbology, and 3D icons were used while performing situation assessment tasks. Two different character read-out (CRO) locations for amplifying information were also evaluated. The test tasks were considered to be situation assessment tasks because the operator was required to review information in the tactical display and to locate tracks that met specific criteria. Each test task was selected to highlight different types of information provided in the symbols themselves or in the CRO for the track. The alternative CRO locations were included in order to address possible performance effects of information not included within the symbols.

METHOD

Participants and Apparatus

Forty-five individuals participated in the testing, the majority of whom were active duty Navy personnel. Nineteen participants were from the Aegis Training and Readiness Center (ATRC) in Dahlgren, VA and six were from the Afloat Training Group (ATG) Norfolk. Of the remaining 20 participants, half had prior Navy service. Many of the 10 participants without prior Navy experience, however, were generally familiar with CIC displays and operator tasks. Distribution of participants with different types of experience was approximately equal across conditions.

All displays were presented on an NEC 21” flat panel set at a resolution of 1280 x 1024 pixels. The Color NTDS and Modified MIL-STD-2525B symbols were displayed using custom 2D display software, and the 3D Icons were presented using a PC-based version of the Area Air Defense Commander (AADC) prototype developed by the Johns Hopkins University Applied Physics Laboratory (APL). The Modified MIL-STD-2525B symbols were all approximately the recommended size of 30 x 30 pixels (DII COE, 1999), and the Color NTDS symbols were approximately 24 x 24 pixels, which is comparable to standard size on shipboard displays. The tactical scenarios shown in the two software packages were identical and included approximately 300 tracks within a 250 nautical mile radius. The tactical scenarios were static, with no

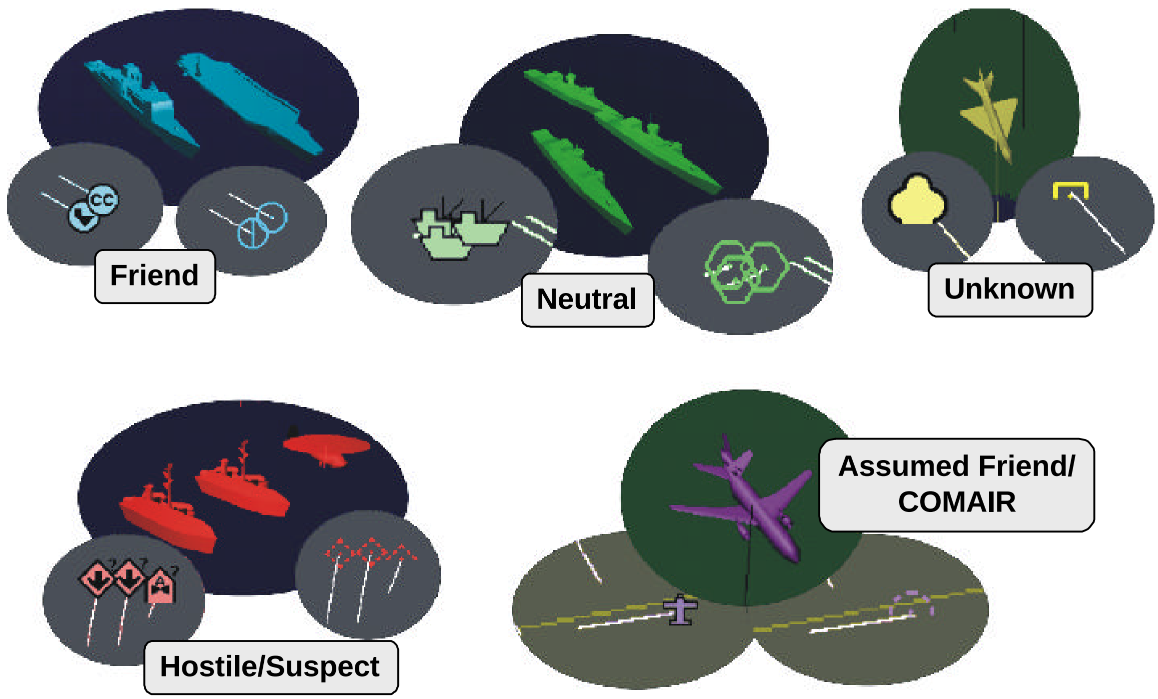

Figure 1. Example Symbols for Color NTDS, Modified MIL-STD-2525B, and 3D Icon Symbol Sets.

movement of tracks while the participants performed the tasks.

Design and Measures

The two independent variables were symbol set and CRO position. Only one of the CRO position options was available for the 3D symbols, and as a result only five conditions were tested. Participants were randomly assigned to a condition, with nine participants per condition. Dependent variables were task completion time and accuracy.

Symbol set. Three different symbol types were used for the test tasks – Color NTDS symbols, Modified MIL-STD-2525B symbols, and realistic 3D Icons (Figure 1). Color NTDS is similar to what is used on most Navy systems today, but color is used in addition to shape to represent the affiliation of the tracks. The color fill variant of MIL-STD-2525B uses the same color codes as Color NTDS, but an additional internal icon or letter code is used within each symbol to provide detailed information on the track type (Department of Defense, 1999). Both Color NTDS and Modified MIL-STD-2525B symbol sets were presented using the same display software. The affiliation color-coding used for testing was the same as that defined in MIL-STD-2525B, with the exception that positively identified commercial aircraft (typically classified as "assumed friend") were colored purple instead of blue. The Modified MIL-STD-2525B symbols were filled, but the external frames required by MIL-STD-2525B were removed from fixed wing commercial aircraft symbols. The 3D icon symbology uses realistic representations of the tracks, displayed in a perspective view of three-dimensional space. For the 3D symbols, the same affiliation color-coding was used, including purple commercial aircraft. Visual search time for specific tracks has been shown to be shorter with MIL-STD-2525B symbols than with realistic 3D icons (Smallman et al., 2001).

The 3D Icons used included a symbol library of only approximately 20 symbols. Although some operational Navy 3D displays draw from a larger symbol library, most of the additional symbols were not relevant for the test tasks used. Only one of the test tasks is expected to be impacted by the size of the symbol library, and this issue is discussed in the Summary.

Exact color RGB values differed for the 2D and 3D displays, and the 3D display had a more colorful background, but symbol-to-background contrast was sufficient in all conditions. The primary effect of the different color background in the 3D display was to make the drop lines more difficult to perceive, but ambient lighting was reduced during testing to make the drop lines sufficiently visible.

Each of the symbol types used includes a different level of information within the symbol. Color NTDS provides a limited amount of track information beyond affiliation (Friend, Neutral, etc.) and category (air, sea surface, subsurface). Modified MIL-STD-2525B conveys all of the information in Color NTDS along with detailed information on the type of track. The internal symbol icons or letter codes allow visual discrimination, for example, of different types of air tracks (fighters, bombers, reconnaissance), types of surface combatants (cruisers, destroyers, patrol boats), and types of commercial shipping (tankers, cargo ships, fishing boats). The 3D Icons convey a similar level of information to Modified MIL-STD-2525B by showing a realistic representation of the physical track. Since representational icons are used instead of abstract symbols, 3D icons are commonly considered to be more intuitive, therefore being easier to learn providing better situation awareness than other symbol sets (Naval News Service, 2001). In addition to information about the track itself, the 3D symbols allow for the explicit display of altitude and attitude (rate of ascent or descent) information without requiring the operator to refer to a text readout. For the situation assessment tasks, drop lines were used with air tracks to indicate both altitude and position relative to the ground. Drop lines were used as opposed to ground shadows as they have been shown to provide better localization performance (Smallman et al., 2000). The 3D display did not include attitude information, only altitude. To improve altitude discrimination, vertical scaling of the air tracks was increased by a factor of ten compared to horizontal scaling.

CRO position. CRO position varied as either adjacent to the track or in a fixed location. The CRO was displayed when the cursor was directly over or adjacent to the symbol or "pre-hooked." The user did not have to use the mouse button to display the CRO.

The fixed position CRO was shown in the upper right of the tactical display, and the track-relative CRO was shown to the lower right of the pre-hooked track. In all of the 2D display conditions, the CRO was shown over a dark background that obscured the tactical display. In the 3D display condition, the CRO consisted of yellow text on a transparent background in either the upper left or upper right corner of the TACSIT. In this condition, CRO position was checked prior to each test to ensure that no tracks were obscured and that all of the text was fully readable. Placing the CRO adjacent to the track was expected to reduce the amount of time required to scan all tracks since the operator does not have to switch visual focus back and forth between each track and the text readout.

Dependent variables. Dependent variables were task completion time and accuracy. Time was measured from when the participant was instructed to begin until the participant stated that he or she had found all of the relevant tracks. Accuracy was recorded as both percent of correct tracks identified and number of incorrect tracks identified. Since the same tactical scenario was used, the correct number of tracks meeting the specified criteria was the same for each participant.

Test Scenario. Identical tactical scenarios were used across all conditions, thereby requiring a between subjects experimental design. Total track load was 296 vehicular tracks and special points within a radius of approximately 250 nautical miles in the Arabian Gulf. The viewable area of the tactical environment varied between tasks, meaning that for some tasks fewer tracks were on the display. In order to ensure that all of the tracks in the 2D displays were visible in the 3D display, the 3D display typically had to be set up to show a larger number of tracks. The 3D display, however, had a larger viewable area than did the 2D displays since it included no text readouts to the right of the tactical display. The filtered dots in the 2D displays were relatively smaller than the filtered cubes in the 3D display, but the larger size of the 3D cubes was required to provide for scaling of the cubes over distance. Without this scaling, relative distances were expected to be more difficult to determine.

Procedure

Participants were first given a short training brief on their assigned symbol type. Participants were then asked to perform each of the test tasks with a practice scenario having a track density about 30% higher than that of the test scenario. Each test task required the operator to review a subset of the displayed tracks to locate those tracks meeting some specified criteria. Depending on the nature of the task, different track filters were applied. For example, if the task dealt with only Air Friend tracks, all other tracks were filtered out. Filtered out tracks were shown as colored dots on the 2D displays and as small colored cubes on the 3D display. Between tasks, the experimenter updated the display to the settings required for the subsequent task.

Participants were not allowed to manipulate the range scale or offset of the display before or during the test tasks. This constraint may be relevant in interpreting the results for the 3D display. Due to greater relative symbol size and symbol complexity, it could be more efficient for operators to assess smaller portions of the 3D display at a time, but participants were not allowed to do so. This decision was made due to the greatly increased training requirements that would be associated with manipulation of the displays. Due to the greater number of dimensions involved, a 3D display inherently has more degrees of freedom and more control features than does a 2D display. The interface manipulation tasks would require significant training to ensure consistent performance in the test tasks, and they would also add greater variability to the response time results. Additionally, the 3D display software used in the testing was not ideal for user manipulation. The display did not change viewpoints

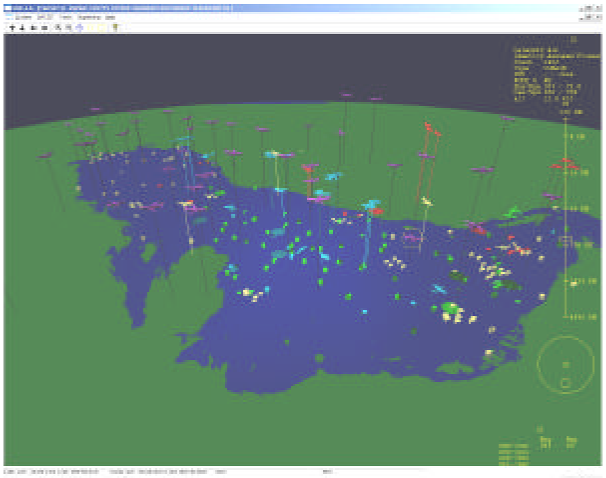

Figure 2. Tactical Display with 3D Icons for Altitude Estimation Task.

smoothly, and on-screen controls had to be used to manipulate the display instead of a dedicated spaceball.

Depending on the task, the participant was asked to either call out the identifying number of each track meeting the criteria or provide a total count of the number of tracks meeting the criteria. Track numbers could only be accessed through the pre-hook CRO. Other than errors of checking the same track multiple times, the experimenter corrected any errors made during the practice tasks. The participants then completed the four test tasks in the same order that the practice tasks were performed.

Each test task was designed to highlight different features of the symbol sets. Tasks differed in the types of tracks to be reviewed and the total number of tracks to be reviewed.

Altitude estimation task. Participants were required to call out the track numbers of all commercial aircraft over water under 25 thousand feet altitude. All tracks except air tracks were filtered out of the display, and the entire tactical environment was shown to the participant. In the 3D display, this task required the use of the drop lines to determine whether or not the tracks were over water or land. The 3D display was shown at an elevation of 35 degrees from the horizontal. This was the lowest elevation possible since the display software did not allow the selection of tracks above the horizon. This elevation allowed for consistent color backgrounds behind air tracks. Figure 2 shows the tactical display used for the 3D Icon condition in this task.

There were a total of 94 air tracks displayed, with 70 of these over water. Thirty commercial aircraft were over water, and three of these were under 25 thousand feet altitude. Compared to the other tasks, the difficulty of hooking each track was high due to the high track load and the close proximity or overlap of many of the tracks.

In all symbol sets, commercial aircraft were both a distinct shape and color. The Color NTDS and Modified MIL-STD-2525B sets provided the same amount of information. The 3D Icons also provided a visual estimate of altitude through both perspective and the drop line underneath each air track. Due to the additional altitude information, it was expected that participants would perform faster with the 3D display than with either 2D symbol set. Due to the large number of tracks and the greater occurrence of track symbol overlap, participants were expected to be faster with the relative position CRO than with the fixed position CRO.

Surface track search task. Participants were required to call out the track numbers of all neutral surface contacts een identified as tankers. All air tracks were filtered out of the display. The 2D displays were set to a 64nm range scale, and the 3D display was set to a larger range scale with a 64nm square grid displayed on the water's surface. The 3D display range scale was as small as possible without obscuring some of the area shown in the 2D displays. Figure 3 shows the tactical displays used for the Modified MIL-STD-2525B, Fixed CRO test condition in this task.

A total of 57 unfiltered tracks were displayed within the 64nm grid, and 44 of these were neutral. Six of the neutral tracks had been identified as tankers. Compared to the other tasks, the difficulty of hooking individual tracks was low due to low occurrence of track symbol overlap, but the total number of tracks to be assessed was high.

In the Color NTDS and Modified MIL-STD-2525B conditions, neutral tracks could be discriminated

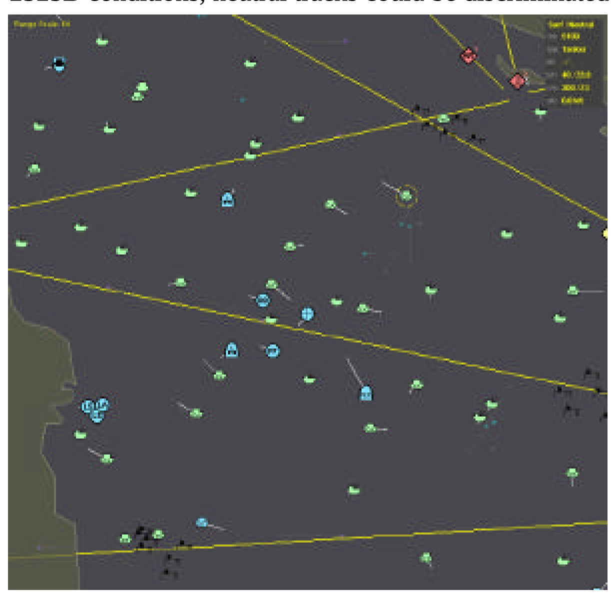

Figure 3. Tactical Display with Modified MIL-STD-2525B, Fixed CRO for Surface Track Search Task.

by both color and shape. In the 3D Icon condition, all neutral tracks were of the same color and shape (as in Color NTDS), but some non-neutral tracks were represented by the same icon. Standard MIL-STD-2525B symbols included an “OT” letter code for tracks that had been identified as “Oiler/Tankers.” This information allowed the participants to visually scan the display to locate tracks with the “OT” code and then pre-hook those tracks and read off the track number. For both the Color NTDS and 3D Icon conditions, the participants had to pre-hook each neutral surface contact and visually check the track type in the CRO. The Modified MIL-STD-2525B symbols were therefore expected to produce faster performance, while performance between the Color NTDS and 3D Icon conditions was expected to be comparable. Due to the low number of tracks to assess, there was expected to be no difference in CRO position for Modified MIL-STD-2525B conditions, but the relative CRO was expected to produce faster performance in the Color NTDS conditions.

Air track search task. Participants were required to call out the track numbers of all friendly air tracks with a “sour” (i.e., “NR” for “No Response”) Mode 4 IFF (Identification, Friend or Foe) value. All tracks other than Air Friends, ownship, and the nearby carrier were filtered out of the display. The 2D displays were set to a 128nm range scale, and the 3D display was set to a larger range scale showing the same set of friendly aircraft. Figure 4 shows the tactical displays used for the Color NTDS, Relative CRO test condition in this task.

A total of 12 unfiltered air tracks were shown in the displays. Three of these tracks had “No Response” for their Mode 4 IFF values. Compared to the other tasks, the level of difficulty in hooking tracks was moderate due to low number of displayed tracks, but many of the tracks were in slightly overlapping pairs (two aircraft at the same CAP station, for example).

In all three symbol sets, all displayed tracks were of the same color, and the same level of information was provided in all symbol sets. Due to these similarities, no differences in performance were expected across symbol sets. Due to the low number of tracks displayed, CRO position was expected to have a small effect, if any.

Air track recognition task. Participants were required to count the total number of suspect fighter aircraft in the immediate area. The only tracks not filtered out were suspect air contacts (there were no hostile contacts) and suspect surface-to-air missile sites. The 2D displays were set to the same 128nm range scale used in the air track search task, and the 3D display was set to a larger range scale to permit full view of the relevant tracks. Figure 5 shows the tactical displays used for the Modified MIL-STD-2525B, Relative CRO test conditions in this task.

A total of 12 suspect air tracks were displayed, in addition to three surface-to-air missile sites. In the 2D display conditions, the missile sites were of a significantly different shape than the air tracks. In the 3D display condition, the missile sites were filtered out in the same manner as all suspect surface contacts. Compared to the other tasks, the difficulty of hooking tracks was low due to low number of tracks to assess

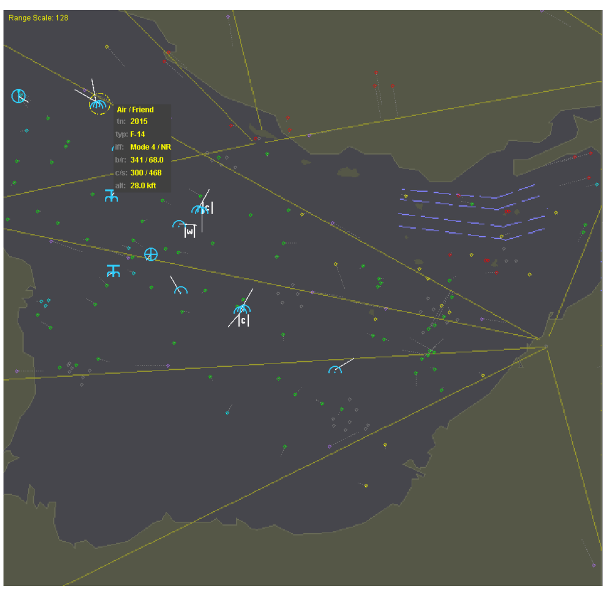

Figure 4. Tactical Display with Color NTDS, Relative CRO for Air Track Search Task.

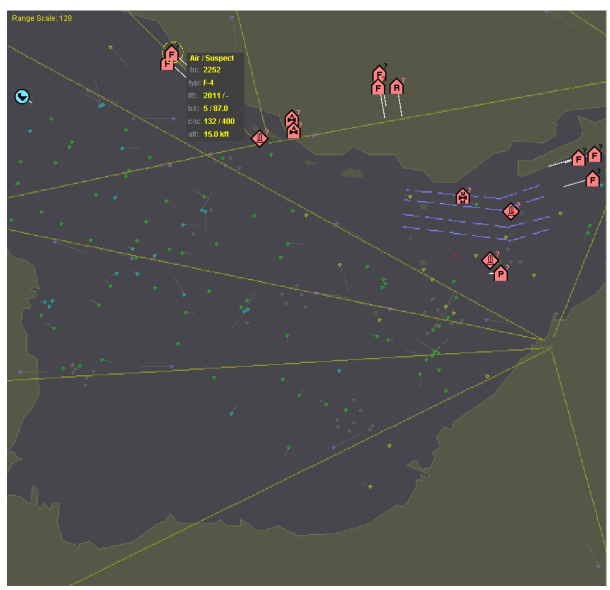

Figure 5. Tactical Display with Modified MIL-STD-2525B, Relative CRO for Air Track Recognition Task.

and to absence of overlapping track symbols.

In the Color NTDS conditions, all suspect air tracks were shown with the same symbols. In the Modified MIL-STD-2525B conditions, the exact function of each air track (fighter, reconnaissance, attack helicopter) was shown, so the participants theoretically only had to look at the display and visually count the number of fighters, never having to pre-hook any tracks. In the 3D display, some additional information was provided in that helicopters were easily distinguishable from fixed wing aircraft and the turboprop maritime patrol aircraft was substantially different from the other swept wing aircraft. This symbol set, however, did not have an exact airframe-to-function mapping since the scenario included a photographic reconnaissance plane (RF-5) that had the same symbol as one of the types of fighter aircraft in the scenario. Therefore, the participants still had to pre-hook each of the suspect air tracks to determine if the track was a fighter aircraft or a reconnaissance plane. Due to the symbol differences, performance was expected to be fastest with Modified MIL-STD-2525B, somewhat slower with the 3D Icons, and slowest with the Color NTDS symbols. Due to the small number of tracks and lack of symbol overlap, CRO position was expected to have no difference. In the Modified MIL-STD-2525B condition, since all of the required information was available in the symbols themselves, performance was expected to be identical between CRO locations.

RESULTS

Altitude Estimation Task

Mean response times and accuracy results for the air track altitude estimation task are shown in Table 1. Although performance with the 3D Icons was marginally faster than performance with other symbols, there were no statistically significant differences in symbol set (p = .0988). Differences in CRO position were also statistically insignificant. Figure 6 shows the means and 90% confidence intervals for response time on this task. Accuracy rates were comparable across all conditions.

Air Track Search Task

Mean response times and accuracy results for the air track search task are shown in Table 2. Symbol set was shown to have a significant main effect (p = .0378), and the post-hoc Bonferroni/Dunn test showed that performance with the 3D Icons was statistically slower than performance with both Color NTDS (p = .0031) and Modified MIL-STD-2525B (p = .0044). As with the previous task, differences in CRO position were statistically insignificant. Figure 7 shows the

Table 1. Altitude Estimation Task Results.

Test Condition	Mean Time [sec]	Accurate Trials
Fixed Position CRO		
Color NTDS	112.7	8/9
Mod. MIL-STD-2525B	92.3	8/9
3D Icons	80.0	7/9
Relative Position CRO		
Color NTDS	100.7	9/9
Mod. MIL-STD-2525B	90.7	7/9

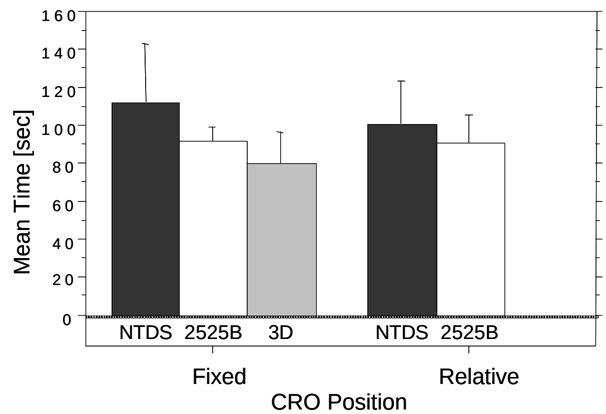

Figure 6. Altitude Estimation Task Response Times.

Table 2. Air Track Search Task Results.

Test Condition	Mean Time [sec]	Accurate Trials
Fixed Position CRO		
Color NTDS	40.8	9/9
Mod. MIL-STD-2525B	41.7	9/9
3D Icons	54.3	9/9
Relative Position CRO		
Color NTDS	38.7	8/9
Mod. MIL-STD-2525B	39.0	9/9

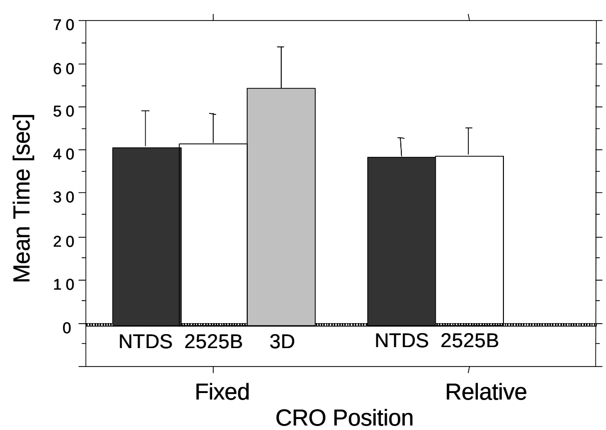

Figure 7. Air Track Search Task Response Times.

means and 90% confidence intervals for response time on this task. Accuracy rates were comparable across all conditions.

Surface Track Search Task

Mean response times and accuracy results for the surface track search task are shown in Table 3. Symbol set was shown to have a significant main effect (p = .0001), and the post-hoc Bonferroni/Dunn test showed that performance with the Modified MIL-STD-2525B symbol set was statistically faster than performance with both Color NTDS (p = .0001) and 3D Icons (p = .0001). As with the two previous tasks, differences in CRO position were statistically insignificant. Figure 8 shows the means and 90% confidence intervals for response time on this task. As before, accuracy rates were comparable across all conditions.

Air Track Recognition Task

Mean response times and accuracy results for the air track recognition task are shown in Table 4. Both symbol set (p = .0004) and CRO Position (p = .0339) were shown to have significant main effects. The post-hoc Bonferroni/Dunn test showed that performance with the Modified MIL-STD-2525B symbol set was statistically faster than performance

Table 3. Surface Track Search Task Results.

Test Condition	Mean Time [sec]	Accurate Trials
Fixed Position CRO		
Color NTDS	86.9	8/9
Mod. MIL-STD-2525B	32.7	9/9
3D Icons	93.1	9/9
Relative Position CRO		
Color NTDS	85.0	9/9
Mod. MIL-STD-2525B	37.4	8/9

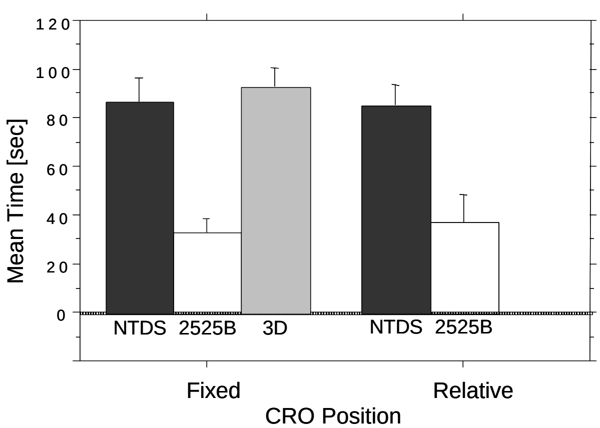

Figure 8. Surface Track Search Task Response Times.

Table 4. Air Track Recognition Task Results.

Test Condition	Mean Time [sec]	Accurate Trials
Fixed Position CRO		
Color NTDS	27.2	9/9
Mod. MIL-STD-2525B	13.2	8/9
3D Icons	25.1	6/9
Relative Position CRO		
Color NTDS	32.1	9/9
Mod. MIL-STD-2525B	21.3	9/9

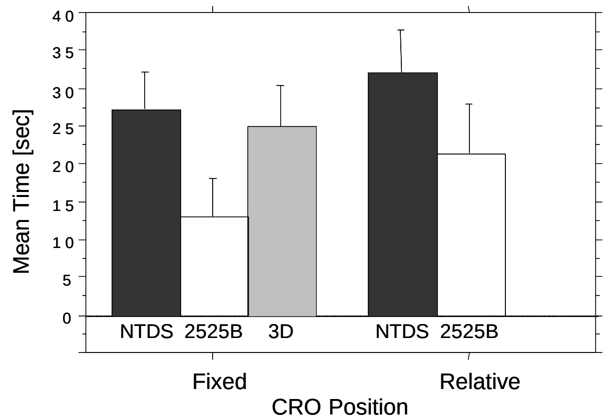

Figure 9. Air Track Recognition Task Response Times.

with both Color NTDS (p = .0008) and 3D Icons (p = .0272). The significant main effect of CRO Position indicated that performance was faster with the Fixed CRO than with the Relative CRO. Figure 9 shows the means and 90% confidence intervals for response time on this task. The accuracy rate for the 3D Icons condition was substantially lower than for the other conditions, with all three errors being overcounts of fighter tracks as opposed to an undercount as in all other conditions for this task and in all conditions of the other three test tasks.

DISCUSSION

Symbol Set

The modified version of MIL-STD-2525B used in these tests was significantly faster than the other symbol sets in the two test tests in which it was expected to be faster. Response time improved with Modified MIL-STD-2525B symbols in both the Surface Track Search and Air Track Recognition tasks. In both of these tasks, the Modified MIL-STD-2525B symbols contained information relevant to the operator, reducing the need to individually select or pre-hook tracks. Compared to Color NTDS symbols, the surface track search task was completed 60% faster (35.1 seconds to 86.0 seconds). The air track recognition task was performed 40% faster than with Color NTDS symbols (17.3 seconds to 29.7 seconds).

Both the Color NTDS and Modified MIL-STD-2525B symbol sets produced faster performance than the 3D Icons in the air track search task. The 3D Icons required 32% longer to search (54.3 seconds to 41.3 seconds (Fixed only)). This difference was surprising since all three symbol sets included the same amount of information within the symbols. The performance change may therefore have been due to other factors such as the increased complexity of the 3D Icons or the visual clutter caused by the larger relative symbol size and presence of drop lines underneath the air tracks. Track symbol overlap may have also played a role. Due to the basic characteristics of perspective view displays as opposed to a top-down view, the 3D display showed a larger number of tracks. The 3D display therefore had more tracks for the user to search visually. Eliminating this difference between display types would require tracks to be filtered out by geographical location, showing only those tracks in a square grid equivalent to the viewing area of a top-down display.

Comparing the results for the surface track search task can eliminate some factors as the cause of the performance difference in the air track search task. In the surface track search task, no significant differences were found between symbol sets. Since the symbol size differences were comparable in the air and surface track search tasks, the difference in the air track search task is expected to be due to the difficulty in picking out air tracks in the greater clutter caused by drop lines, to the presence of track overlap, the greater complexity and variability in air track symbols and/or the larger number of track symbols to visually scan.

The altitude estimation task was expected to show a benefit for 3D Icons over the 2D Color NTDS and Modified MIL-STD-2525B symbols since an estimate of altitude is available from visual inspection of the 3D Icons. Although there was a trend to faster response times in the 3D Icon condition, no differences were significant. This unexpected result may be due to the high track load for the task, which made it harder to discern which drop lines were associated with which air tracks. Discrimination of drop lines for this task was critical since participants were to evaluate only COMAIR tracks over water, and ground location of tracks could only be determined through use of the drop lines. Failure to accurately associate drop lines with air tracks would both prevent use of drop lines to estimate altitude and cause participants to check air tracks over land, a problem which did not exist in the 2D display conditions.

The lack of difference may alternatively be due to the fact that in an effort to increase accuracy, participants simply ignored the available inexact altitude cues and manually selected more tracks than would otherwise be necessary. If the second cause is true, then performance may improve with training and experience. If the first cause (complexity and clutter) is true, the similarity of performance between symbol sets would be expected to persist over time for heavy track loads. Employing a different search strategy with the 3D Icons, such as continuously changing the display point of view, may also have improved performance. This strategy, however, would have required additional time to manipulate the user interface. Further research may be warranted to determine if such a strategy with experienced operators can demonstrate the performance gains so frequently predicted for 3D displays. The use of stereoscopic displays to provide depth information may make it easier for users to visually separate and identify track symbols.

The use of 3D Icons was expected to be at least marginally faster than that of Color NTDS in the air track recognition task. Although the function of the tracks to be searched was in question, the 3D Icons provided a portion of that information through airframe. This allowed helicopters and turboprop aircraft to be easily discerned from fighter airframes, something impossible with the version of Color NTDS symbology used in the test tasks. Despite this advantage, response times were equivalent with the 3D Icons and Color NTDS symbols. Accuracy for this task, however, was diminished with the 3D Icons, and was worse than for any condition in any other task. In each case, the participants wrongly included the reconnaissance aircraft – which had the same airframe as the fighter aircraft – in the total number of suspect fighters. These errors illustrate the potential problems with symbol recognition and multiple functions for the same airframe, problems which arise primarily when realistic icons are used instead of abstract function- or mission-based symbols. When the same platform is used for different missions – such as the Strike, DCA, tanker, and potential EW functions of the F/A-18 Hornet airframe – critical information is denied to the user.

CRO Position

Differences between the Fixed and Relative CRO positions were expected to be most pronounced for test tasks with more tracks to be assessed or more track symbol overlap. A significant difference was found, however, only for the test task with the fewest tracks to be assessed and the least amount of track symbol overlap. The consistent findings of no significant differences in the first three test tasks indicates that there is little to no response time difference between the two layout options, and a specific performance difference between the two is not expected to have been the cause of the difference in the air track recognition task.

The air track recognition task was a different type of task than the other three test tasks. Since only an overall total count was necessary, the selection or pre-hooking of tracks was not required to read a track number. The test results indicate that participants did not complete the task in the most effective manner. For both Modified MIL-STD-2525B conditions, no track selection was necessary since there was no track overlap and all that the participant had to do was count the occurrences of the required symbol. For the Modified MIL-STD-2525B condition, however, performance with the Fixed CRO was significantly faster than performance with the Relative CRO, when there should have been no difference at all if participants were following the optimal strategy. This difference, when there fundamentally should have been no difference, indicates that participants were not completing the task in the manner expected. If the Fixed CRO is fundamentally faster than the Relative CRO, the same differences should have shown up in the other test tasks.

Observations from the tests indicate that participants had to work harder and got more frustrated with trying to select overlapping tracks in the Fixed CRO conditions. It is possible that there is a workload or fatigue difference that would be manifested only during extended use of the displays.

SUMMARY

Response time improvements of 40% to 60% were shown for tasks in which added information in the symbols could lead to better performance, and the additional information led to no degradation of performance in cases where it was not relevant to the task. In all cases, Modified MIL-STD-2525B symbols either showed a performance improvement or no difference over other options tested. The use of realistic 3D Icons failed to show any significant improvements in performance, even in an altitude-related task. The 3D Icons actually led to worse performance in a search of air tracks. Since platform type was not relevant for this task, the small 3D Icon symbol library was not considered to have had an impact on the results. These results for 3D Icons may be due to the heavy track loads used in the test tasks. Although most of the tracks on screen may be filtered out, they still contribute to visual clutter. In the surface track search task, performance with the 3D Icons may have improved with a larger symbol library. Effectively designed symbols could have allowed the users to visually discriminate between commercial and combatant ships, or possibly even between oil tankers and other commercial ships. But due to the level of visual detail required to show these differences, performance would not be expected to match that possible with the more easily identified symbols of the Modified MIL-STD-2525B symbol set.

The results for the CRO position comparison were surprising in that performance differences were shown only for the test task least likely to show any differences. Due to the lack of differences in other test tasks, it is assumed that, at least over short periods of use, CRO position will not impact operator response times. Given no performance differences, it could be proposed that a Relative CRO location be used to conform to operator preferences. Such a decision, however, must be considered in the context of the number of items within the readout. There were only seven line items in the CRO tested, while current Aegis pre-hook CROs have approximately twice as many line items. Doubling the line items would double the amount of the tactical display obscured by the test readout. An alternative CRO design could mitigate the effects of covering the tactical display. Due to software limitations, the Relative CRO used for testing had an entirely opaque background, preventing the user from seeing any symbols underneath the readout. Figure 10 shows a potential improvement for the Relative CRO. Unlike the experimental version, this version attenuates the colors under the readout, allowing for both legibility of text and visibility of symbols underneath.

The differing results across test tasks illustrate the need to design displays on the basis of the tasks for which they will be employed, not on the basis of the information to be displayed. But in the case of Navy surface combatants, it is unrealistic to design displays for a limited number of tasks. Not only may a single operator have to perform different tasks at different times, but future system capabilities may require the operators to employ the displays in different ways.

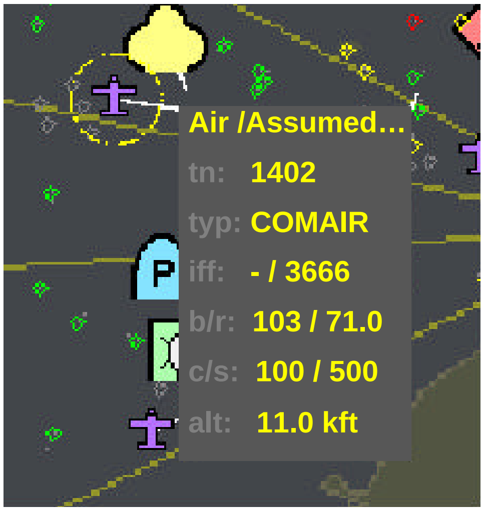

Figure 10. Alternate Relative CRO Design.

Track filters and other display manipulation controls such as toggling between showing and hiding drop lines need to be easily and quickly accessible to the operators. In cases where drop lines are to be used, it may be useful to highlight the drop line of the hooked or pre-hooked track to allow the operator to determine which drop line is associated with which track without having to change the display settings. For some tasks, the best use of different display types may be for the operator to search for specific tracks in a 2D top-down display, but to then evaluate the attributes of the track in a 3D perspective view display. Although a single display surface could be toggled between 2D and 3D views, one alternative would be for the track hooked by the user on one display to be automatically highlighted in the other display.

Design decisions are at times based on the operator's expected performance or an extrapolation of previous research results. For both symbol sets and CRO locations, objective testing either discovered differences that were not expected or found no difference where one was expected. The 3D Icons were expected to lead to better performance in dealing with air tracks, but performance was either equivalent or worse than with 2D symbol sets. These results may be due in part to a failure of benefits demonstrated with more sparsely populated tactical environments to be carried over to environments with a higher track load. Operator expectations predicted performance gains with a text readout adjacent to the selected track, but no performance improvements were apparent. Each of these results indicates a need to continue to seek objective data to support subjective predictions.

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