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TECHNICAL REPORT 1850
February 2001

**Symbicons:
Advanced Symbology for
Two-Dimensional and
Three-Dimensional Displays**

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**Pacific Science and Engineering
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ADMINISTRATIVE INFORMATION

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EXECUTIVE SUMMARY

Three-dimensional (3-D) views of battle spaces usually show military assets as miniature realistic icons. Two-dimensional (2-D) top-down views of battlespaces use non-realistic conventional symbols. Future consoles may use a suite of 2-D and 3-D views. Which symbology should be used for these different views?

Our previous research found inconsistent performance benefits for symbols and icons by track attribute. As a result, we created a hybrid—"Symbicon" symbology—that combines the best aspects of symbols and icons. Symbicons possess an upright letter or logo that codes for platform (e.g., cruiser, fighter). The letter or logo is taken from conventional symbols and placed inside a shape outline adapted from realistic icons to code for platform classification (air, sea) and heading.

We measured how well participants could identify Symbicons for four track attributes (platform name, platform classification, heading, and threat affiliation) for eight military platforms. We compared participant performance for Symbicons with performance for 3-D icons and conventional 2-D symbols (MIL-STD-2525B). The results were as follows:

- **Platform Name.** Participants identified platform names faster with Symbicons than with 3-D icons. Identification was as fast as 2-D symbols.
- **Platform Classification.** Participants identified Symbicons marginally faster than 3-D icons and 2-D symbols.
- **Headings and Threat Affiliations.** No differences were found.

Although participants found it easier to identify platform names with Symbicons than with 3-D icons, our data were generally non-significant and do not make a compelling case for Symbicons. Our experimental naming procedure may have been too undemanding to measure reliable differences. The benefits of Symbicons for track attributes will become apparent in more difficult operational tasks. In the visual search of displayed tracks, the Symbicon coding of classification, threat, and heading will aid peripheral vision in detection and classification.

Conventional 2-D symbols were more quickly and accurately named than realistic 3-D icons. Our previous findings agree with this conclusion. We recommend using conventional 2-D symbols or potentially Symbicons rather than realistic 3-D icons for rapid, accurate platform identification.

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INTRODUCTION

Three-dimensional (3-D) views of battle spaces usually show military assets as miniature realistic icons. Figure 1 shows realistic icons on a prototype 3-D display for the Area Air Defense Commander console (Dennehy, Nesbitt, and Sumey, 1994). Little is known about a user's ability to accurately classify and identify realistic 3-D icons.



Figure 1. The 3-D perspective view with realistic 3-D icons.

In previous studies, we researched the relative performance benefits for standard two-dimensional (2-D) military symbols versus realistic 3-D icons for naming the platform (Smallman, St. John, Oonk, and Cowen, 2000), recalling the platform (Smallman, Schiller, and Mitchell, 1999), and visually searching for the platform (Smallman, Oonk, St. John, and Cowen, 2001). These three tasks produced mixed results. Standard military symbols were named faster than 3-D icons (Smallman, St. John, Oonk, and Cowen, 2000).¹ Participants were presented with icons or symbols one at a time and asked to name them as quickly as possible. The participants were slower in naming the icons because the visual similarity of the platforms (e.g., cruisers and frigates are similar in appearance) makes them difficult to differentiate and identify. Unlike icons, abstract symbols can be designed as dissimilar as necessary to promote rapid identification and naming.

In contrast, participants recalled track headings more accurately when tracks were represented as icons rather than as symbols on a geo-plot display (Smallman, Schiller, and Mitchell, 1999). Participants studied a complex, evolving tactical situation and were asked periodically to recall the

¹ We used MIL-STD-2525B (Department of Defense, 1999) symbols, which have different symbols for each platform.

identity and attributes of specific platforms. When participants were visually searching for tracks with a specific heading in a crowded display, participants named the icons faster than the symbols (Smallman, Oonk, St. John, and Cowen, 2001). Track heading was easier to find and remember because heading could be made conspicuous by turning the entire icon in the proper direction. In contrast, the military symbol code heading, by projecting a course leader (a short black line emanating from the symbol), is in the proper direction while the body of the symbol remains north-up.

Future consoles may use a suite of 2-D and 3-D views (St. John, Smallman, Bank, and Cowen, 2001). The suite may need a consistent symbology to reduce correspondence problems between the two viewing formats². This consideration, combined with the mixed results of our earlier symbol work, suggests building a new symbology that combines the best aspects of symbols and icons for either 2-D or 3-D displays. So, we created a hybrid—"Symbicon" symbology—combining the discriminable platform information of military symbols with the conspicuous platform classification and heading information of realistic icons. Symbicons have an upright letter or logo from conventional symbols. The letter or logo codes for platform (e.g., cruiser, fighter) and is placed inside a shape outline adapted from realistic icons. The shape outline codes for platform classification (air, sea) and heading (figure 2). Symbicons are not a formal alternative to conventional military symbology. Instead, they explore the potential of a hybrid symbol design concept.

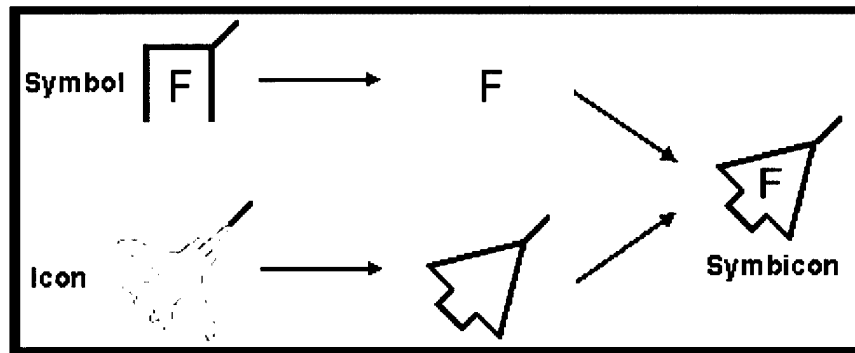


Figure 2. Symbicon for a fighter, created by combining the interior of a conventional MIL-STD-2525B symbol with a discriminable, shaped outline of a realistic icon.

It takes three steps to create a Symbicon:

1. Extract the interior of a conventional military symbol that contains the platform name, usually coded by a letter or logo (figure 2).
2. Create generic air and sea platform shape outlines from realistic icons to code platform classification (e.g., air, sea) and to clearly show heading. The outlines for specific platforms are not required because the interior letter or logo codes for platform. The outline conveys general platform classification. For simplicity, the generic fighter outline was used for all air platforms including helicopters and missiles, and the generic ship outline was used for all sea

² For example, we recently started to examine a suite of 2-D and 3-D views in tactical routing as a test bed for examining more complex and realistic U.S. Navy tasks (St. John, Smallman, Bank, and Cowen, 2001).

platforms including submarines. Our outlines will be looked at again when the Symbicon design concept is pursued further.

3. Embed the platform letter or logo into the shape outline and fill the outline with threat affiliation color. The threat affiliation is coded by the color of the fill: blue for friendly, green for neutral, yellow for unknown, and red for hostile. The shape of the black frame of the symbol redundantly codes threat affiliation, so removing the frame loses no information. Realistic icons similarly use only color to code threat affiliation. Finally, a speed leader is added to code for speed and to stress heading. We created four sea Symbicons: carrier, oil tanker, cruiser, and submarine. We also created four air Symbicons: fighter, bomber, helicopter, and missile. Our objective was to look into how well participants could identify track attributes represented as Symbicons in comparison with conventional 2-D military symbols and realistic 3-D icons.

METHOD

PARTICIPANTS

The participants were 36 students from local universities who were paid for their participation. They were unfamiliar with military track symbols.

MATERIALS

The stimuli were similar to those used in our previous track identification study (Smallman, St. John, Oonk, and Cowen, 2000). We drew eight military platforms as realistic 3-D icons, conventional 2-D military symbols, and hybrid Symbicons. Four were air platforms (bomber, fighter, helicopter, and missile) and four were surface/subsurface platforms (carrier, cruiser, submarine, and tanker). The platforms were drawn at five headings (north, northeast, east, southeast, and south) and with four threat affiliations (friendly, hostile, unknown, and neutral). The 3-D icons, the 2-D symbols, and the Symbicons were of equal size. Figures 3 and 4 show examples of the stimuli.

	3-D Icons				2-D Symbols				Symbicons			
	Friendly	Hostile	Unknown	Neutral	Friendly	Hostile	Unknown	Neutral	Friendly	Hostile	Unknown	Neutral
Bomber												
Fighter												
Helicopter												
Missile												
Carrier												
Cruiser												
Submarine												
Tanker												

Figure 3. The 3-D icons, 2-D symbols, and Symbicons for all eight platforms, four affiliations, and northbound heading.

2-D Symbols

The 2-D symbols were conventional military symbols drawn according to the specifications of MIL-STD-2525B (Department of Defense, 1999). Letters or a logo shape in the center of the symbol designates the platform. For example, "C" is the code for cruiser, and a bow-tie shape (resembling

rotor blades) is the code for helicopter. The platform classification (e.g., air, sea, under-the-sea) is coded by the symbol frame. Frames open at the bottom represent air platforms, closed frames represent sea platforms, and frames open at the top represent under-the-sea platforms. Frame shape fill color designate threat affiliation (e.g., friendly, hostile, unknown or neutral). For example, a round frame with blue fill represents friendly tracks. The track heading is coded by a course leader that consists of a black line emanating from the symbol in the proper direction.

	North East	East	South East	South	North East	East	South East	South	North East	East	South East	South
Bomber												
Fighter												
Helicopter												
Missile												
Carrier												
Cruiser												
Submarine												
Tanker												

Figure 4. The 3-D icons, 2-D symbols, and Symbicons for all eight platforms, friendly affiliation, and four of the five headings.

3-D Icons

The 3-D icons were created by rendering realistic platform images based on 3-D models taken from CorelDREAM 3-D (Corel® Corporation, 1996) and adding a speed leader to the front. Threat affiliation was coded by filling the icons with the same colors as the 2-D symbols (e.g., blue for friendly, red for hostile, yellow for unknown, green for neutral). Heading was coded by rotating the icon in each of the five directions. The icons were rendered from a viewing angle of 45 degrees above and to the south of the icon. The images were rendered in 3-D Studio Max® (Autodesk® Inc., 1999). The camera was elevated 45 degrees above the horizontal plane and far enough away from the model so that the icon filled a 1.5-inch by 1.5-inch square on the screen (4.6 degrees of visual angle).

Symbicons

Symbicons combined the features of symbols and icons. The letters or a logo shape from the center of the MIL-STD-2525B symbol designated the platform name. The platform classification (e.g., air,

sea) was coded by placing a shape outline of a ship or aircraft around the letters or logo. Threat affiliation was coded by filling the Symbicons with the same colors as the 2-D symbols and the 3-D icons. Track heading was coded by turning the shape outline in each of the five directions. A speed leader was added to the front of the Symbicon to code for speed and to stress heading. Changes in track heading caused the speed leader and shape outline to rotate, but the Symbicon interior (i.e., the letters or logo) remained north-up.

PROCEDURE

Participants were divided randomly into three groups ($n = 12$): the 2-D symbols condition, the 3-D icons condition, and the Symbicons condition. Each participant served in four blocks of trials (counterbalanced), one for each attribute (platform, platform classification, threat affiliation, and heading). Each block contained 160 trials (eight platforms by five headings by four threat affiliations) presented randomly. The participants finished all four blocks in about 20 minutes; they took a short break between each block.

Participants were given a brief description of the symbology for their condition. For 5 minutes, they studied a poster showing the full set of symbols that they were about to see. They were then seated about 18 inches from a 15-inch computer monitor. At the beginning of each block, participants were told which attribute they were to identify (e.g., platform name, platform classification, threat affiliation, and heading). They were instructed to identify the attribute with a single word as quickly as possible and to speak their responses into a microphone directly in front of them. Each trial started with a short, blank interval followed by the presentation of a stimulus at the center of the color monitor. The correct word for the stimulus attribute was provided on every trial. The word was presented on the computer screen directly beneath the stimulus, 300 ms after a verbal response was detected. Participants then pressed a key to continue to the next trial. Verbal responses were tape recorded and scored. The computer recorded latencies of the verbal responses to an accuracy of about 1 ms.

RESULTS

Figure 5 shows the mean latencies for the correct trials for each attribute (platform, heading, threat affiliation, platform classification) by symbology condition (3-D icon, 2-D symbol, Symbicon). A small main effect was found for symbology type, $F(2, 33) = 3.24, p < .06$. Overall, 3-D icon attributes were named more slowly than either 2-D symbol or Symbicon attributes. A main effect was also found for accuracy (mean percent correct) for symbology type, $F(2, 33) = 4.66, p < .05$. The attributes of 3-D icons were named less accurately than those of Symbicons or 2-D symbols.

A main effect for attributes was also on latencies, ($F(3, 99) = 21.88, p < .0001$), and accuracy, ($F(3, 99) = 5.32, p < .01$). Overall, platform name and threat affiliation were identified slower than platform classification and heading. Platform identification produced more errors than heading identification. A statistically significant interaction was found between attribute and symbology conditions (for latencies, $F(6, 99) = 16.64, p < .0001$; for accuracy, $F(6, 99) = 6.54, p < .0001$). Results for each attribute are discussed below.

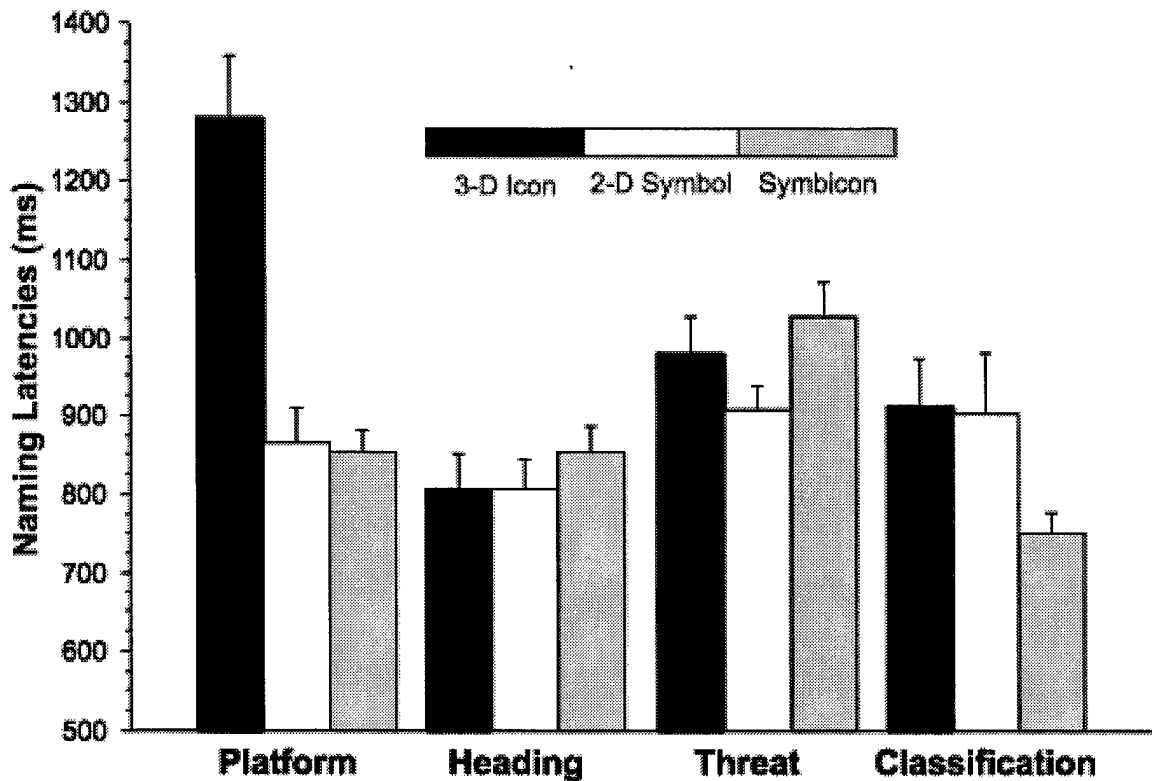


Figure 5. Mean latencies for the correct trials for each attribute by symbology condition.

PLATFORM NAME

Figure 6 shows mean platform naming accuracy (in percent correct) and latency by symbology condition and block.³ A main effect of symbology type was found for accuracy, $F(2, 33) = 25.96$, $p < .0001$, and latency, $F(2, 33) = 15.34$, $p < .0001$. Symbicons and 2-D symbols were named more accurately (on average about 12% more) than 3-D icons. Symbicon responses were (on average) 405 ms faster than 3-D icon responses. The 2-D symbol responses were (on average) 394 ms faster than 3-D icons responses. Responses on later blocks were also generally faster, $F(2, 33) = 18.71$, $p < .0001$, and more correct, $F(2, 33) = 15.95$, $p < .01$. There was no interaction between block and symbology type on speed, which suggests that further practice would not have altered the latency pattern. There was an interaction between block and symbology type for accuracy, ($F(6, 99) = 3.8$, $p < .01$), with accuracy for the 3-D icons improving over time relative to the (almost perfect) 2-D symbol and Symbicon performance.

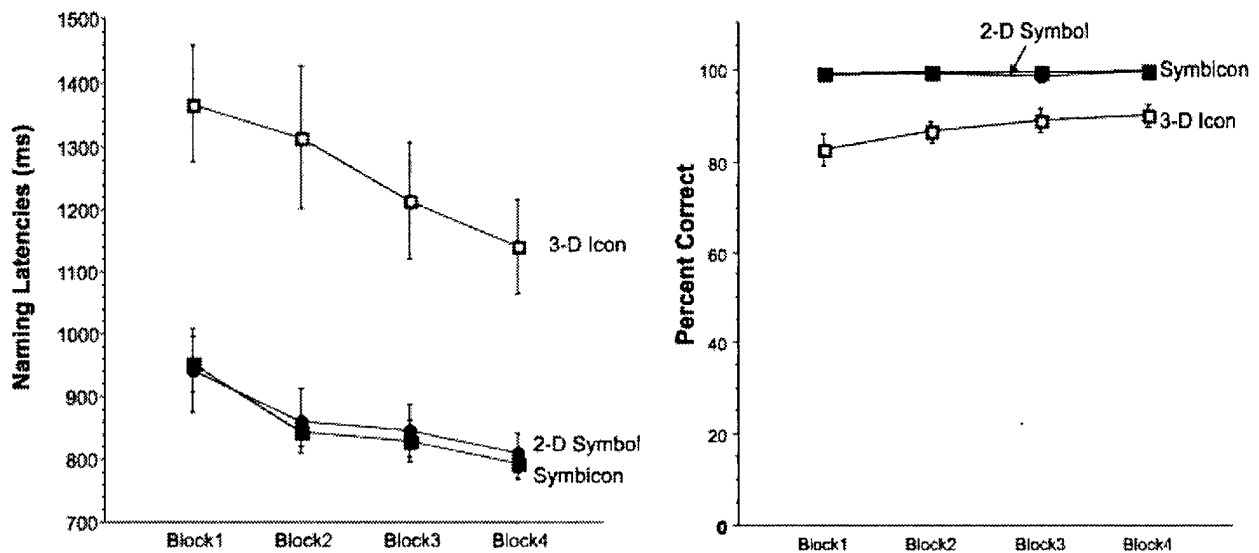


Figure 6. Platform identification latency and accuracy by symbology condition and block.

In a previous study (Smallman, St. John, Oonk, and Cowen, 2000), we found that 2-D symbols that contained the first letter of the platform name were identified faster than the other 2-D symbols. The naming advantage of the 2-D symbols could be caused by letter-name priming rather than faster identification of the 2-D symbols. Still, even the 2-D symbols without letters were named faster than the same 3-D icons.

We did a similar analysis on the current data. The latencies for identifying the platform were analyzed by whether there was a letter in the 2-D symbol or Symbicon⁴ (figure 7). "Letter" items were named more quickly than "No Letter" items for 2-D symbols, ($t(23) = 20.96$, $p < .0001$), and

³ Each block of trials was broken up into four sub-blocks, one for each attribute (platform name, heading, threat affiliation, platform classification) so that performance could be measured across blocks for each attribute. Each sub-block contained 40 trials.

⁴ Symbicon and 2-D symbols have the same interior letters or symbols (figure 3).

for Symbicons, ($t(23) = 24.75, p < .0001$). For 3-D icons,⁵ we found the opposite result. Responses to "No Letter" items were faster than those to "Letter" items, ($t(23) = 16.94, p < .0001$). Still, the "No Letter" 3-D icons were named slower than the "No Letter" 2-D symbols and Symbicons, $F(2, 33) = 5.29, p < .01$. The 3-D icons were identified more slowly than either 2-D symbols or Symbicons, irrespective of the presence or absence of letters in the 2-D symbols or Symbicons.

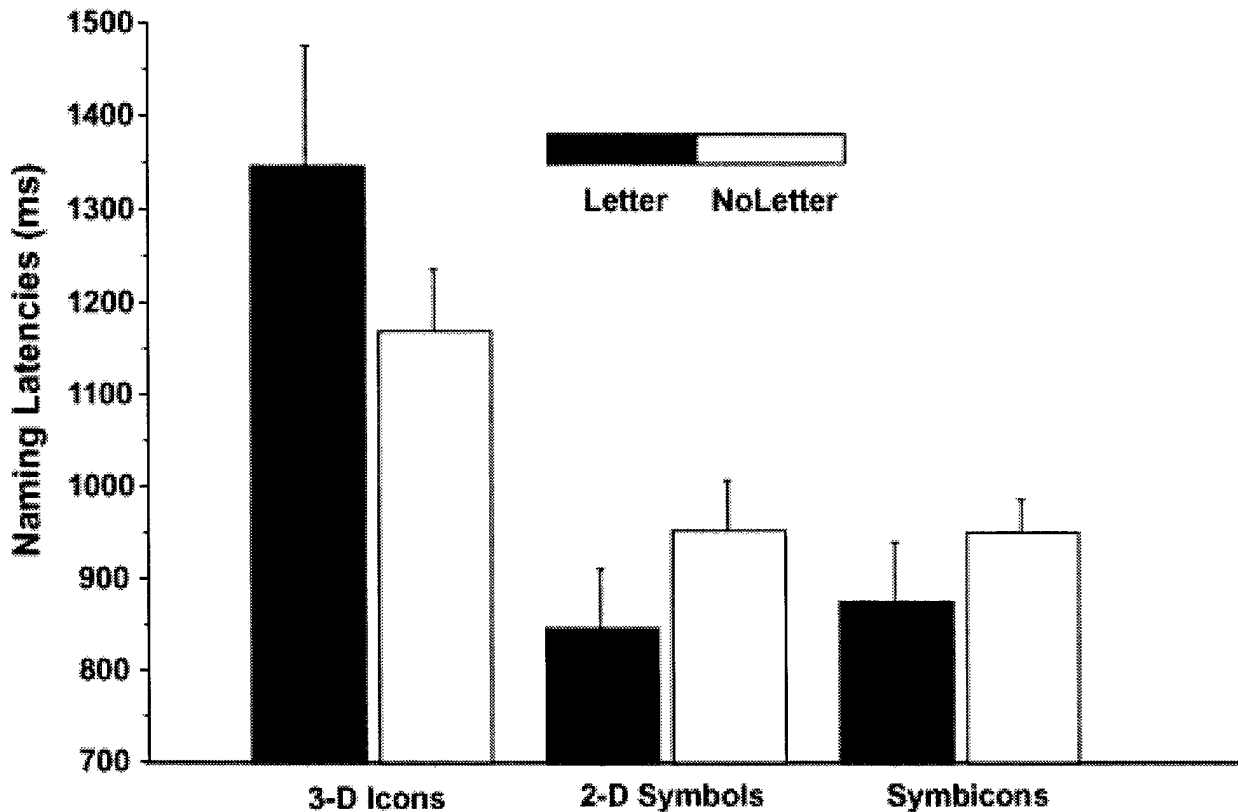


Figure 7. Mean latency to name platform across conditions by presence or absence of letter in the interior of the 2-D symbols or the Symbicons.

PLATFORM CLASSIFICATION

Figure 8 shows mean platform classification accuracy (in percent correct) and latency by symbology condition and block. Although the platforms represented as Symbicons appear to be classified more quickly than 2-D symbols and 3-D icons, this effect was not statistically significant for either latency or accuracy. Participants took longer to classify 2-D symbols than Symbicons in Block 1, $F(2, 33) = 3.78, p < .05$. No significant differences were found among the symbology conditions in later blocks. Symbicons, with their simple platform outlines, were at least as good for platform classification as the 3-D icons, and potentially better than the 2-D symbols.

⁵ There were no letters in the 3-D icons. Identification of 3-D icons was measured between "Letter" platforms and "No Letter" platforms from the 2-D symbols.

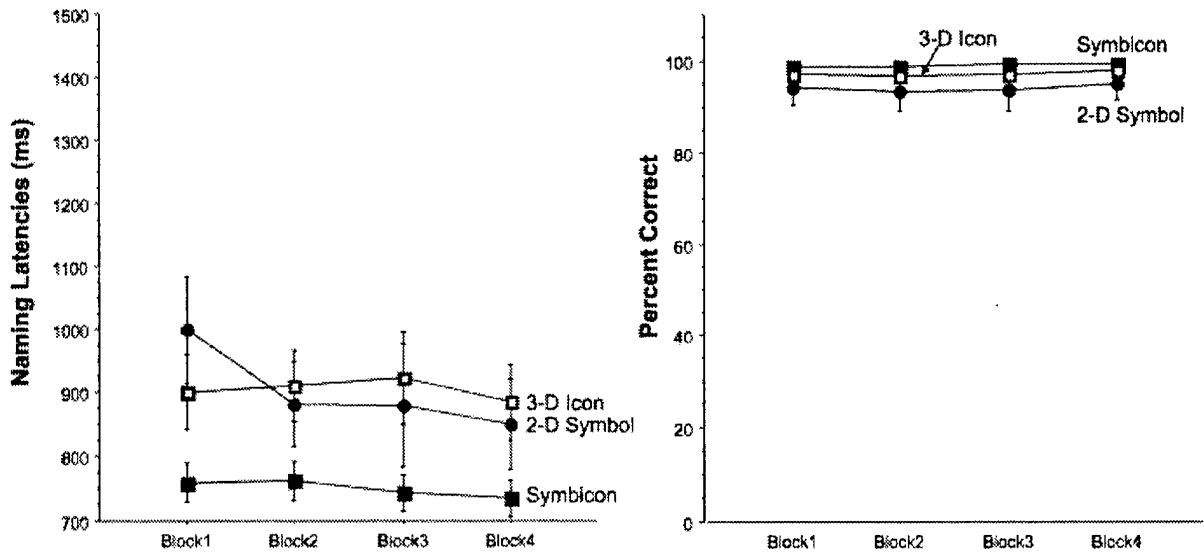


Figure 8. Platform classification latency and accuracy by symbology condition and block.

HEADING

Figure 9 shows mean heading identification accuracy (in percent correct) and latency by symbology condition and block. A main effect of block was found for latencies, $F(2, 33) = 22.31$, $p < .0001$. Heading was identified more slowly in Block 1 than in later blocks. There was no significant effect for symbology condition or any other main effect or interaction. The Symbicons appeared to convey heading about as well as either the 2-D symbols or the 3-D icons.

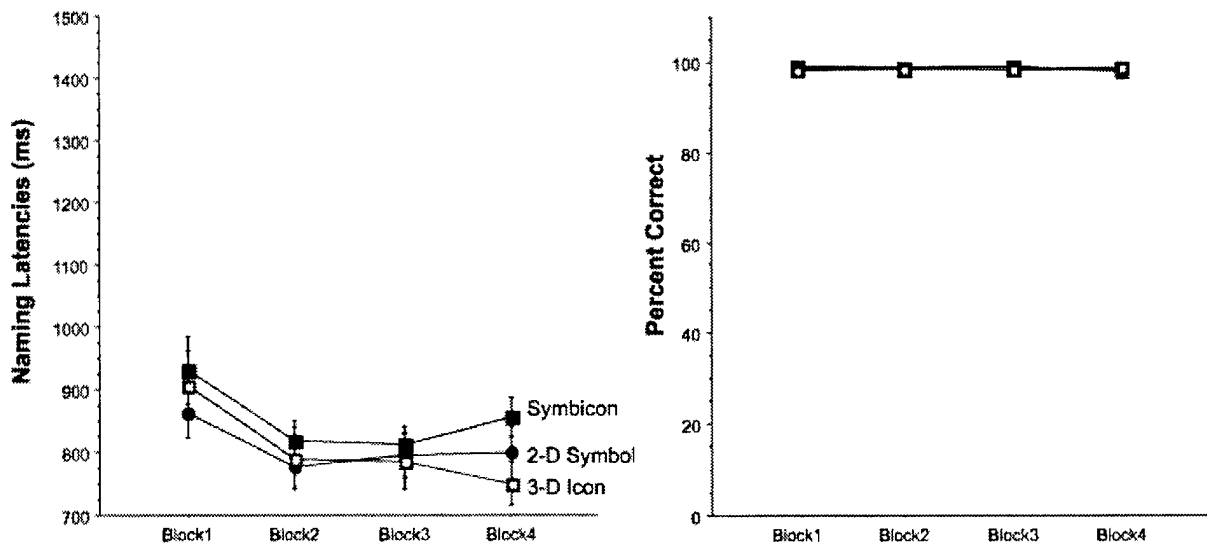


Figure 9. Heading identification latency and accuracy by symbology condition and block.

THREAT AFFILIATION

Figure 10 shows mean threat affiliation identification accuracy (in percent correct) and latency by symbology condition and block. A main effect of block was found for the naming latencies, $F(2, 33) = 12.8, p < .0001$. Threat was identified more slowly in Block 1 than in later blocks. No other main effects or interactions were found. The Symbicons appeared to convey threat affiliation about as well as either the 2-D symbols or the 3-D icons.

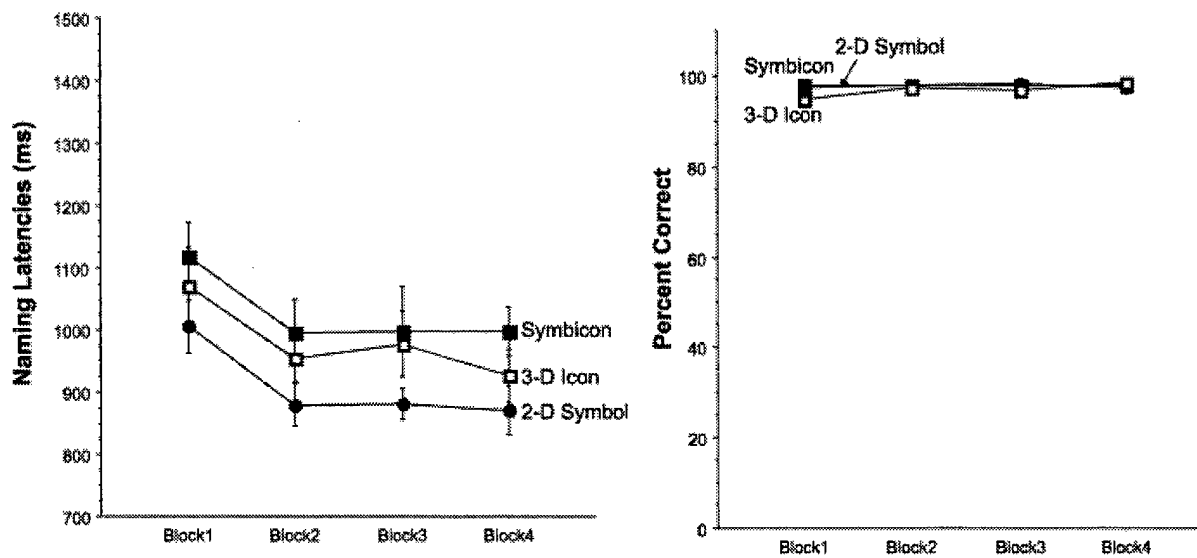


Figure 10. Threat affiliation identification latency and accuracy by symbology condition and block.

DISCUSSION

Our expectation was that the hybrid Symbicons would be as good as 2-D symbols for conveying platform and threat affiliation and as good as 3-D icons for conveying platform classification and heading. Although elements of these expectations occurred, the overall performance of the Symbicons was disappointing.

The failure to find a significant Symbicon or 3-D icon advantage over 2-D symbols for the attributes of platform classification and heading is worrisome. The lack of differences and fairly short latencies suggest that the identification of attributes of stimuli presented individually may not be sufficiently difficult to produce differences among conditions. Participants may have been able to focus on the relevant features of stimuli to name an attribute despite its visibility because only one symbol was presented at a time. A more difficult test of attribute perception, such as visual search for a particular heading, may show differences among symbology conditions. In the visual search paradigm, many symbols are presented simultaneously in a cluttered display. The superiority of 3-D icons for heading information was originally found in visual search and recall tasks (Smallman, Oonk, St. John, and Cowen, 2001). Clutter would make it more difficult to find low-visibility features away from the direction of gaze, and may lead to measurable differences among symbol types. We plan to look into this possibility.

<i>Frame</i>	3-D Frame			2-D Frame	
	Air		Sea	Air	Sea
	Realistic Attitude		Analogical Attitude	Analogical Attitude	Sea
	15° down	Level Flight			
<i>N</i>					
<i>NE</i>					
<i>E</i>					

Figure 11. Sample Symbicons drawn by frame (3-D versus 2-D), classification, attitude, and heading.

Because of experimental design concerns, the Symbicon stimuli tested were rendered in 2-D. If Symbicons are useful for track identification in an applied visual search task, how might Symbicons be rendered for a real-world 3-D display such as the Area Air Defense Commander console (Dennehy, Nesbitt, and Sumey, 1994)? Our 2-D Symbicons should be rendered in 3-D to avoid appearing flat and clumsy in the 3-D battle space. Figure 11 shows a sample of possible renderings of 3-D Symbicons for a fighter and an aircraft carrier. Participant identification of track attributes for tracks displayed in a 3-D battle space (displayed as a perspective view) are discussed further in Smallman, Oonk, St. John, and Cowen (2001).

We have replicated the findings of our previous track identification study (Smallman, St. John, Oonk, and Cowen, 2000). The 2-D symbols were identified much faster and more accurately than the 3-D icons. This is important because the advantage over 3-D icons was found for Symbicons and 2-D symbols. One criticism of our previous study was that realistic coding made the icons difficult to tell apart. Symbicons are realistically coded, but only at a coarse level of detail. They remain intuitive, but visually dissimilar.

Another criticism of our previous experiment was that symbols were easier to learn than icons because 2-D symbols were visually similar at all headings while the realistic coding of heading made icons visually dissimilar at different headings. The 3-D icons may take longer to identify because they are learned across the different orientations while 2-D symbols are easier to identify because they are learned at one up-right orientation. Symbicons, which have multiple orientations like icons but code platform identity like symbols, were found to be better than icons for platform identification. For platform identification, discriminability is more useful than orientation of the symbology.

Symbicons hold some promise as a useful symbology by combining the best of 2-D symbols and 3-D icons. Participants found it easier to identify platform name with Symbicons than with 3-D icons, but our data were generally non-significant and do not make a compelling case for Symbicons. Our experimental naming procedure might have been too undemanding to measure reliable differences. The benefits of Symbicons for track attributes will become more apparent in more difficult operational tasks such as a visual search of displayed tracks where the Symbicon coding of classification, threat, and heading will aid detection and classification in peripheral vision.

In any case, conventional 2-D symbols are more quickly and accurately named than realistic 3-D icons. Our previous findings agree with this conclusion. We recommend using conventional 2-D symbols or potentially Symbicons rather than realistic 3-D icons for rapid, correct platform identification.

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14. ABSTRACT Symbicons are hybrids that combine the best aspects of symbols and icons. Symbicons possess an upright letter or logo that is placed inside a shape outline. We measured how well participants could identify Symbicons for four track attributes (platform name, platform classification, heading, and threat affiliation) for eight military platforms. We compared participant performance for Symbicons with performance for 3-D icons and conventional 2-D symbols (MIL-STD-2525B). Although participants found it easier to identify platform names with Symbicons than with 3-D icons, or data were generally non-significant and do not make a compelling case for Symbicons. Two-dimensional symbols were more quickly and accurately named than realistic 3-D icons. Our previous findings agree with this conclusion. We recommend using 2-D symbols or Symbicons rather than realistic 3-D icons for rapid, accurate platform identification.					
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