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RADAR SYMBOLOGY STUDIES LEADING TO STANDARDIZATION:

II. DISCRIMINATION IN MIXED DISPLAYS

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ABSTRACT

This report covers continued studies toward standardization of coding symbols for an information display. Experiments were directed toward locating "the most readily discriminated five-symbol code complex" as measured by errors and location times.

Experiment I attempted to simplify testing procedures by using a card sorting task. The same five-symbol code was presented as a black-on-white simulated display in Experiment II. Results were not comparable and the simulated display was used in further experiments with a variety of codes.

Legibility and association values of individual forms varied with the population of shapes within the code complex. Experimental results led to general recommendations for code design. Further studies are anticipated.

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RADAR SYMBOLOGY STUDIES LEADING TO STANDARDIZATION:

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INTRODUCTION

The use of radar early in World War II dramatically increased awareness of on-going activity within a defended area. As radars became more sophisticated and were interfaced with computers, the radar screen became a prime source of information for the military.

The fundamentals of radar search are simple. A narrow beam of energy is directed into space. If anything is present in its path, a portion of this energy is reflected back to a receiver at the source. The time between transmission and return of the reflected energy is a measure of the distance to the suspected target while the horizontal and vertical angles of the transmitted beam reveal information on bearing and altitude. Returns are impressed on a variety of cathode ray tubes (CRT) where they are represented as disturbances in the phosphor coating along a time-based sweep line.

The most informative presentation of general on-going activity is the planned position indicator (PPI). This display is a polar coordinate representation of the area with a time-based sweep line revolving about the antenna position. Any object falling within the transmitted beam is seen as a "pip" at the appropriate range and bearing.

Since clouds and terrain features reflect the radar beam, these returns must be separated from target returns. In the early days of radar all analysis of this type was handled by the radar console operator, who learned to recognize "target signatures." As computers were wedded to the radar system, much of the integration and analysis of data could be machine-processed. Later it became possible to add "synthetic information" to the raw returns by generating a geometric form which surrounded a particular "pip." This form identified a target and further simplified the operator's task.

Originally only a few geometric shapes could be generated and these became the usable target vocabulary. As new methods created additional forms, the symbol vocabulary changed. Unfortunately this change was not represented by an orderly growth from a basic word list. New meanings were assigned to earlier forms and new symbols replaced other forms. Bergum and Burrell (8) reported difficulties created under time stress by reversal of meaning in coding. They recommended a standardization of radar symbols before the problem intensified. Over the years the need for standardization has been continually emphasized, yet new codes appear with each new system. Now that a wide variety of symbols can be presented, standardization is an absolute necessity.

The state of the art has advanced to the point that radar screens of the future can be expected to present much more information to the operator. Synthetic video produced by computer analyses of radar returns can transform the CRT into a meaningful picture of action. Targets can be completely identified as clear symbols on an uncluttered ground. Map overlays, equipment positions and terrain features can be called upon demand. The radar screen will thus become a dynamic information display presenting the entire air and surface action over a large area.

There is a temptation to build large vocabularies of meanings based on information which the computer can supply. Gebhard (31) warns that such complicated codes are of no value unless they can be interpreted by the operator. Morgan (48) gives two strict rules for shape coding: (a) shapes that are compatible with and have association value with coded objects should be given first consideration; (b) only shapes which can be readily discriminated should be used in a code system.

Baker and Grether (4) state that the number of shapes which can be discriminated is large and that their use is limited only by space and ability to associate symbol and function. Torre and Sanders (56) consider association values within the air defense picture and set up tentative rules for symbol design. Davis (22) further pursues stereotyped meanings and suggests that the circle be reserved for friendly targets. She advises that selection of other symbols within a code complex should be based on how readily they can be discriminated and how readily they can be learned.

Honigfeld (41) reviews the literature on coding and recommends a new attack on standardization. Glaser, Ramage and Lipson (34) warn of severe penalties in accuracy when a display contains too much information. As a rule-of-thumb, they advise using only as many symbols as are absolutely necessary. They suggest that Miller (46) and his "magical number seven, plus or minus two," should be considered in restricting the parameters of a code design.

The Russian engineering psychology literature similarly explores methods of encoding information but offers no explicit findings. Leont'yeya et al (45) state that the capacity of a machine is better understood than the capacity of its operator. They note that codes are designed to satisfy the needs of the "planner" with little attention to the operator who will decode the information. Such an encoding system does not endure because it does not serve its purpose. They recommend consideration of speed of perception as a measure of decoding efficiency and add that code design becomes more urgent as increased amounts of information become available.

With the need for standardizing radar symbology so clearly demonstrated, it is difficult to understand why codes continue to proliferate. A survey of the literature would indicate that each code designer leans heavily on early studies which seem significant to his own theory. The findings of these studies have been repeatedly summated without reference to the original articles and the resulting confusion is of little value in ultimate code design.

Early studies on visibility of geometric forms tend to creep into any decision on codes. These were aimed at proving or disproving the Gestalt theory of figure goodness and generally argue the merits of the circle or the triangle. There is a tendency to quote these studies out of context and to interweave various findings which are strictly non-comparable. Solid and linear forms, black on white and white on black, equal-area and equal-height figures are lumped together without explanation of design. A review of the most quoted studies illustrates the problems inherent in a literature survey.

Kleitman and Blier (43) found a triangle superior to a square, circle or star. They used solid black equal-area forms against a white ground to test subjects on peripheral and direct vision. Their findings in the two testing situations are closely related and appear to give a strong preference to the triangle. Toward the end of their report they mention that all four targets were seen at about the same angular subtense (4 1/2 minutes) in a walk-up test. The equal-area design gives the triangle an advantage in angular subtense.

Munn and Geil (49) also used equal-area forms viewed peripherally. They report that the triangle was recognized over the greatest perimetric field followed by the square, circle, rectangle and hexagon in that order. Angular subtense is again a possible explanation for the first three ranks. It is also obvious that only the triangle has no confusion form in the five-symbol design.

Collier (17) presented seven different solid forms in a peripheral view. His sizing method is not described. Scoring was in terms of extent of perimetric field and a subjective measure of certainty. He reports that equilateral and isosceles triangles are vastly superior, followed by the square, parallelogram, circle, hexagon and octagon in that order. Regardless of sizing method, it is apparent that confusion possibilities are greatest between the circle, hexagon and octagon. Little weight can be placed on the reported advantages of the two triangular forms which were identified merely as triangles.

Helson and Fehrer (39) used six equal-area solid black-on-white forms including a circle, half-circle, square, rectangle, triangle and "square with a small square removed." Their measures included light and form thresholds, just noticeable form and form certainty. The triangle and rectangle are reported as the best forms. The circle did not place first on any measure and was reported as "neither good nor bad." All advantages could be explained in terms of angular subtense and/or confusion forms within the matrix.

In a similar study, Whitmer (58) presented equal-area solid forms as peripheral displays. He also reports the triangle as superior, followed by the diamond, square, rectangle, circle and hexagon. Again angular subtense and confusion forms are probably biasing results.

Hochberg, Gleitman and MacBride (40) approached the problem from a new direction. Their targets were equal-area circle, square and St. Andrew's Cross projected as bright forms of ascending intensities on a dark screen. The circle was recognized at the lowest light threshold and the St. Andrew's Cross required the greatest illumination for visibility. No triangle was included in their study. In this case, visibility is inversely related to angular subtense in direct opposition to other equal-area studies. Conclusions are that a good figure is simple, compact, symetrical and familiar as expected in the Gestalt approach. There is no attempt to justify the inverse findings in studies using black forms on a white ground. The possibilities of a decrease in "perceived brightness" over larger angular extents are not considered.

Hanes (36) suspected apparent brightness as a factor in previous equal-area experiments. He presented circles, equilateral triangles and squares in three sizes equal in area to a 1/16, 1/8 and one-inch diameter circle. While his illumination boxes and controls are well described, the targets are identified only as photographic film presentations. The discussion suggests that he used bright targets on a darker surround. Subjects were given two equal-area targets which were either alike or different. One figure was set at a standard brightness (brightness range 0.1 to 100 millilamberts) and the subject adjusted the other to match brightness of the first. Averaged over three illumination levels the triangle had the greatest apparent brightness in the two smaller sizes. This situation reversed for the largest size (area equal to one-inch diameter circle) with the triangle now having the lowest apparent brightness. Hanes suggests that at this size the subject becomes aware of differences in maximal linear extent and interprets the greater length of the triangle as a brightness decrement. He concludes that area, perimeter, visual angle and "apparent size" all contribute to the legibility of symbols.

It is evident that these much quoted studies have little to offer in the search for the most desirable symbols. Perhaps the most valuable findings in these studies are the apparent changes in visibility of an individual symbol with presentation method and the suggestion of an interaction effect when highly similar characters are added to a limited code complex.

Studies using a larger variety of symbols also fail to reveal information on the characteristics contributing to legibility. Perhaps the greatest problem in these studies is caused by including an unbalanced representation of form families. The circle may have confusion forms represented by ellipses and a variety of polygons while linear open forms may have no possible confusion forms. Unbalanced designs of this type are highly biased.

Casperson (16) is frequently quoted by the anti-Gestalt group. Reviews generally state that he found the circle and ellipse inferior in a 30-symbol study. Examining the study we find that Casperson used only six basic symbols, each proceeding through five non-systematized variations which tended toward a progression from a solid compact form toward linearity. Subjects were required to give the family name for each form so that a circle was reported as an ellipse and a square was called a rectangle. Raw data is incompletely recorded and results are averaged over area and height-to-width ratios. Conclusions give a variety of rules for determining leg ility within a form family. Neither the report nor the raw data is of specific use in code design.

Sleight (51) included 21 geometric solid or linear black forms on clear plastic chips. Symbol size is described as related to a one-inch diameter circumscribed circle; however, his illustrations appear to be based on height alone. Generally, solid forms were used with a heavy emphasis on polygons. A cross in the form of a plus sign and a swastika were the only true linear characters. Six identical sets of each form were included for a total of 126 symbol chips spread as a mixed display on a 25-inch white circular ground. Subjects were scored on time and accuracy in sorting a single form from the total display. Since there were always exactly six targets, search time was to some effect truncated by count. Errors were reported as negligible and were not considered in scoring. Subjects also ranked the forms on "attention-getting" value. The swastika ranked first on both time and attention rating. The circle and crescent ranked second and third on time but were rated seventh and fifth on attention value. The diamond, triangle, ellipse and square fell near the middle of both scoring procedures. The trapezoid and four polygons forms were poorest on both counts. This study could be interpreted as giving definite advantage to the circle even in the presence of multiple polygons which approached circular form. Since the symbols were a full inch in size in a near point task, there was no possibility of blur in a subject with reasonable visual acuity and confusion elements were minimal. This study does seem to point toward the circle as a good symbol in a mixed display.

Bowen, Andreassi, Truax and Orlansky (13) projected linear forms which appeared as bright strokes on a darker ground. The 20 characters in this series include rounded and straight-line closed linear forms and three straight-line open forms. Symbol size is described as based on a 5/8-inch circle. Measurement of the illustrations indicate that 5/8 inch was the major dimension. Since viewing was at 50 inches this size represents a visual angle of 43 minutes or a Snellen acuity equivalent of about 20/150. Each symbol was presented twice under three conditions of noise, two conditions of blur and two conditions of distortion for a total of 480 presentations. A tachistoscopic projector exposed each symbol for one-half second. The subject identified the symbol on a paper matrix showing all possible views. Scoring was based on a confusion matrix. Results are reported averaged over all conditions, first as the probability of correct identification of an individual symbol, and then as an "articulation" score for sets of symbols of various sizes. This series has been widely used in code design on the basis that the symbol sets recommended in this report had been used in a simulated display. Actually only one set of four symbols was presented as a simulated display and that set did not conform to recommendations. In fact one of the symbols, a plus sign with two short vertical modifiers, had proved so unreliable in the first experiment that its use was negatively recommended. It was this symbol which rated highest on the simulated display experiment.

The simulated display consisted of a group of photographic negatives mounted on a circular transilluminated screen. In each presentation of 40 characters, an individual symbol appeared eight to 13 times. The subject counted the number of designated targets. Scoring was on the basis of location time plus a derived correction time related to errors. The modified plus sign gave the lowest time score followed by circle, square and triangle in that order. The authors suggest that the advantage to the plus sign may have been related to the fact that it was the only open figure. Another complicating factor is noted. The symbols were not held to a standard orientation but were symmetrical about the radius of the display circle. The most valuable finding is the final superiority of the modified plus sign, which was poorly discriminated as an isolated symbol in the previous experiment but stood out clearly as a different form amid a group of enclosed figures. This finding is especially valuable because it demonstrates the importance of the context in which a symbol appears in determining how well it can be discriminated.

Williams and Falzon (59) presented 100 different forms in mixed linear and solid, symmetrical and non-symmetrical, nonsense and pictorial form families. Individual symbols were presented tachistoscopically for one-half second as a bright-on-dark display. Subjects located the viewed symbol on a black-on-white paper matrix series. Scoring was based on accuracy, confusion errors, search time and numerous other variables. The investigators found that they had included too many factors for efficient analysis but were able to isolate simple geometric or pictorial forms as advantageous.

In a second study Williams and Falzon (60) reduced their matrix to a circle, triangle, square and 90° diamond with horizontal, vertical or diagonal linear modifiers extending beyond the symbol or contained within its borders. Using scoring and projection techniques of the earlier study, they found the circle and square superior to the diamond and triangle and also determined that modifiers contained within the symbol led to fewer confusion errors than extended modifiers. The latter finding appears useful.

These studies using a large variety of symbols influenced selection of codes in later experiments. All have been interpreted out of context and beyond the scope of their experimental design. None presented a realistic display situation with the possible exception of the second experiment of Bowen et al (13). In this case the conditions of the second experiment including only four symbols which did not conform to their recommendations have tended to be transferred to the 20-symbol experiments.

True radar simulator studies are limited in number and scope. They tend to point out equipment problems rather than to give information on symbol form.

Baldwin, Wright and Lehr (6) presented raw radar pips moving across a screen at speeds equivalent to 500 to 900 knots using a clear screen and also simulated Electronic Counter Measures (ECM) noise. Subjects were trained under four conditions: (1) the target is brighter than the noise, (2) the target has a distinctive shape, (3) the target has greater brightness and also a distinctive shape and (4) all information is obtained through passive watching of a presentation. Subjects trained to watch for shape only did best on a clear screen. With ECM the combined shape and brightness group was superior.

Bartlet and Williams (7) ran a similar study and found that brightness was the best clue on a clear screen while pattern discrimination was the major factor with ECM. This study may have initiated interest in pattern recognition through noise.

Blair (11) evaluated three code complexes (four symbols in each code) using the few forms available at the time. He found that codes including two rotations of half or three-quarter circles caused difficulty. His best code had the least similarity between symbols.

Crook et al (18, 19) presented a limited character display at a variety of magnifications. They found forms subtending 13 to 25 minutes of arc superior to larger or smaller characters. Scoring was based on time and accuracy.

More closely related to a symbolic display are the studies of Gerathewohl and Rubenstein (33). Using an Air Force Simulator they presented solid equal-area (70mm) triangles, circles, squares and St. Andrew's crosses on a PPI scope. The targets appeared as solid bright figures. There was some evidence that the circle was a superior target; however, the equipment broke down before the experiments were concluded.

Gerathewohl (32) repeated these studies, adding a variable contrast. The studies included both clear screen and ECM simulation. In these studies the triangle was the most frequently identified target; however the triangle was named more frequently and hence had a high confusion score. While conclusions were guarded in both studies, Gerathewohl has been quoted by proponents of both the circle and the triangle.

Horton (42) also used solid bright targets on a PPI scope for a task of reading range and bearing of a specific form. His characters were the circle, eclipse and a solid arc closely resembling a trapezoid. The forms were "equated for perceived area." Sizes or area are not given. Shape had no effect on speed or accuracy of reading coordinates.

Dardano and Donley (20) projected bright line symbols on a phosphor-coated screen. Their targets were a circle, cross, cross within circle, open half circle and open three-quarter circle. Size and stroke width are not given. They presented either 24 or 48 symbols with the proportions of individual forms systematically varied. Subjects marked each symbol group and were scored on time and accuracy. The cross within circle rated best followed by cross, circle, half circle and three-quarter circle. The three-quarter circle accounted for most of the confusion errors and was considered a poor target. Taking their findings together with the stereotyped meaning studies of Torre and Sanders (56) they suggested the cross within a circle as a hostile target, the circle as a friendly interceptor and the cross as unknown.

Dardano and Stephens (21) did a follow-up study using the same series of symbols with the three-quarter circle omitted. They also replaced the projector with a symbol generator. Size of the basic circle or cross was varied in 1/16-inch increments within the 1/8 to 1/2-inch size range. Stroke width is not given. They followed the scoring procedures of the earlier study, and their results now indicated that the cross within the circle was the poorest symbol and the circle was superior. They noted a brightness advantage for the circle and half circle created by the generation method which might have influenced results; however, they felt the omission of the three-quarter circle created new problems. They conclude that strong similarities of symbols are undesirable.

Fried (28, 29) continued studies on these four symbols under a variety of continuous-wave noise conditions, simulating ECM effects. He now found that the cross significantly superior to the other three symbols in clear or noisy displays. There were no significant differences between the circle, half circle and cross within the circle. He had used a new symbol generator. A review of his equipment indicated that the cross had a strong brightness advantage in this system.

This series of studies tends to put some emphasis on apparent brightness as a legibility advantage. It also points out that changes in display methods or in the symbol series may create invalid or non-reproducible results.

Harris, Green, Wilson and Liaudansky (38) studied the design of charactron symbols for CRT displays, following an orderly, step-wise experimental design. Preliminary testing used a flying-spot scanner to simulate characters. Twenty-one special geometric symbols of linear and solid forms were projected as bright on a dark ground. Symbols included both geometric forms and pictorials which were assigned simple meaningful names. Subjects were over-trained in symbol naming using a flash-card presentation. In the final testing the symbols were presented singly at five-second intervals near the center of a PPI. Subjects named each symbol as presented. There were no corrections of errors. Scoring was based on a confusion matrix. The authors' conclusions indicate that variations of a single form family should be avoided. Symbols within a coding alphabet should be as unlike as possible.

Pattern recognition studies have attempted to identify the characteristics which make forms perceptually different. To date their definite contributions have been minor and, generally, poorly understood.

Baker, Morris and Steedman (5) created nonsense forms by random filling of a square matrix. The forms varied greatly in area, visual subtense and the number of changes in direction of the peripheral outline. They conclude that the best measure of a good pattern is the ratio of the target (T) area to the area (A) of circumscribing circle. If T/A is small the target is located more rapidly and with fewer errors. By this formula a circle would be the poorest possible target.

Steedman and Baker (54) pursued this study further adding blur and size differences. They found blur within the range of their tests had no effect if the displayed reference standard was equally blurred. Visual subtense was strongly related to legibility in sizes of 20 minutes or less.

Boynton (14, 15) presented a single critical form of angular construction against a background of irregular curved nonsense forms of similar size. On some exposures no critical form was presented. Subjects were on an irregularly presented monetary reward schedule to reduce guessing in a boring situation. This study and numerous subsequent experiments in the same laboratory are directed toward identifying factors that influence the visibility of a form. Generally findings have been related to contrast, density, observation distance and exposure time, factors that have been fairly well defined previously.

Deese (24) approached pattern recognition with random straight-line forms generated within a two-inch diameter circle. He classed his targets as simple or complex, regular or irregular. Complexity was based on the number of changes in direction. Regular forms had only right-angle changes while irregular forms contained varying angles. The subject was required to locate a demonstrated target from a set of five similar nonsense forms. Results are not clear cut. The more complex forms with right angle turns are best if only one form needs to be remembered. Performance in general suggests that subjects do best when the nonsense form reminds them of something.

French (26) presented dot patterns on a noise-degraded CRT. The report concludes that the more dots included in the pattern, the greater the probability of detection. Gaito (30) finds straight lines superior to curved forms and feels angles give much information.

Mooney (47) performed a recognition-recall experiment with irregular black and white forms and concluded that pattern learning comes from a single glance rather than prolonged inspection. Fitts, Weinstein, Rappaport, Anderson and Leonard (25) generated nonsense figures on an 8 x 8 matrix, using a probability formula for generation. In a recognition test the totally symmetrical figures and those symmetrical about a vertical axis were superior to asymmetrical figures and those symmetrical about a horizontal axis. Booth and Glorioso (12) report a CRT computer-generated patterning device that will permit further study of these factors. Murray (50) suggests that symmetry may have a time advantage in reducing transformation requirements within the visual pathways.

Attneave (2) and Attneave and Arnoult (3) used irregular solid forms plotted from a random-numbers table in an attempt to identify the factors contributing to judged complexity of form. They find that asymmetry, angular variability, the number of sides and the ratio of the square of the perimeter to the total area can be weighted to produce a formula which accounts for 90 percent of judged complexity. This research is also continuing.

The status of knowledge in code selection can be summed up by the 1957 National Research Council report of its meeting on form discrimination as related to military problems. White (57) of the U. S. Navy described the electronic displays of the various services and the conglomeration of codes that had sprung up with each new display. He asked for a documented standardization of symbolic codes before the situation was completely out of hand. Harker (37) of the U. S. Army asked for realistic display studies related to actual jobs, using the full dimensions of the natural environment. He stated that measurements of psychological functions which must be tenuously related to the task have little utility. Bersh (9) of the U. S. Air Force noted that studies on forms have been too heavily loaded on single-form visibility. For rapid, accurate decoding of information, he felt the influence of symbols on other symbols within a code complex should be carefully analyzed. These representatives of the armed services all emphasized the importance of time and errors in decoding displays.

Blackwell (10) immediately stated that current knowledge was probably of little use in solving any practical problems of the military. After the papers had been completed, he repeated this statement and added that the studies reported bore no resemblance to actual situations in life.

Smith (53) reviewed the historical stages of form-discrimination studies for the meeting. The Italian artists of the Rennaisance in their attempts to create two-dimensional representations of a three-dimensional world gave psychology the original information on monocular cues to distance and original notions of form discrimination. The associationists put their emphasis on sensations and local signs. The Gestalt school was first concerned with total impression of the observer. Smith referred to the Gestalt laws as "mainly Monday morning quarterbacking," and added that the major contribution of this period is the "initial formulation of problems which are as yet unsolved." He described the present era as an attempt to cope with urgent practical problems necessary for survival of the species. This era, he said, is in its infancy and its direction is still poorly defined. Investigation of nonsense forms is aimed at uncovering the basic factors which make a form visible or at designating an equation of visibility. While these studies may be of great value in terms of learning, they do not meet the immediate practical problems of the military. Smith suggested attention to forms which might actually be used for identification.

Tanner (55) discussed form perception as related to information theory. He felt we must know much more about the environment, the operator, and the task before we can designate the "channel capacity" in any complex viewing situation.

Arnoult (1) told the group about his pairing method for studying angular nonsense forms and rating symbols on complexity. Boynton (14) criticized this method for failure to include a full population of confusion forms. He then described his own procedure which presented only one angular target within a large population of curved irregular forms. Neither study provided information for choice of a code.

Debons (23) noted difficulties in translating academic information into data useful in other fields. He suggested an extensive literature review. Sleight (52), who had suggested simulation as an ideal method for studying man-machine performance, doubted the usefulness of a literature search. He argued that psychologists do not write or speak in a manner that communicates their meaning to colleagues. Under such circumstances he felt the literature had little meaning for others. The discussion periods lent weight to this argument. No one appeared to understand the theory behind any study other than his own.

Arnoult (1) suggested that the group members had two general theories of attack. He felt that people interested in interpretation of radar screens and other practical displays need to gear their studies to periods of five to 10 years because of engineering obsolescence. Psychologists interested in the basic principle of form perception are working within a time frame of 800 years or perhaps until the human being is obsolete. He questioned whether the Armed Forces were interested in supporting such long-term research. This question seems to have been answered: the nonsense form studies have continued and multiplied, and the military still does not have the answer to its problems.

SUMMARY

Any new research problem traditionally starts with a literature review. Theoretically, this gives good background information and points out a general avenue of approach for further studies. In many instances the building blocks for a research design are located in reports of earlier studies. At other times a stereotyped pattern may develop a "stumbling block to the truth."

Our literature search did not uncover information closely related to symbolic coding of information displays. Perhaps it would be more appropriate to say that no studies were oriented toward decoding the display. Emphasis was on locating "good figures" from the Gestalt definition and proving or disproving their effectiveness.

There was a large amount of controversial data on the relative discernibility, or pure visibility of the circle, square and triangle. Codes were then logically derived from discernibility findings. The total codes were generally not tested.

A few studies did consider the possibility that two or more highly visible forms might be too similar for use in a mixed display. None of these studies of inter-symbol discriminability used a display with a large variety of symbols scattered randomly over an area. In several instances three or four symbols were studied in a very realistic design on a simulated CRT, but in all instances equipment failed or character generation favored one symbol and conclusions were guarded.

Any realistic display of mixed symbols must be carefully designed to avoid positional advantages and patterning cues. A single code complex requires a number of display drawings and each code change represents a complete set of these drawings. The drafting-board work is tedious and exacting. Perhaps this work accounts for the fact that earlier inter-symbol confusion studies employed simpler designs. While these techniques were flexible, they do not seem to simulate or represent an information display. Usually subjects became familiar with a total test battery and were then given the task of sorting, selecting or naming symbols individually presented on cards or by tachistoscope. Performance scoring usually included some timing element. Inter-symbol discrimination scores, however, were almost totally dependent on errors.

Tachistoscopic tests were especially unsatisfactory, since they required repetitive test runs with the subject naming or defining the target. Data from these studies suggests that subjects developed a preference for a particular symbol and named it more frequently. Using any method of limits, this preferred target reached the criterion of correct identification at either a smaller size or faster exposure. This same target also appeared as the most frequent confusion figure for other symbols. Regardless of the mathematical manipulations used to correct

for this factor, results were definitely tempered by the preference element. Tachistoscopic studies also generally used a seven to ten-foot working distance since projectors are designed for a fairly long slide-to-screen separation. Under these conditions there was little resemblance to the radar operator's task.

Sorting procedures were near-point tasks and had the advantage of requiring some perceptual-motor coordination. While card manipulation was in no way related to the manual requirements at a PPI console, the sorting procedure did interweave with the viewing process and provided a better task simulation. Unfortunately, sorting cards into individual categories does not permit timing on individual symbols. Studies using these techniques reported only inter-symbol confusion errors and total sorting time. In most instances the time element was considered as a measure of increased task complexity with additional symbols.

Studies designed on separation of an individual symbol from a complex card deck reported errors of confusion, errors of omission and time for each category. This technique had all the advantages of the sorting methods and provided more useful data. It is the most flexible of the simple design methods. A single symbol may be replaced, densities may be varied and additional categories may be added with minimal effort. For our studies this method was chosen for comparison with a more realistic display. If findings provided comparable data, the simple technique would be the method of choice on further experiments.

EXPERIMENT I - SYMBOLS IN ISOLATION

Studies of discriminability involving a number of symbols have leaned heavily on sorting or similar techniques. The subject is given a variety of symbols on individual exposures and is asked either to sort them into categories or to separate a single type from the total. The procedure is simple and requires a minimal design effort, but it may be questioned whether the confusion effect of mixed symbol types in a single display is reproduced by this method.

Since sorting techniques would permit the greatest flexibility in testing, initial efforts employed this procedure. Tests were designed to present symbols on individual cards within a mixed deck. There was no distracting material on a given card. Confusion elements were present only as the total variety of similar forms within the test decks. Final testing required individual sorts on two dimensions -- a basic symbol and a modifying element. The procedure is similar to sorting playing cards by suit and face value.

In all instances two unbalanced card decks were used to permit varying item counts with a constant total. With this procedure, card-handling time was equalized and search was directed toward an individual item without the subject knowing the total count.

Familiarization Procedure

Preliminary familiarization material consisted of non-standard playing card decks with varying suit and face-value counts. In the first task the subjects simply counted the card decks as rapidly as possible. Since all subjects were familiar with playing cards the 55 count invariably brought questions. Subjects were told that they were using special sets of cards made up from several decks. This prepared them for their second task, a timed sorting of the Kings. There were six Kings. Sorting by face value or suit continued with alternating decks until sorting times reached a plateau. At this stage all subjects handled the cards well and had become aware of the fact that counts varied from suit to suit and deck to deck.

Additional familiarization included counting two unbalanced decks of blank 3 x 5 cards with the two-deck total equalling 110. This practice gave experience in handling the material used in actual testing. Counts were timed until this two-deck count also reached a plateau.

To give the experimenters practice in perfecting test techniques, all procedures were initially run on casual troops who would not be available for the entire test session. Thus both subjects and experimenters entered the test sessions with appropriate basic skills.

Subjects

Subjects were rougly matched on the basis of playing-card sort and blank-deck counting times and errors. Improvement in performance during the familiarization period was considered as a learning trend and was included in the subject-matching procedure. Four groups of seven subjects were identified in this initial procedure.

All potential subjects were tested on the Bausch and Lomb Ortho-Rater for visual acuity, far and near. Two had scores of 8 (20/25) and the remainder scored 10 (20/20) or better on both far and near. The age range was 19 to 52. Civilian and military technical employees within the laboratory provided our subject pool.

Pre-Testing

Since a double-fatigue testing order was desirable, four groups of matched subjects were needed. The pre-tests were designed to group subjects by speed and accuracy for the final tests. Alpha-numeric symbols were used in this phase to avoid a practice effect. Otherwise, the pre-test material followed the final test design exactly.

Test material was centered within $\pm$ 1/4-inch radius on 3 x 5 cards. Each sub-test consisted of two 55-card decks. The five basic symbols or suits of a series appeared from 9 to 13 times in each deck for a two-deck count of 22. Modifying symbols, or face values, appeared 3 to 8 times in a deck for a two-deck count of 11. While the test decks were used and timed alternately, item sorts were inversely ordered to avoid possible recognition of the total two-deck count. Times and errors were later combined for individual items over the two decks and are strictly comparable.

In the pre-test series, 10-point capital letters A through E represented suits and 10-point numerals 1 through 9 and a blank space represented face values. Three sets of test decks were included: alphabetic alone, numeric alone, and an alpha-numeric combination. In the combined series, the numeral or blank always followed the letter. Symbols were typed on the cards within a $\pm$ 1/4-inch radius. The upper left-hand corner was cut from each deck to assure proper letter orientation after shuffling. A segmented linear code on the reverse side of the test cards aided the tester in rapid identification of errors.

There was no emphasis on either speed or precision. From the earliest familiarization series the experimenter used the stopwatch in a position where it could be easily read by the subject in order to give a speed "set." During the pre-test series, errors were also emphasized. When a subject omitted one or more target cards from his sort the remaining deck was handed to him with a request that he make certain he had <u>all</u> of the targets. Errors of confusion (including of incorrect symbols in a sort) were immediately located by the experimenter using the segmented line code on the back of the cards. These errors were removed from the sort and called to the subjects' attention. Repeat sorts were not timed. The experimenter recorded time and both confusion and omission errors, and reported the results to the subject after each series.

This procedure in the pre-testing phase was intended to give equal weight to time and errors. On successive preliminary tasks the subjects did become more efficient on both counts. It was obvious, however, that some were striving to improve their speed while others worked mainly on perfecting an error-free technique. These factors were also balanced in the final grouping of subjects.

Pre-Test Ordering

In order to counterbalance learning and fatigue effects on performance, a double fatigue order was perserved. Four testing orders were followed in sequence as subjects appeared for testing (Table 1).

TABLE 1

Testing Orders for Pre-Test

Order 1	Order 2	Order 3	Order 4
1. Simple, numeric	Simple, alpha	Composite, alpha	Composite, numeric
2. Simple, alpha	Simple, numeric	Composite, numeric	Composite, alpha
3. Composite, numeric	Composite, alpha	Simple, alpha	Simple, numeric
4. Composite, alpha	Composite, numeric	Simple, numeric	Simple, alpha

Presentation of the five possible letters and the 10 modifiers also followed a progressive rotation within each order. In all instances the alternated decks followed inverse item ordering. This, coupled with rapid test sequences, reduced the possibility of learning the total target counts. No subject stated that he had noted a patterning in card counts.

Individual scoring sheets in the various fatigue orders held the experimenter to his program without difficulty. To further simplify scoring, the correct count was recorded in red ink for each item listed. Score sheets were below the subjects' line of view at all times.

Pre-Test Procedure

During the test the subject and experimenter faced each other across a table in a well lighted, shadow-free area. Each subject adjusted his chair until he felt he was handling a blank card deck at his best. The experimenter then handed him the first test deck with a cover card over the symbol. He was instructed to keep cards oriented with the cut corner at the upper left. The experimenter then named the required target and at the order "Go" the subject began his sort, slapping the table with his final card as a signal of completion. Stopwatch timing based on these two signals had proved most reliable in previous timing experiments.

The experimenter recorded the time and moved the sorted cards to the scoring section. He then started the subject on the target for the second deck. There was adequate time for counting the sorted cards and checking confusion errors before the next sort was completed. If there were no errors the original deck was shuffled and testing continued. When errors of omission were noted subjects were required to recheck the remaining deck (untimed). Errors of commission were pointed out in the sorted cards. After each complete test sequence there was a two-minute rest period before the following sequence began. Total testing and error-correction time for an individual subject averaged about 40 minutes with three rest periods during the session.

Counterbalancing in the later test sequences required four matched groups of five subjects each. During pre-testing seven subjects had been scheduled for each testing order. If an individual was highly irregular in his performance or error scores were excessive, a second subject was substituted in the same sequence. It was necessary to locate three additional subjects before matching the four groups of five subjects.

Results

Matching of subjects was checked on total testing time and errors. The complete test run included 10 double-deck alphabetic sorts and 20 numeric sorts. Each subject sorted 3300 cards and selected 440 target cards during his test session. Since there were five subjects in each testing order, times and errors within an order represent 16,500 cards with 2200 target selections. Table 2 represents the adequacy of initial group matching.

Counterbalancing was adequate for the alpha versus numeric fatigue ordering which balanced groups 1 and 4 against groups 2 and 3. Summing across these groups gives a time of 349.28 minutes with 56 errors for subjects tested on numerics first, against 350.71 minutes and 48 errors for the groups who started on the alphabetic cards.

TABLE 2

Total Performance on Alphanumeric Card Sorts
N=20

Order	N	Time in Minutes	Errors
1	5	176.25	25
2	5	177.48	37
3	5	173.23	11
4	5	173.03	31
Total	20	699.99	104

Balancing on the single and composite task was less adequate. Here groups 1 and 2 are paired with 3 and 4. Scores summed across these pairs give a time of 353.73 minutes and 62 errors for the groups with the simple sort initially against 346.26 minutes and 42 errors for those sorting on the composite task first. The time elements were reasonably well balanced but errors differed significantly between orders 2 and 3. Subjects were regrouped to correct this imbalance on later tests.

The pretest data was analyzed according to the original groupings since fatigue orders entered into the design.

Statistical procedures included simple analyses of variance, Neuman-Keuls (61) tests of significance of differences and Pearson correlations of total times. Error differences on total test runs were tested by the Chi square statistic. Individual item errors were too small for this test.

On all test runs variations between subjects exceeded any within-subject differences. The poorest subject required almost twice the time of the best subject on any individual run.

For the simple alphabetic sort, total times varied from 25.27 minutes for D to 26.02 minutes for B. Differences were not significant. The alphabetic sort on the composite deck varied from 22.68 minutes for A to 23.73 minutes for B and differences were again not significant.

Total times for the complete alphabetic runs were 127.34 minutes for the simple task, against 115.18 minutes for the composite. The two runs correlated +.663. Student's (35) test for difference of two correlated means gave a $t = 2.53$ (1 tail test, 19 df, $t_{.99} = 2.528$) with performance significantly superior on the composite task. Errors (30 on simple versus 26 on composite) did not differ significantly.

On the simple numeric cards, total sorting time ranged from 22.63 minutes for the blank to 23.74 for the number five. Differences were not significant. On the composite task the performance ranged from 21.87 minutes for the numeral 5 to 23.09 for the 6 with differences again not reaching the .05 level.

Total times for the complete numeric runs were 233.17 minutes for the simple versus 227.44 for the composite. The two runs correlated +.679. Time differences did not approach significance (t-less than 1.0).

The simple and composite tasks resulted in 17 and 31 errors respectively. Using the chi square corrected for continuity (44), errors were significantly greater on the composite sorts. In this instance $X_c^2 = 3.56$ (X^2 of 2.71 is required for P = .05).

Analysis by test order showed no evidence of learning advantages transferring from alphabetic to numeric runs. There was significant (.05 level) time improvement from the first to third sorting task with errors remaining stable. On the fourth task a slight increase in errors and time suggested a fatigue factor.

Reviewing the familiarization data made it appear that counting a blank deck and sorting a deck for an individual symbol required almost equal time. The average time for counting five unbalanced double decks (550 cards) was 6.08 minutes. Sorting the same number of cards for a single alphabetic symbol averaged 6.37 minutes. Correlation of the two tasks was only +.337. For significance at the .05 level the correlation for 20 subjects must be $\pm$.444 (27). None of the four sorting tasks correlated with the card count at this level. The highest correlation was slightly under +.370. Subjects had dealt the cards individually during counting procedures. During the sorting tasks all subjects had developed a method of fanning or spreading the cards and viewing them in groups of three to six.

Conclusions

The few significant differences during the pretest were probably the result of poor grouping of subjects. The data was used to regroup so that times and errors were essentially equal for the four testing orders to be used in the final test.

The suggestion of fatigue entering into the fourth testing order called for longer rest periods and shorter test sessions in the final test.

Correlations between card counting and sorting did not reach significance. Subjects handled the cards differently in the two tasks. The improvement in performance during the first three test runs may have depended largely on changes in sorting techniques since the alphanumeric targets were highly familiar. All subjects had reached a performance plateau and had settled down to their preferred sorting method before testing was completed.

The pre-test served its purpose by preparing subjects and experimenters for the test proper.

Sorting Test

The final symbol in isolation test followed the alphanumeric design with two-deck totals held constant. The suits, or basic dimensions, were represented by five geometrical symbols. Face values or modifiers consisted of alphanumeric or line modifiers. Three double decks of cards were made up for the test.

Set 1 consisted of the basic unmodified symbols. Set 2 used internal alphanumeric modifiers. Set 3 used internal and external linear modifiers similar to the Naval Tactical Data System (NTDS). Figure 1 illustrates the basic shapes and the linear modifiers.

Geometric symbols were recommended by a contractor and were based on simplicity and familiarity, as recommended in discernibility studies abstracted from the literature. The set included a circle, half-circle with inclosing diameter, triangle, diamond and square.

Size ratios, angles and linear modifiers were selected by the experimenters using precision photographic slides and a back-projection method to simulate a Cathode Ray Tube (CRT). Symbols were first studied in ideal sharp detail using a one-quarter inch diaphragm on the short-throw projection lens. Degradation effects were simulated by increasing the diaphragm opening (adding coma and spherical aberration to the projection system), by decreasing illumination and by directing glare source to produce specular reflection on the screen.

Modifiers which distorted rapidly were eliminated in this procedure. Linear modifiers which crossed the basic symbol were poor in the most ideal condition. Auxiliary symbols based on dot or line numerosity lost their coding value with the slightest degradation. All modifiers of these two types were removed from the test repertoire.

The triangle degraded more rapidly than any other enclosed figure. For this reason, basic symbol size was determined by the triangle which would enclose a 10-point "B". Other symbols were ratioed to this basic size. Shapes and sizes are included in Table 3.

Symbols were drawn inside plastic templates and were centered within $\pm$ 1/4-inch radius on 3 x 5-inch cards. A K&E 61-3270 "KOH-I-NOOR" Technical fountain pen with a #4 point gave a satisfactorily constant line width which averaged 1/9 of the symbol heights. Linear modifiers were also drawn with this pen. Alphanumeric modifiers used standard elite typewriter numbers and uppercase letters. The segmented line coding for error check followed the pretest design. The corner cut was continued as an aid to proper orientation.

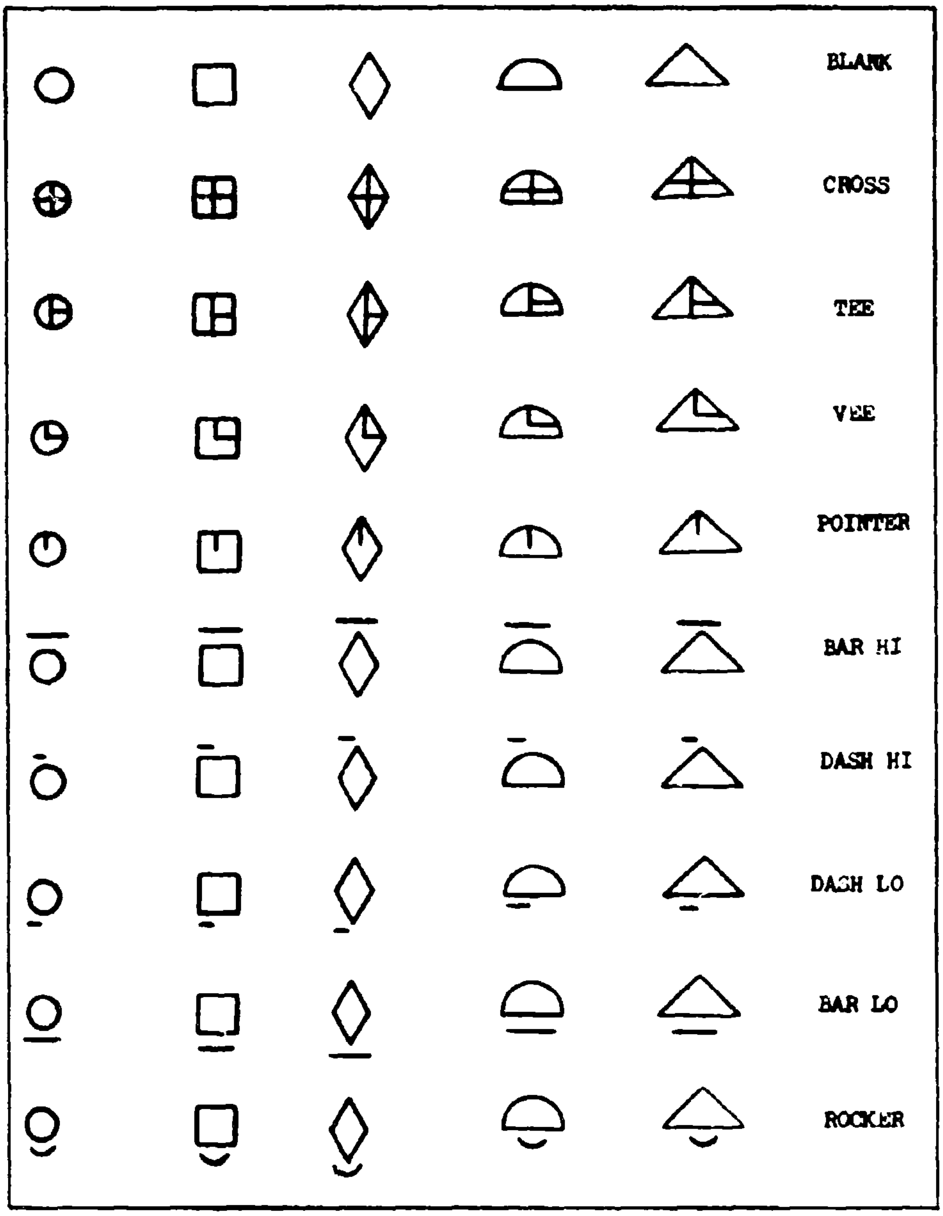

Fig. 1. FORMS FOR SYMBOLIC CARD SORT

TABLE 3

Symbol Specifications for the Sorting Task

Form	Dimension
Circle	7/32" diameter
Square	1/4" side
Half-Circle	3/8" diameter
Triangle	90^{o} isosceles, 1/4" altitude
Diamond	60^{o} apical angle, 1/4" sides

Subjects and Procedure

The 20 subjects selected by the pretest participated in the sorting task. The four new groups of five subjects each were almost perfectly matched on time and errors in the pretest sessions.

Test administration and scoring methods followed the earlier design. In all instances the unmodified test forms were presented first as a familiarization procedure. The two modified sets were presented in double fatigue order. Group 1 and 4 began with the shape alpha series, while 2 and 3 began with the shape modifier series. The shape sort was the first procedure for groups 1 and 2; the modifier sort was first for 3 and 4.

Since the linear modifiers were unfamiliar forms, all subjects were asked to study the demonstration sheet illustrated in Figure 1. This material was reviewed until a subject responded accurately when asked to name an illustrated modifier or to locate a named modifier. Since group 3 had modifiers of this series as the first task, demonstration and check procedures were repeated twice with a 30-minute rest period intervening. The sorting procedure followed the second demonstration and a five-minute rest. The remaining subjects were also given two demonstrations, with the first as a prelude to scheduled rest periods and the second preceding the linear modifier sort. We could not expect to equalize familiarity of alphabetic and linear modifiers during these sessions. The demonstrations did make the material familiar enough for some measurement of performance.

Results

Results closely approximate the pretest. Table 4 summarizes times, standard deviations and errors for the 20 subjects. Five item tests contained 22 of each target in a double deck of 110 cards. The times and errors summed over all sorts for the 20 subjects represent the location of 2200 targets from 11,000 cards. Ten item test scores represent location of 2200 targets from 22,000 cards.

There is a strong similarity in times for the five item sorts. The two simple tasks, alpha alone and shape alone, require more time and result in greater errors than tasks requiring location of the same symbols from a composite target. Inter-correlations of these sorts vary from +.67 to +.93. Since a two-variable, 19-degree of freedom correlation coefficient of .561 is significant at the .01 level (27), the five item tasks are definitely related and subjects who perform well on one have a tendency to perform well on another. The five item tasks on geometric shapes all correlate +.81 or higher. The highest correlation (+.93) is between plain shapes and shapes complicated by a linear modifier. With this correlation the time difference (Student's t) is significant at the .02 level for the 20-subject pool.

TABLE 4

Summary of Card Sorting Time and Errors, Total Runs
N=20

Target Class	Total Time In Minutes	Standard Deviation	Errors of Omission and Commission
Five Targets in 110 Cards			
Alphabetic alone	127.35	1.229	30
Alpha of alphanumeric	115.19	1.360	26
Shape alone	127.75	2.442	29
Shape of shape alpha	120.16	1.838	17
Shape of shape modifier	120.62	1.518	9
Ten Targets in 110 Cards			
Numeric alone	233.17	4.0843	17
Numeric of alphanumeric	225.42	4.6789	31
Alpha of shape alpha	221.88	2.733	13
Modifier of shape modifier	227.53	2.524	40

Plain shapes and the shapes of the alphanumeric modified series correlate .818. In this case, the lower correlation reduces the difference significance to only .07, with the time advantage for the more complicated task.

Simple analyses of variance of the five targets in each series and Newman-Keuls tests on differences between targets give little information. In all cases, the significant variance is between subjects. The highest within-treatment or intersymbol F ratio was 1.09 ($F_{.95}(4, 76) = 2.51$). In no series does an individual target difference approach the .05 level of significance. Total times for the three forms of modified targets again reveal no significance difference.

Errors were greatest on the plain shape test. A chi square treatment gives a value of 11.0, which is significant at the .01 level (df = 2). Since this was the first sort in all instances, it was probably at a disadvantage. Errors related to the two forms of modification give a X_c^2 of 1.89. Since 2.71 is the value required for a .05 significance (df = 1), the data does not indicate an advantage to either method. While confusion and omission errors were consistently most frequent on triangles and diamonds, the number of errors was too small for chi square testing.

Similar treatment of modifier data gives a slight but not significant time advantage to the alphanumeric series. Error differences gave a X_c^2 value of 12.74, indicating that the alphanumeric series results in significantly (.01 level, df = 1) less errors. This advantage is of questionable value since subjects were much less familiar with the linear modifiers.

Analysis of variance and Newman-Keuls tests reveal no significant differences within modifiers of a series. Errors were spread quite evenly over the various modifiers.

Correlations of all sorting times with the card count task continue at +.32 to +.38. Correlations with the similar pretest scores are all between +.75 and +.85. Time and error differences between similar tests are not significant.

Conclusions

When the card sorting technique is used, the symbols recommended by the contractor appear almost equally salient. Since the sizes of the five targets were ratioed to give equal discernibility, the equality findings encourage dependence on pure legibility or visibility advantages for the selection of symbols. The testing method must be validated against a more realistic task simulation before such a selection procedure can be recommended.

Sorting procedures require visual alertness and dexterity in handling cards. Since the radar operator's task also involves both perceptual and motor skills, there is some similarity between the test and the desired skills. While sorting in a single dimension required almost the same time as counting a card deck of equal size, the two measures correlated at a very low level and offered no solution to separating the perceptual and the motor portions of the task.

There was some possibility of determining task breakdown within the test design. Each basic symbol appeared in 20 percent of the total decks, while each modifier was present in only 10 percent. To locate an equal number of modifiers, subjects handled twice the number of cards used in the basic symbol sorts. The differences in time on the five and 10-item tasks could provide a measure of the motor portion of the task.

Similarly half of the time for modifier sorting required total card handling equal to the entire alphabetic sort. In this case, the target cards were also reduced by half and time difference might result from having fewer targets from the decks.

The three composite sorts for 20 subjects were used to estimate time factors. Results indicate an average time of .580 seconds to reject a card and .915 seconds to accept it. The first figure might be considered as the time for manipulation, recognition and a "no-target" decision. The additional .335 seconds could represent confirmation of a "yes" decision and separation of the target card from the deck.

These figures hold up well enough in predicting sorting on the geometric forms that there may be some meaning to them. They also suggest that card-sorting procedures may consist of a series of binary "yes-no" decisions with a verification of all "yes" decisions. Under such conditions, the testing procedure does not appear to be closely related to the radar operator's task.

If the card sorts are a series of individual decisions, symbol recognition may be a minute fraction of reaction time. In this case, findings may be of little value for our use. The following experiment is an effort to validate the sorting procedure as a measure of target visibility on a mixed display.

EXPERIMENT II - CONFUSION STUDIES - FIRST SERIES

While the sorting techniques of experiment I suggests that the recommended symbols may be well chosen, the test in no way represented the radar operator's task. The radar scope presents information on a number of targets of mixed types scattered across the scope as a poorly organized array. The operator decodes this array and acts upon it.

During surveillance periods friendly air/supported targets (AST) flying anticipated paths dominate the screen. An occasional unknown or unidentified craft appears, usually entering at the perimeter. The operator watches for changes in flight patterns, or deviations from air corridors. When an unknown target enters the screen he interrogates it and awaits identification as he follows its course. At this stage his task is monitoring and alerting with only two basic target types on his screen.

During an engagement, the screen presents a rapidly shifting picture. Unknown symbols become friendly or hostile as identification is completed. The unidentified category is now potentially hostile and requires rapid identification. Enemy AST taking advantage of terrain contours or cloud formations may have penetrated deep into the areas under surveillance, before appearing as "pop-up" targets. Hostile tactical ballistic missiles (TBM) may appear suddenly and our own TBMs come into play as needed. The operator is now faced with five target classes of variable densities. At this point his task has become more complicated and his performance is a critical factor in the success of defensive or retaliatory action. It is in this situation that an ideal coding method may create a temporal and informational advantage leading to increased mission effectiveness.

It is improbable that the radar operator who faces such a crowded and heterogeneous picture will study each symbol individually and make a binary decision on its representational value. For efficient decision-making he needs to see the entire engagement picture as a background with targets so chosen that individual classes may be called into a patterned figure. Ideally, the figure ground effect should be immediately reversible with target classes called into saliency at will. Such selectivity may be accomplished by push-button callup; however, this would increase operator actions within a critical time period.

A highly discriminable basic coding alphabet with a perceptual organization hierarchy, or multiple figure-ground reversibility, would be ideal. Since the radar scope presents an irregularly changing scene, the Gestalt figure-ground rules of proximity, closure, continuity and common fate, cannot be forced into the situation. What seems to be needed is a family of highly discernable symbols differing so strongly along some major dimension that each class may be individually perceived as the figure.

Rules for a good geometric shape coding have been repeatedly listed:

a. Primary symbols should be large and enclose a space.

b. No auxiliary symbol should cross, distort, interfere with or in any way obscure the primary symbol(s).

c. Symbol complexes should not normally exceed two geometric symbols (possibly three in some circumstances), a location dot, and a speed and direction vector line where applicable.

d. When other information is required, it should be in the form of numerical representation (e.g., one, two, or three marks to indicate magnitude of object) or in actual numbers and letters.

e. The geometric center of the symbol and/or a large clear dot should indicate location.

f. Auxiliary marks should be compact solid figures.

The original source of this series of rules is not referenced and has not been located. Generally, they are supposedly based on Gestalt logic or "good-figure" design for individual symbols. Bowen (13) points out that the Gestalt rules tend to produce similarity of shape while discrimination calls for non-similar forms. Bowen's studies, however, continue to follow the rules given above, probably because it is almost impossible to produce a series of forms without a degree of similarity.

The forms recommended for our basic studies and used in the card-sorting experiment conform to the listed rules and were probably selected on that basis. While they appear to be well selected for isolation studies, the question is whether they will be equally satisfactory as a mixed display.

Test Design

Confusion studies were designed to approximate the anticipated radar-operator task at a moderate saturation level. A north-oriented, 90^o sector was plotted on 8 x 10 1/2-inch white paper. The x, y coordinates for the 25 target positions as illustrated in Figure 2 were located by a random-numbers technique. All target centering held within a $\pm$ 1/8-inch radius of the chosen points.

Individual test sheets contained a set of five target symbols with each symbol appearing four, five or six times. A test run consisted of 10 different test sheets with varying symbol locations. Within a test run each symbol appeared twice in each position (for a total of 50 times within a test run). This design equalized search areas for the various symbols without creating a strong patterning effect.

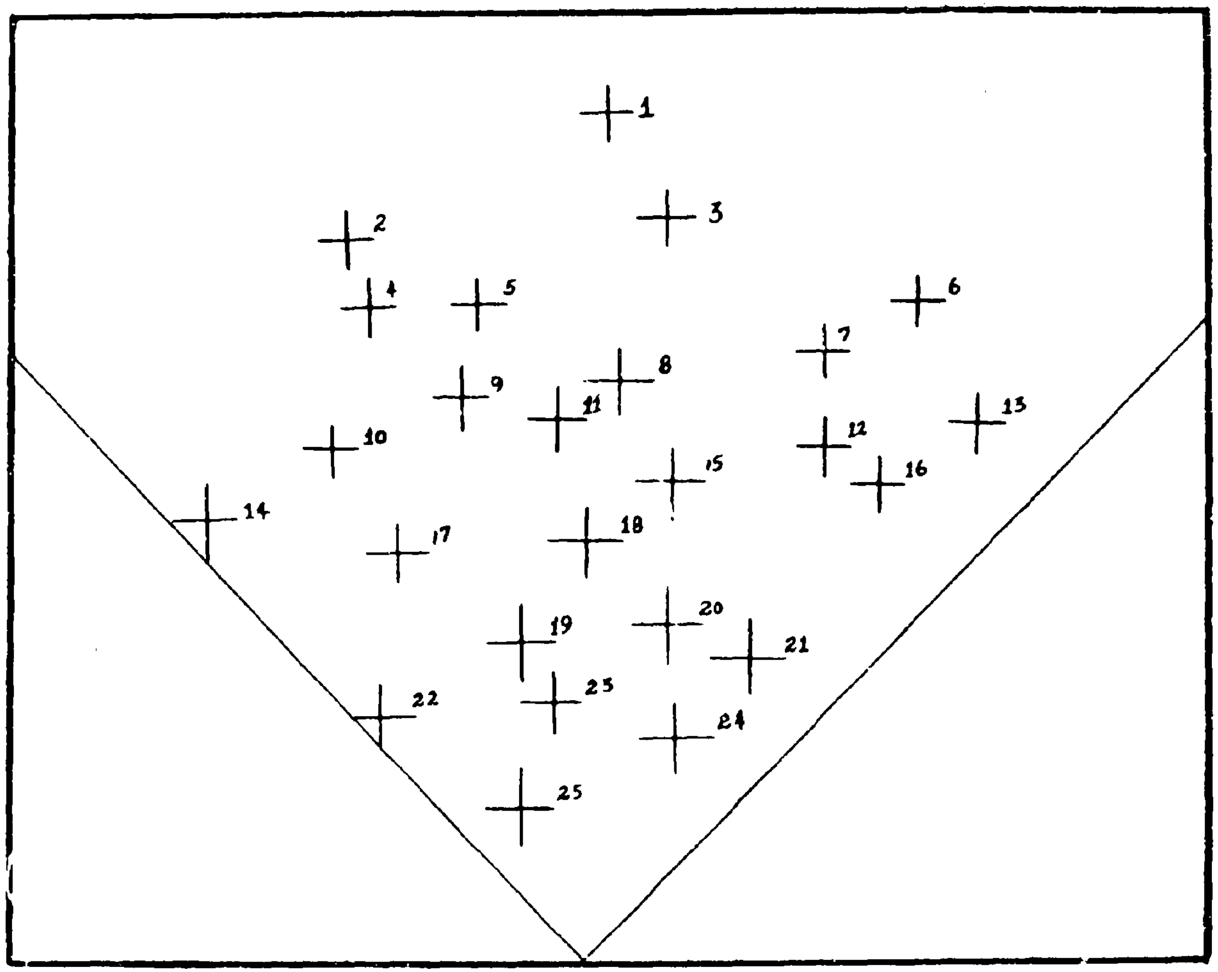

Fig. 2. LOCATION OF TARGETS IN CONFUSION STUDIES

Master test sheets were hand drawn with a BIC broadline, black ink, ballpoint pen. Line drawings with this pen were equal in width to the #4 Rapidograph but inking was more irregular for better simulation of CRT resolution. Plastic templates were used to maintain symbol-size regularity.

The first test series utilized the contractor-recommended symbols of the isolation test. An equilateral triangle was substituted at the suggestion of subjects. This series included four separate sets of material: (a) unmodified symbols, (b) symbols modified by uppercase letters within the symbol. (c) symbols modified by uppercase letters exterior and to the right of the symbol, and (d) symbols with linear NTDS modifiers. All modifiers were included to measure their interference with shape recognition and to increase clutter. Since the modifiers did not have to be identified in testing, they were randomly placed.

The basic symbols are described in Table 5. The four complex display sets of this series are illustrated in Figures 3 through 6.

TABLE 5

Basic Symbols for Series I

Meaning	Shape	Size
Friendly, AST	Circle	7/32-inch diameter
Friendly, TBM	Half circle with enclosing diameter	3/8-inch diameter
Hostile, AST	60^{o}, 120^{o} diamond	3/16-inch sides
Hostile, TBM	Equilateral triangle	1/4-inch sides
Unknown	Square	1/4-inch diagonal

The final test sheets were fifth-generation xerox copies, since optimal contrast and resolution is not to be expected in any changing display. Kleer-Vu plastic covers provided protection, an erasable field and a surface for a realistic specular reflection common to CRTs.

A full test sequence required five copies (one for each basic symbol tested) of each 10-sheet run. Randomized order within runs of 10 further reduced recognition of patterning effects during testing.

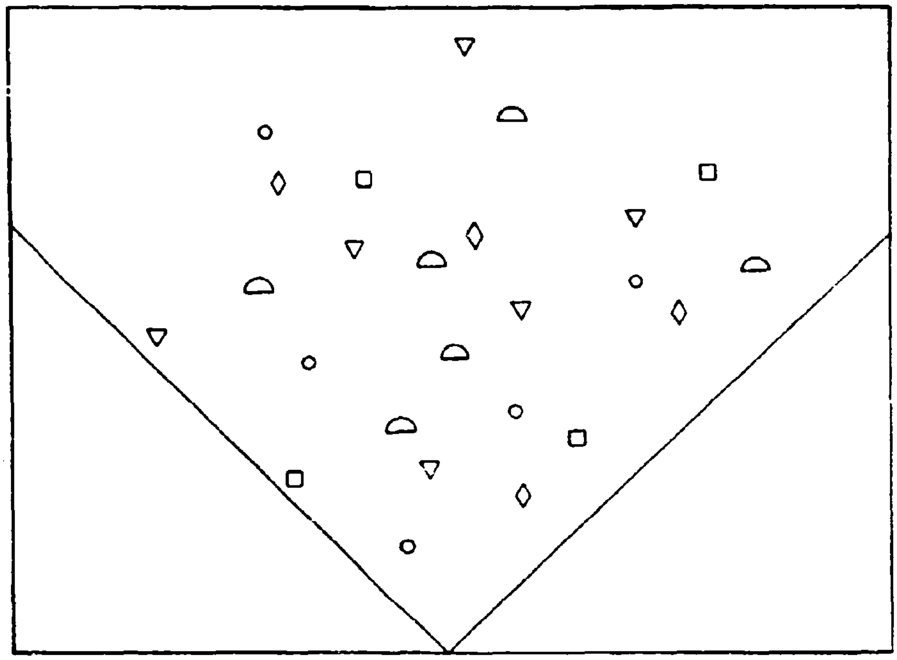

Fig. 3. SERIES Ia

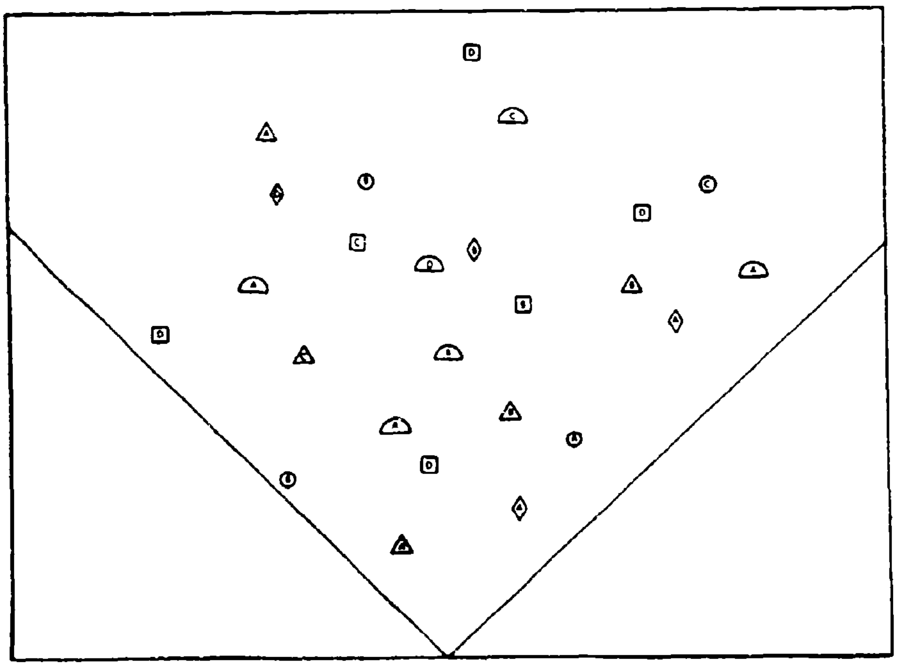

Fig. 4. SERIES Ib

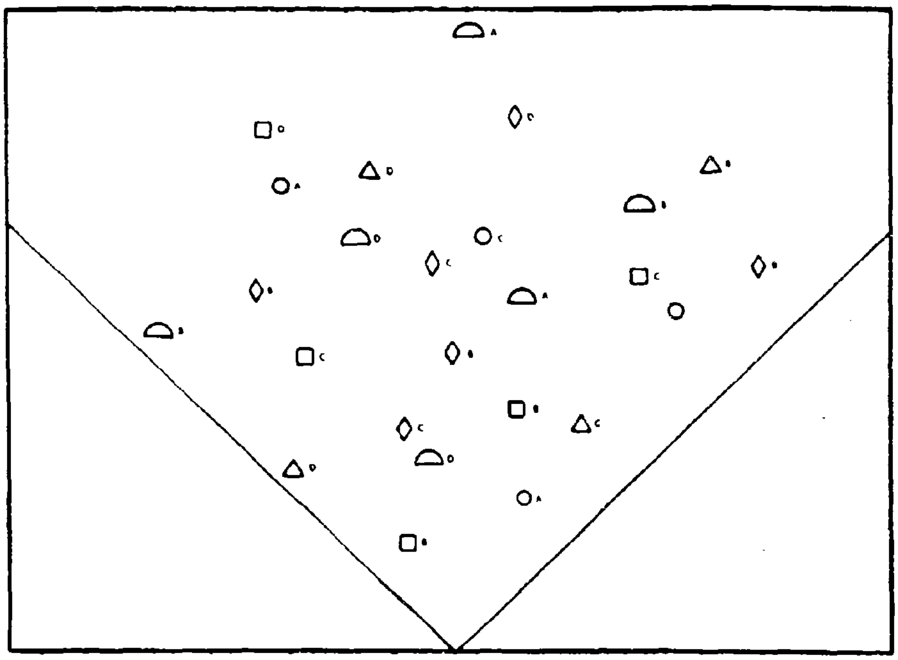

Fig. 5. SERIES Ic

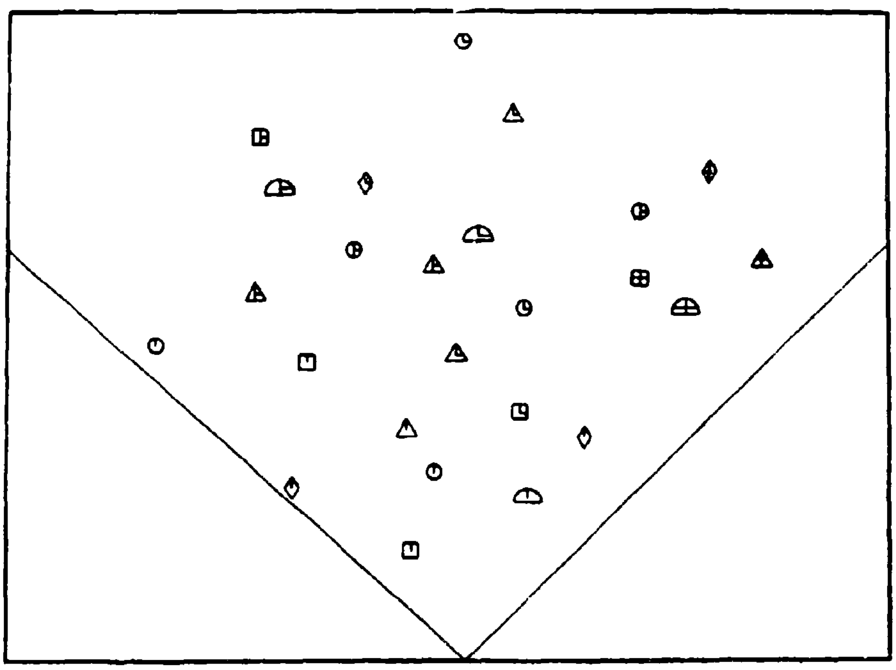

Fig. 6. SERIES Id

Each 50-sheet sequence for a symbol set was mounted in loose-leaf, hard-back notebooks for rapid presentation. The subject marked the designated targets with a pencil-type felt marking pen as he turned through 10 test sheets to complete his run. The markings could be removed with an alcohol-saturated cloth after scoring. The plastic covers cleaned completely without stain and the materials remained in excellent condition throughout the period of testing.

Subjects

The subjects for the first series were the same used in the symbols-in-isolation study. Regrouping produced almost perfect balance on time and errors on that test to maintain fatigue order. All these subjects had considerable familiarity with the first series as a result of the previous tests. Their cooperation and interest were excellent.

Procedure

A large well-lighted table was used for all confusion tests. A Weston Model 614 Foot-Candle Meter gave an average reading of 62 foot-candles on the table surface. The task-area brightness, on the open test book, averaged 35 foot-lamberts as measured by a Photo Research Corp. Spot Brightness Meter, Model SB 1/2. Immediate-surround brightness at the table averaged 10 foot-lamberts, giving a task-to-surround brightness ratio of 3.5:1 and a task-to-surround contrast of 71 percent. Specular glare areas on the test-sheet covers were 60 foot-lamberts or more.

The subject chose a chair of comfortable height and readjusted it to his satisfaction. The experimenter presented a notebook of practice sheets similar to the test material and explained the task. Each subject was instructed to turn the cover sheet at the word "Go," to mark all of the circles on each successive sheet, and to tap his pen as he finished the final sheet.

The experimenter timed each run and observed any hesitations in starting or in signaling the end. If a subject hesitated in signaling, the experimenter designated a second symbol as the target in a repeat run. Subjects cleaned the practice sheets between runs while the experimenter discussed the similarity of the test to the tasks of a radar operator. After a subject had stabilized in his signaling procedures, he was given a two-minute rest period before the test proper.

Each of the subject groups was assigned one of the four ordered permutations of sub-test modifications. The five basic symbols were similarly ordered within the five subjects of each group. Fatigue and learning factors were thus counterbalanced both within and between tests.

Each subject completed all five targets of a set in rapid succession, pausing only until the experimenter recorded time and designated the next symbol. When he completed his first set, the subject was given a rest break and asked to walk around and stretch his legs. During this period the experimenter located and recorded errors of confusion or omission.

When the subject returned he was told how many errors he made. Times were given only on request, since subjects regularly looked at the stopwatch as they tapped the table at the end of a run. The next set of the appropriate order was immediately introduced. Testing again included the five symbols of the set in rapid succession. The subject then cleaned his first test book while the experimenter scored errors on the second set.

The same procedure was followed until the fourth set was completed. During the final scoring period subjects were asked to fill in a questionnaire (see Appendix A) regarding the test.

Results

A simple analysis of variance considering the five symbols as the repeated measures, or treatment, again seemed the most direct method for studying the data. This design would also provide the basis for defining significant time differences by the Newman-Keuls method (61). The statistical procedure pattern is included in Appendix B, Table 1B. Raw-data and total-data reduction figures have been omitted for simplicity. All data sheets are on file at the Human Engineering Laboratories.

In the first procedure, each set of the series is considered separately to point out symbol trends. A second analysis uses total time on each of the four complete sequences to locate modifier advantages. Chi square analysis of error trends is treated separately. All sets of Series I demonstrate homogeneity of variance by the F_{max} test. (61). Analysis of variance reveal significant differences at the .01 level for both subjects and symbols.

Table 6 presents a summary of times and errors for the 20 subjects used in this series. In this table a run represents location of 50 symbols from a 10-page presentation including 250 mixed symbols. A sequence represents the five symbol runs of a set with 250 symbols located in a total exposure of 1250.

The earlier card-sorting test using the symbols of this series had indicated equality of search time for the different geometric forms. When the same symbols were located on a mixed display, this equality vanished. In all four sets of this series the circle and half-circle targets were located in at least 25 percent less time than triangles and diamonds. Errors differed even more greatly.

TABLE 6

Summary of Times and Errors on Experiment II
N=20

Set		Shape: Triangle	Circle	Diamond	Square	Half Circle	Total
a. Unmodified							
	T	22.40	14.71	22.85	21.46	15.24	96.66
	s^2	.0566	.0435	.0702	.0399	.0339	.0794
	E	38	1	34	25	7	105
b. Inner alpha							
	T	24.87	19.06	26.14	24.63	16.67	111.37
	s^2	.0472	.0476	.0697	.0588	.0524	.0877
	E	31	7	32	6	2	78
c. Outer alpha							
	T	23.25	17.13	24.33	22.05	16.63	103.39
	s^2	.0531	.0475	.0562	.0683	.0650	.0814
	E	23	4	33	6	3	69
d. Line Modifier							
	T	23.37	15.76	25.16	20.94	15.83	101.06
	s^2	.0585	.0353	.0847	.0485	.0462	.0862
	E	22	0	27	12	8	69

T = Sum of time in minutes for 20 subjects for each run or sequence
s^2 = Variance
E   Errors of omission

Sets of Series I are illustrated in Figures 3 through 6.

Symbols within the sets differed significantly. According to the Newman-Keul statistic, the circle and half-circle are superior to the linear figures at the .01 level in all sets. The square is the best of the linear forms and is superior to the triangle and diamond at the .05 level.

Differences in errors are significant at the .01 level, according to the chi square statistic. The diamond and triangle account for 75 percent of all errors of omission. There were only 22 errors of confusion in the entire series. All but one of these was between the diamond and the triangle.

Total times for a complete sequence of the five symbols within a set are also treated by analyses of variance. Subject and treatment variances are both significant at the .01 level. The data is homogeneous in terms of the F_{max} test. Newman-Keul tests of difference indicate that the times for the unmodified forms are superior to the linear modifiers at the .05 level and to the two alphabetic sets at the .01 level. Linear modifiers or letters to the right of the symbols do not differ significantly in their effect on total time and are both superior at the .01 level to letters within the symbols. While differences are significant, they represent time savings of only about 10 percent.

The unmodified forms of set 1 were processed most rapidly; however, errors were greatest on this set. This suggests that modifying information on the screen may keep the operators more alert.

Linear modifiers had little effect on the times for the circle, half-circle and square. The use of alphabetic modifiers within the symbol increased times for all forms and also gave the highest error count of any of the modified sets.

Subjects had a tendency to be fast or slow consistently regardless of symbol or set. Table 7 records a select series of Pearson Product Moment correlations which illustrate this trend. Proper selection of operators could significantly reduce search time. Our fastest subject processed data in approximately one-half the time of our slowest throughout the test.

It is especially interesting that neither card-sorting of symbols nor card counting correlates with the task of locating symbols in a mixed array.

TABLE 7

Pearson Product Moment Correlations
Task Times (N = 20)

Task	Mean	r	Index of Forecasting Efficiency
1. Series Id circle vs Series Id triangle	.788 1.258	.777 **	.3705
2. Total sequence Ia vs Total sequence Ib	4.833 5.568	.9305 **	.6339
3. Total sequence Id vs Shape of shape modifier card sort	5.053 6.031	-.005	.00001
4. Total sequence Id vs Blank card count	5.053 .608	-.056	.0016
5. Card sort plain shape vs Blank card count	6.392 .608	.387	.078

** .01 significance level, N = 20 requires r = .561 (27)

Discussion

The confusion tests present information in a reasonable approximation to the anticipated PPI display. Since there is essentially zero correlation between performances on isolated symbols and mixed arrays, these experiments do not justify the use of sorting tests to select ideal shapes for a geometric code.

In both experiments symbol sizes were ratioed to relative visibility. Sorting tests indicated that the design produced equal salience. That confusion studies did not give similar results suggests that pure discernibility is inadequate as a lone criterion in selecting a code. There appears to be interference or competition among the various straight-line forms when presented in a mixed array. Discriminability and discernibility are not identical factors.

The five basic symbols selected for study differ significantly in discriminability. The circle and half-circle are located rapidly with few errors of omission or commission.

The triangle and diamond, while equally visible, require almost 50 percent more time than the curved figures and account for eight times the errors. The square gives an intermediate performance.

If these were the only symbols or modification methods available, the choice would lie between linear or outer alpha modifiers. The linear methods would probably be most promising because of their great flexibility in coding. The greatest time-saving possibility would then be realized by proper operator selection.

Unfortunately we have no clues on operator selection. Examination of the data shows no trends relative to age, education, visual acuity or interests. The two fastest subjects differed in age, education and interests and were comparable only in their great boredom with the test. The two slowest subjects were similarly ill-matched except in performance.

The subject with lowest visual acuity was consistently superior in time and error-free performance throughout this series and a number of subsequent tests. He was a young enlisted man and a college graduate in business administration. Another young enlisted man who had excellent performance in this and subsequent tests was also a business administration major. Perhaps these subjects had gained skill in working with sheets of figures. While this might be a highly selective criterion, it is not a usable selective method for radar operators, who are chosen with an eye to their technical ability to maintain the electronic components.

Operator selection methods should probably be given additional consideration in an effort to maximize performance. Scanning methods used by the best operators should also be reviewed, since training procedures provide another avenue toward improved efficiency.

While operator selection and training deserve additional investigation, proper selection of symbols presents the most promising approach to rapid and accurate identification of targets. Performance on the various forms was highly correlated, with strong differences in time and errors. These differences spread across the subject population without exception. In such a situation, an ideal choice of symbols within a set could be expected to increase the efficiency of any operator. Our efforts were directed toward this objective.

EXPERIMENT III

Symbol Meaning

Previous studies (22) in these laboratories covered 68 geometrical forms representative of symbols which might be generated on a CRT by current equipment. Symbols were drawn on individual cards. Subjects sorted the cards into friendly, hostile and unknown categories and then ranked their choices within each category. In order to avoid an absolute forced choice, a fourth category, "other," was permitted. Subjects were told that only symbols with no meaning or with a strong non-military meaning should be placed in this category. When cards were selected as "other," the subjects designated the meaning by a note.

Results indicated that all simple enclosed forms had a generally friendly meaning. Of these only the circle was ranked consistently high within that meaning. As internal linear modifiers were added to these forms, the friendly meaning weakened. As the modifiers increased, the form became increasingly hostile. External linear modifiers shifted all symbols into the unknown or into the "other" category where they were identified as either too complicated or without meaning. We strongly suspected that, in spite of instructions, the subjects had interpreted the unknown category as "I haven't the vaguest notion."

The friendly connotation of all simple enclosed forms and changes in basic meaning with addition of modifiers did not suggest that the NTDS system extension used in Experiments I and II were ideal. Difficulties in locating the triangle, square and diamond in Experiment II also indicated that these symbols lacked the definite qualities needed in a useful code.

Looking over the results of our earlier stereotyped meaning studies we were struck with the fact that four of the five symbols in Experiment I and II had friendly meanings. The half-circle, concave downward, had not been selective in the meaning test but had excelled in the simple learning experiment. Of the four friendly symbols the circle had been ranked significantly highest and had been superior in the learning experiment. In fact, the circle, square, triangle and diamond held the same positions in the simple learning study as in Experiment II. Perhaps there was a bit more meat in our earlier findings than we had realized.

The original battery of 68 symbols had been complicated by modifiers, forms differing only in orientation or connectivity and other strong deviations from simplicity. It seemed possible that the task had been too complicated for clear-cut decisions. We set about to reduce this battery to its basic form. All modified figures were deleted. Compound forms which were continuous enclosures made up of two basic symbols were reduced to a single "ice cream cone." This form had shown up well in the earlier studies and was retained in both orientations. Certain forms such as the asterisk would degrade beyond recognition on the CRT. These also were dropped.

The Saint Andrew's cross, the snow flake and the crossed ovals (or atom) would approach each other in form at reduced size. Of these, the atom was retained since it is the simplest to generate.

All straight-line enclosed forms and their parts had been duplicated by similar curved line counterparts. This confusion appeared poorly founded and the distorted forms were omitted. Eventually the battery of symbols was reduced to 23.

This reduced battery was drawn up into a format including the 253 possible pairs. Each symbol appeared first in 11 pairs and last in the remaining 11. The ordering of pairs was randomized. The material was arranged on 3 x 11-inch lined sheets and the 10 sheets were xeroxed. The forms are included in Table 8.

Subjects

The 20 subjects from Experiment I and II were given the paired-comparison meaning test. All had completed questionnaires (Appendix A) prior to testing. Subjects were tested in pairs, but they were on opposite sides of the room and seated back to back. An experimenter remained in the room during the test.

Procedure

Subjects had become familiar with the problems of the radar operator in previous instructions. They were given further information on the use of coded data in the air defense picture. Friendly, hostile and unknown meanings were explained in patterned random order to each group of subjects. After each meaning had been defined, subjects were given a set of the comparison sheets and a 3 x 5-inch card. The experimenter explained that the symbols on the forms were to be considered one line at a time. The card was to be used to follow the material rapidly by sliding it down the page one line at a time. The subject was asked to consider each pair as the only symbols available for the designated meaning. He was to circle the symbol he would prefer in that choice. Instructions followed a paired-comparison routine of emphasizing selection without prolonged thought. Selection was continuous and uninterrupted.

After completing one meaning selection the subject was given a second series of sheets containing identical material in a different order. He was told that these were the same symbols but that he was now to consider their use for a second meaning. The third meaning was treated in the same manner.

Data was then tabulated for the total number of times each symbol was circled for an individual meaning. Since there were 20 subjects, a symbol could be circled a maximum of 440 times in any meaning category.

TABLE 8

Symbology Meaning

Paired Comparisons - Totals

N = 20

		FRIEND		FOE		UNKNOWN		
		No of Choices	Rank	No of Choices	Rank	No of Choices	Rank	GRAND TOTAL
1.		241	9.5	189	16	211	15	641
2.		131	22	285	4	201	17.5	617
3.		189	17	298	2	249	5	736
4.		213	14	240	10	212	13.5	665
5.		224	12	248	7	213	12	685
6.		148	21	293	3	210	16	651
7.		242	8	178	18	219	10	639
8.		250	5	242	9	230	9	722
9.		241	9.5	184	17	294	2	719
10.		206	16	201	14	263	4	670
11.		290	2	145	22	212	13.5	647
12.		163	20	250	6	237	7.5	650
13.		243	7	175	19	237	7.5	655
14.		173	19	261	5	295	1	729
15.		357	1	66	23	130	23	553
16.		266	4	198	15	201	17.5	665
17.		121	23	306	1	216	11	643
18.		247	6	246	8	279	3	772
19.		211	15	236	12	163	21	610
20.		269	3	152	21	162	22	583
21.		237	11	166	20	243	6	646
22.		217	13	237	11	170	20	624
23.		185	18	234	13	155	19	614

Results

Results are tabulated on Table 8. The total occasions each symbol was preferred for a given meaning is recorded for each symbol. Ranking of symbols within each meaning category is also included.

The circle, oval, and square are frequently selected as friend and at the same time rank very definitely low in the unknown and hostile meanings. A rectangle with the shorter dimension vertically oriented ranks high as a friend but has low selectivity in meaning. Beyond this rank there is no clear-cut break between ranking as friend or not friend.

Within the hostile category the first two choices also rank quite high as unknown. The jet plane and the half square open at the bottom must be considered simply as not friendly. The third and fourth ranking forms in the hostile meaning are the vees, apex up and down. These symbols are highly selective for the hostile meaning. It is interesting that the triangles, which are merely completions of the vees do not follow any meaning trend.

The unknown category is again the least clearly defined. The intersecting arcs show the strongest trend as in previous studies. Tangent ellipses and the upper and lower halves of this form are quite selective for this meaning.

Discussion

The reduced test battery resulted in much more significant trends toward meaning. Symbols with strong selectivity and strong preference may give an advantage in rapid location on a mixed display.

It is also evident that within this test battery the basic trends of our earlier studies (22) continue to hold and tend to be confirmed by their repetition. They also agree basically with the "guarded" conclusions of Torre and Sanders (56):

1. Simple enclosed forms tend toward a friendly meaning. The circle ranks highest followed by the ellipse, square, and horizontal rectangle in that order.

2. Simple enclosed forms which are not highly selective in meaning include the diamond, triangle, and vertically oriented rectangle. These symbols also had a low total use in the free-drawing test and may be considered as having low salience.

3. Open angular straight-line forms are strongly associated with the hostile meaning and are apparently highly salient. Open forms which approximate a triangle are superior to complete triangles both in saliency and selectivity.

4. Complex curved-line forms, both open and closed, lean toward the unknown meaning.

EXPERIMENT IV - CONFUSION STUDIES - SECOND SERIES

The results of Series I findings suggested that the triangle and diamond are very poor symbols and the square is only slightly better. The next logical step should be locating the causes of increased time and errors with these symbols.

It seemed possible that the major problem was caused by the use of these three similar forms in a single set rather than by inadequacies of the individual symbols. On this theory, sets that do not repeat the three similar forms should clarify the findings.

It seemed logical to enlarge the current TSQ51 code, which includes a circle, 90° diamond and a "U" formed from the lower 75 percent of an octagon. These forms represented ASTs in the friendly, hosilte and unknown categories respectively. Choosing symbols for friendly and hostile TBMs was necessary to complete the code.

Some familial relationship within the friendly and hostile meanings was considered advisable for rapid interpretation of the total air-defense picture. Available forms were studied with this grouping in mind. Findings in Experiment III, the study of stereotyped meaning, were also considered.

Of all 23 basic symbols, the oval seemed an ideal choice for a friendly TBM. The large half-circle had also proved significantly non-hostile and had been found to give excellent performance in conjunction with the circle during Experiment II. The oval and large half-circle were selected to represent a friendly TBM.

The hostile TBM required a straight-line angular form to pair with the 90° diamond. Selection was further limited by the presence of the open octagon. After reviewing results in Experiment III, the "vee" or pointer was selected because of its strongly hostile meaning. Although this form approximated the triangle, it had proved significantly stronger and more hostile in the meaning experiment. A vee with a 45° angle was selected as differing most radically from the diamond. In conjunction with the half-circle, an apex-up orientation offered the best possibility. If the oval was used with the major axis vertical, the pointer would be oriented with the apex to the right. Both orientations presented the open area in an orientation differing from the "U".

There was also the possibility that providing a redundant cue such as a size difference could increase the discernibility of the circle and diamond cue. This was considered in the test design.

Series II Design

The Series II test design again presented four sets of symbols and followed the location design of Series I. Internal linear modifiers v ere included for clutter effect. The complete sets are illustrated in Figures 7 through 10.

The circle, 90^{o} diamond and the partial octagon dimensioned to 1/4-inch width and height were common to sets a and b. For the remaining symbols, set a used the enclosed upper half of a 3/8-inch diameter circle and a 1/4-inch high 45^{o} pointer with apical angle at the top. In set b these symbols were replaced by a 35^{o} ellipse with a 5/16-inch vertical major axis and the 45^{o} pointer with apical angle to the right.

Sets c and d followed the symbol forms of set a with size differences. In c the circle diameter was reduced to 3/16 inch. For d the reduced circle size was coupled with a 1.4x increase in the 90^{o} diamond to make the size difference evident.

With this design, comparison of sets a and b should reveal the relative merits of the half circle and ellipse as well as of the 90^{o} rotation of the pointer. Sets a, c and d, with increasing size ratio between the diamond and circle, should identify the advantages of size as a redundant cue in patterning symbols.

Subjects and Procedure

Subjects from Experiment I through III again participated in this series. Test procedures and fatigue ordering were identical to Series I. Since the 20 subjects had previous experience on tests of this type, a learning advantage could have been maintained over the three-week period between testing sessions.

To obtain some measure of contaminati~n of results :rom the effects of previous testing, two symbols from Series Id -- the square and triangle -- were selected for retest during the new series. To preserve a fatigue order, subjects in groups 1 and 4 were retested on the triangle before the Series II sequences and on the square after all tests of Series II were completed. Subjects in groups 3 and 4 were given the retest material in reverse order.

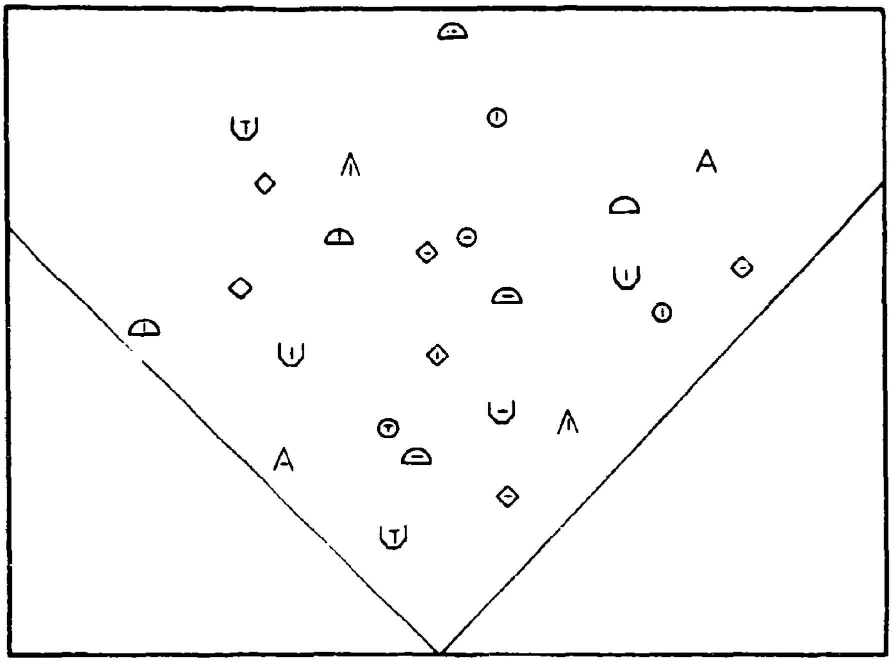

Fig. 7. SERIES IIa

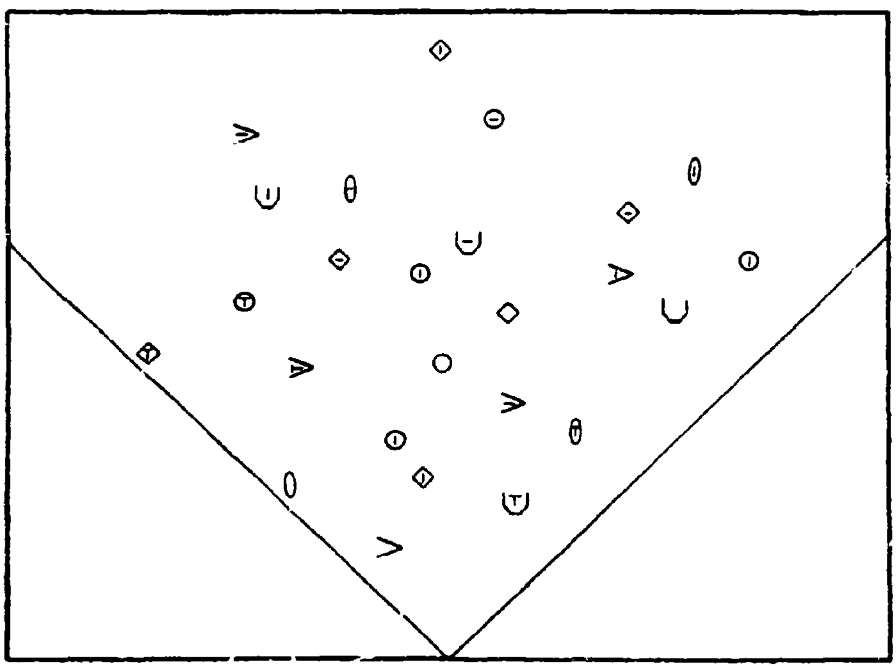

Fig. 8. SERIES IIb

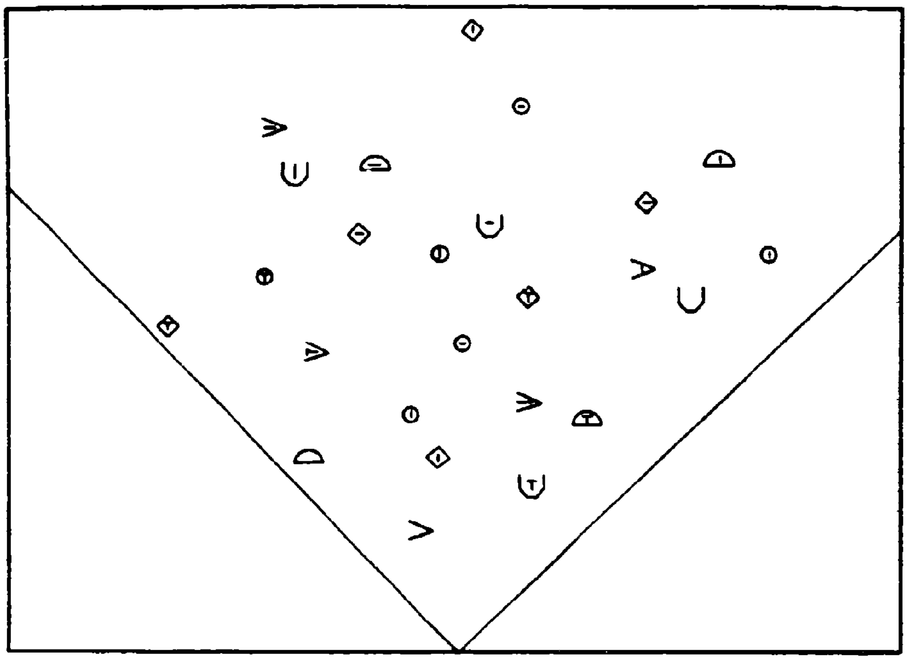

Fig. 9. SERIES IIc

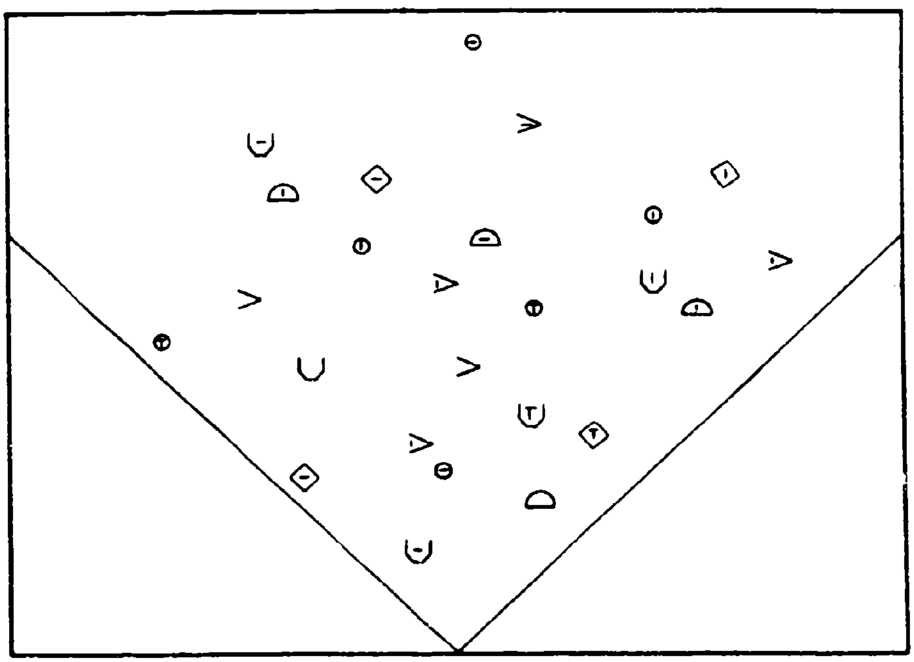

Fig. 10. SERIES IId

Results

Table 9 gives total times and errors on the elements of this test.

It is immediately evident that times have improved. Since subjects had previously been tested in Series I, experience might be suspected as a factor.

Because we were using the same subjects, we had guarded against this factor by including pre- and post-tests on two forms from Series I. There were no significant changes in either time or errors, nor did the pre- and post-tests reveal significant differences. All differences appeared to derive from the chosen symbol sets.

Times for the square in the original series give a mean of 1.047 minutes and S^2 of .0485. On the retest the mean time is .986 and S^2 = .0590. Test-retest correlation is +.714. From the correlated data formula (44), the standard error of the difference is calculated as .0399. A two-tail student's test of differences between means at the .05 level requires a $t = \frac{\bar{D}}{S_{\bar{D}}} = 2.093$. Thus, with the obtained $S_{\bar{D}}$, the difference between means would need to be .084 or greater. Since the obtained difference is only .061, we cannot reject the hypothesis that no change in performance occurred. There were 12 errors in the original test and only 8 on the retest. Hypothesizing equality, the X^2 value is less than 1.0. Since a X^2_C of 3.84 is required for P = .05, df = 1, equality cannot be rejected and no significant changes are evident on retesting.

Times for triangle in the original series average 1.1685 min, S^2 = .05851. On the retest the mean time is 1.1600 minutes and the value for S^2 = .0501. Test-retest correlation here is +.580, considerably lower than for the square but still a correlation significant at the .01 level. The standard error of the difference between means is calculated as .048. A standard error of this magnitude requires a difference between means of 0.1004 for five percent level of significance using "t" distribution as above. The obtained difference is .0085 minutes, so we cannot reject the hypothesis of no change in performance. The relatively low correlation of the test-retest in the triangle may have further implications for learning retention.

There were 22 errors on the original test and 21 on the retest. In this instance X^2_C = 0 and equality again cannot be rejected. This indicates that Series II performances which are improvements over Series I may represent an improved coding method.

Factor analysis and Newman-Keul procedures indicate that within Series II total time differences exist only between sets b and d. Set d times are significantly (.05 level) lower. Chi square statistics gives .01 significance to error differences with set d low and set b high on errors. Based on total performance, set d would be chosen over all other combinations in Series I or II.

To demonstrate the effects of changes within the sets of Series II, individual symbol classes were analyzed separately with the set design considered as the treatment variable. Analysis of variance and the Newman-Keul procedure were run on the five symbol-meaning categories.

TABLE 9

Summary of Times and Errors on Experiment IV, Series II
N = 20

		Pointer	Circle	Diamond	U	Half Circle	Ellipse	Total
Set								
a. Size constant with half circle	T	15.58	15.40	20.22	17.03	17.07		85.30
	E	3	4	16	19	10		52
b. Size constant with ellipse	T	14.58	18.13	19.90	14.22		20.87	87.70
	E	10	10	17	6		48	91
c. Circle smaller	T	15.96	15.66	20.59	16.92	16.45		85.58
	E	4	0	21	30	5		60
d. Circle smaller and diamond larger	T	15.60	12.99	19.57	17.02	16.97		82.15
	E	9	1	15	24	11		60

T = Sum of time in minutes for 20 subjects on a run or sequence
E = Errors of omission

Sets are illustrated in Figures 7 through 10.

Individual symbols follow an interesting trend. Sets a, c, and d, which used the identical form sets with the relative size varied, evidence the best time on the circle and pointer, slightly slower times on the half circle and the U, and the poorest time (significant at .01 level) on the diamond. The bulk of the errors are on the diamond and the U.

Set b, with the half circle replaced by a vertical ellipse and the pointer oriented horizontally, demonstrates an entirely different trend. The pointer and the U now give the best times and are superior to the other three forms at the .01 level. The circle and diamond are now on a par and the ellipse proves the slowest in processing. Errors are also significantly higher in this set. The ellipse is the greatest offender and the circle also shows increased errors.

The effect of total set context on an individual symbol is not significant for the pointer or diamond. In the case of the U, set b is superior at the .01 level. For the circle, set b showed the poorest time (.01 level). These findings, added to the fact that the ellipse is similarly inferior (.01 level) to the half circle present in the other sets, suggest the ellipse as the cause of both changes. This is noted for further study.

The circle time is significantly better (.01 level) in set d. In this instance reducing diameter of the circle and increasing the size of the diamond may have optimized the patterning effects. There is also a slight but not significant reduction of time on the diamond in this set.

Discussion

All sets of Series II show a time advantage over all sets of Series I. Experience is not the explanation, since items from the previous series used as pre- and post-tests show no improvement.

It would at first seem that removing the triangle created all changes, but the triangle was not truly replaced. The pointer is simply a triangle minus its base. We sharpened the angle of this pointer by reducing it from 60 to 45°. At the same time we increased the upper angle of the diamond, magnifying the difference of the angular portions. Which of these factors is responsible for the very large time and error reductions of the new symbol? The angular advantage for differentation applied also to the diamond. Here times and errors are reduced only slightly. This would seem to indicate that the open form leads to the improved performance.

On the other hand, there is a second open form, the U. Performance is rather poor on this symbol except in set b, where the half-circle was replaced with an ellipse. Since this change improves performance on the U, there is only one possible contributing factor: the base diameter on the half-circle must be patterning with the lower line of the U. This seems quite possible, since both time and errors on the half-circle have increased slightly over the same form in Series I.

The less desirable changes in set b are almost entirely related to time and errors on the circle and the ellipse. There seems little doubt here that the circle and ellipse are competing figures simply because they are both pure curved-line forms.

Considering the various interference effects, it seems probable that the best set of symbols should be as completely different as possible. This brings up a real problem. We do not seem to have five simple and entirely different symbols in our repertoire.

EXPERIMENT V

Results of the previous experiments pointed toward the need for a set of symbols with strong differences on some dimension. It appeared that the circle could be quickly patterned against a ground of straight-line forms and that it held its advantages even in the presence of an enclosed half-circle of equal height. When an ellipse was substituted for the half-circle, the circle required more time than it had with the half-circle and the ellipse required far more time than the half-circle had.

The triangle and diamond also apparently interacted. When a pointer replaced the triangle, it was an excellent symbol whether oriented on a vertical or horizontal axis. The diamond was poor in conjunction with either the triangle or pointer and thus gave evidence of being a poor symbol. One problem was evident throughout the test sessions -- subjects repeatedly described problems with triangles and illustrated by pointing to diamonds. Since all of the subjects played cards, this was an unusual situation.

The two open forms of Series II did not confuse. There was some evidence that the open octagon had interference from the enclosed half-circle since this form improved in both time and errors when the ellipse replaced the half-circle. In this case, the similarity of the two interfering forms existed only in the presence of a horizontal straight line.

To further identify dissimilarities that made a set of geometric shapes distinctive, we surveyed written comments of the subjects. In the questionnaire at the end of Series I of Experiment 2, all subjects had stated that circles and half-circles were easiest. Eighteen also complained of the triangle and diamond as confusing.

Only one subject said he had detected a patterning of the test material. He described three of the 10 symbol patterns accurately enough to prove that he had indeed recognized them. He said that circles, which were his first assigned targets, seemed to pop up and appear as a unified design upon a mixed field. He began to look for a similar effect when searching for other targets. By changing his search method, he was able to locate the half-circles as a total pattern but other symbols were seen individually. Since the patterns were identical for all symbols, apparently the "pop up" was less dramatic. This subject had diamonds for his final target. In spite of his pattern discovery earlier in the test, he took 50 percent more time for the diamond search than he had for the circle.

After Series II, this same subject said the pointer was good. He modified his search as a diagonal movement across the target material and the pointers popped up even better than the circles; however, he insisted the patterns were different for the two targets. On retest with the triangles from Series Id, he could not locate a pattern nor could he describe a better search method.

Twelve other subjects commented on their ability to locate the pointer by a diagonal search. All stated that a random search seemed easiest for the circle and half-circle. Only two of the subjects failed to mention advantages of different search methods.

Series IId also indicated some advantages in providing redundant size cues. Location times for the circle were most rapid when it was appreciably smaller than all other symbols.

The combination of results from testing and interviews suggested that three lines of thought be pursued in attempting a better series. The symbols should be as unlike as possible, they should include redundant cues, and they should permit a radar operator to see them as a pattern if he adopted an appropriate search method.

We now had three good symbols for a series. The circle and half-circle paired well for a friendly meaning. The pointer was an excellent hostile symbol and could possibly be paired with a form which would give better results than the diamond. Since none of these three forms had a vertical component, a square or plus sign offered a good choice although both forms had been related to a friendly meaning in previous experiments. The "unknown" symbol remained a problem. Intersecting arcs oriented vertically were chosen as most unlike the remainder of the series. This form had an apparent major axis in the vertical dimension and thus differed from the half-circle and horizontal pointer. It presented both horizontal and vertical open areas as opposed to plus sign with its open areas on the obliques. This symbol had also been strongly associated with the "unknown" meaning in experiment II.

The circle was further reduced in size to 5/32-inch diameter, with the half-circle held at the 3/8-inch diameter. The pointer continued at 1/4" major dimension and was oriented with apical angle to the right. The intersecting arcs were based on a 3/16-inch diameter circle to fall between the sizes of the other curvilinear forms. Looking back at this design, it seems probable that a slightly larger dimension might have been desirable.

These four symbols were common in two designs of Series III. The fifth symbol was a 1/4-inch diagonal square in set IIIa (Fig. 11) and a plus sign with 1/4-inch legs in set IIIb (Fig. 12). Alphabetic modifiers were included for the clutter-effect.

The third set of this series was a second contractor design based on a logical "lexicon." In this instance, all symbols were 1/4-inch high and were made up of straight-line segments. Pairing within the basic friendly or hostile meaning was extremely strong with circle and ellipse as friendly AST and TBM against an X and a plus sign for the two hostiles. The "unknown" was an isosceles triangle with the 45^{0} apical angle down. These were the nouns of the series. The modifiers or adjectives recommended as part of the lexicon were used for clutter in the presentation.

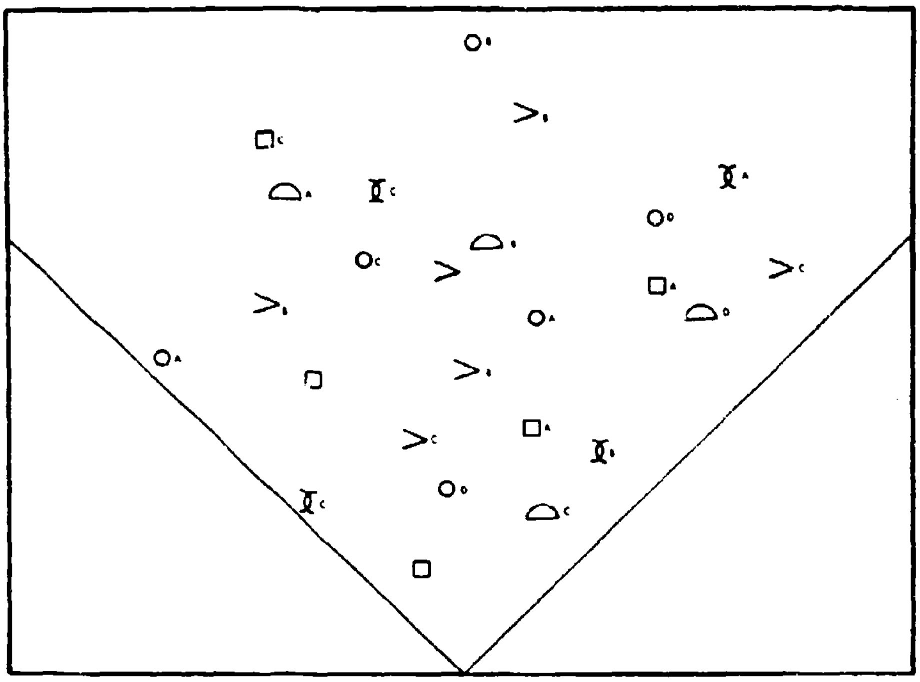

Fig. 11. SERIES IIIa

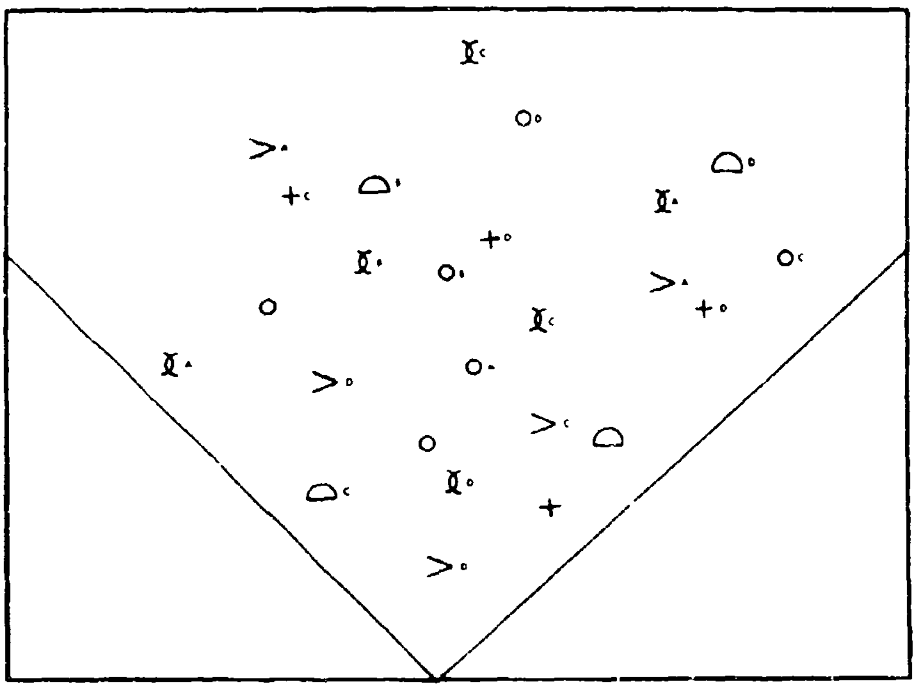

Fig. 12. SERIES IIIb

This set has been designated as Series IIIc and is illustrated in Figure 13. The segmented ellipse with its vertical major axis has a definitely pointed appearance as in the design recommended by the contractor. While this set violated all three tentative design rules derived from our earlier studies, it had the advantage of presenting a logically derived language.

Subjects and Procedure

At this point there were 10 sets of modified symbols. The unmodified Ia set was omitted. Ten new subjects matching our original group in age, education and technical background were selected for a comparative study. All subjects scored 9 or higher on the near-point tests of the Bausch & Lomb Ortho-Rater. No attempt was made to match subjects on ability. While familiarization runs were administered with symbols not included in any of the test series, there was no attempt at training to a plateau.

The sets were numbered from one to 10 and testing orders were determined using a random-number design, following a 10 x 10 matrix with no set permitted in the same row or column a second time. In accordance with this design, each set was administered one time in each of the 10 sequence positions. Testing orders were assigned randomly to the 10 subjects. Individual target presentations followed ascending and descending five-item orderly rotations. These procedures resulted in a reasonable balancing of fatigue and learning effects on a group of unmatched subjects.

Testing and scoring was identical to previous experiments. Rest periods followed alternate sets, with subjects cleaning the test books during this time.

Results

Errors and times for the 10-subject pool are summarized in Table 10. Total scores for a five-symbol set show progressive improvement with each design change growing out of a previous experiment. Sets in Series I and II follow the trends of the earlier experiments. The logical lexicon, Series IIIc, proves the least satisfactory; Series IIIa gives the best performance. The time ratio of the best to worst set is 1: 1.6 and error ratio is 1:6.

Variances follow a similar trend, with the greatest 2.285 for IIIc and the smallest .637 for IIIa. The resulting Fmax of 3.59 fails to reject homogeneity of variance. The Newman-Keuls test separates times into three classes. The HEL designs IIIa and IIIb are superior to the TSQ51 sets of Series II at the .05 level. All sets of Series I and the lexicon, IIIc, are inferior at the .01 level.

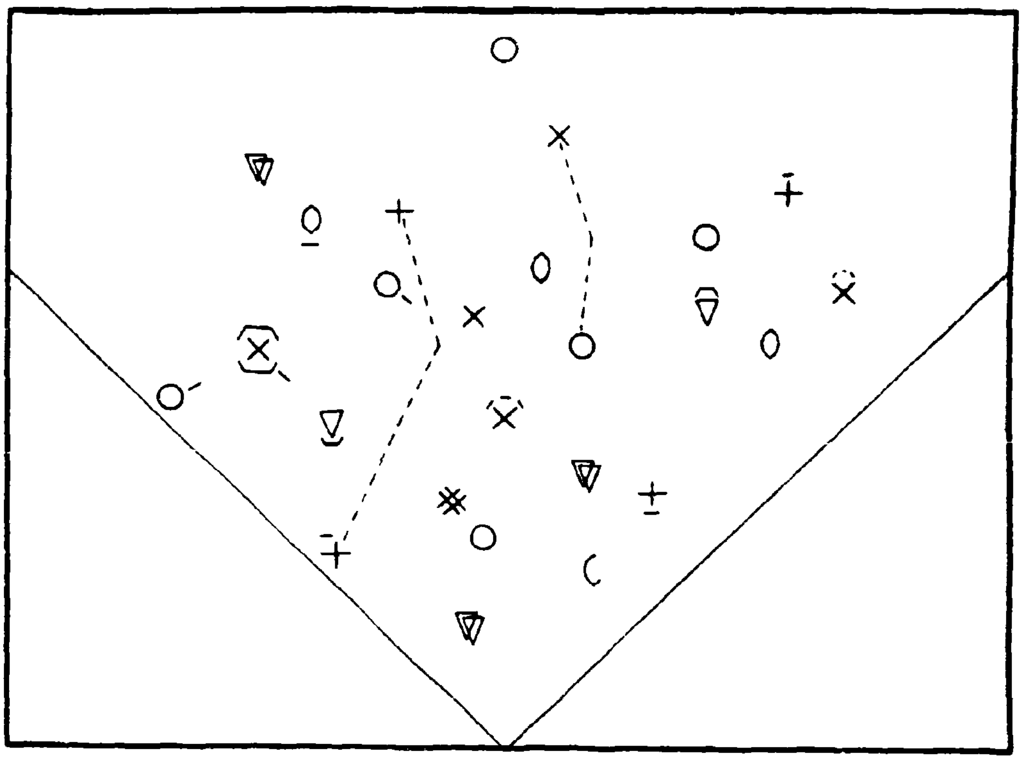

Fig. 13. SERIES IIIc

TABLE 10

Summary of Performance on Experiment V

Total Errors and Time in Minutes for 10 Subjects

	Friendly AST			Friendly TBM			Hostile AST			Hostile TBM			Unknown			Total Set	
Set	S	E	T	S	E	T	S	E	T	S	E	T	S	E	T	E	T
I b		2	9.00		2	7.87		21	12.56		15	11.92		3	11.96	43	53.31
I c		0	8.91		1	7.73		15	11.68		13	11.46		4	11.12	33	50.90
I d		0	7.54		1	7.61		17	12.27		6	11.37		2	9.92	26	48.71
II a		2	7.49		2	8.34		5	9.52		0	7.66		7	8.21	16	41.22
II b		5	8.67		15	10.13		12	9.77		2	7.18		3	6.74	37	42.49
II c		0	7.34		3	8.00		7	9.50		5	7.59		13	7.92	28	40.35
II d		0	6.11		5	8.07		5	9.55		1	7.59		8	8.26	19	39.58
III a		3	7.75		0	5.59		3	7.57		1	5.89		4	7.60	11	34.40
III b		1	7.01		0	5.57		1	8.03		3	7.17		5	8.86	10	36.64
III c		14	8.78		10	10.71		3	11.59		20	12.77		19	11.78	66	55.63

S = Symbol and modification used
E = Errors for 10 subjects
T = Total time in minutes for 10 subjects

Grouping errors into the mean time classes indicated by the Newman-Keuls procedure and weighting expected errors by the number of sets in each class, gives an X^2 of 49.28, rejecting equality at the .001 level.

The 10 forms under each recommended meaning category are next compared for effectiveness within their code complex following a simple analysis of variance design (n=10, k=10). Homogeneity of variance is tested by the F_{max} statistic ($F_{max\ .95}(10, 9) = 9.91$). Findings on this check are mentioned only when homogeneity of variance is rejected. Treatment comparison uses the Newman-Keuls procedure.

Friendly AST

The friendly AST was represented by a circle in all 10 sets. Total symbol location times for the 10 subjects varies from 6.11 minutes in IId to 9.00 minutes for Ib. The Newman-Keuls procedure reveals significant differences, clumping symbols into three classes. The first class contains only IId which is superior to symbols in the second class at the .05 level. The third class, containing IIb, IIIc, Ib, and Ic, is inferior to all others at the .01 level.

The best performance on this target occurred where the circle had the smallest relative size in the code set. Since the circle had been decreased in size, this advantage cannot be attributed to pure discernibility.

The poorest performance on the circle occurred in the presence of a square to the same size dimension or an oval. Both of these designs had been considered faulty in our earlier experiments. The interference effect between the oval and ellipse is strong enough to leave no question. The effect of the square on the circle is less definite. The square in IIIa had been made larger than the circle to counteract the suspected interference and times on the circle had improved as hypothesized. This fact might bear more weight if the linear modified circle and square of Series I had not proved superior to the same symbols with internal or external alphabetic modifiers. Casting about for an explanation of this difference we studied the test sheets for the three sets. The circles appeared much smaller on Ic. This was not an artifact. We had made an error in our drawings and the circle was smaller, providing a redundant cue.

Friendly TBM

The friendly TBM is an ellipse in IIb and IIIc and a half-circle in all other sets. Times vary from 5.57 for IIId to 10.71 for IIIc. The Newman-Keuls test again gives three classes of difficulty, with the first class superior to the second at the .05 level and the third class inferior to all others at .01.

Interference between the circle and ellipse is again apparent. The class 3, or poorest targets, are in IIb and IIIc, the two sets with this combination of symbols. These two sets also account for 25 of the 39 errors within this meaning. In IIb there is also a suggestion of interference between the diamond and ellipse.

Class 1 symbols, or the best targets, are within sets IIIa and IIIb. Apparently neither the horizontal component of the square nor the plus sign interferes with the base line of the half-circle.

The remaining, class 2, sets combine the half-circle with either the open octagon or the triangle. Of these, the open octagon results in greater changes of times and errors for the half-circle.

Hostile AST

The times for hostile AST vary from 7.57 for the square of IIIa to 12.56 for the diamond of Ib. The Newman-Keuls test again divides into three classes.

The best, class 1, symbols are the square and the plus sign within IIIa and IIIb. These are superior at the .05 level to the 90° diamonds of the four sets of Series II. The third class targets represented by Series I and IIIc are inferior to all others at the .01 level. The vertically elongated diamonds of the three sets of Series I also account for 53 of the 89 errors, suggesting interference by the triangle included in this code.

It is interesting that the square and plus sign which rank best in the hostile AST meaning and within their code complexes are poor symbols in other codes.

Hostile TBM

Hostile TBM targets range from 5.89 for Series IIIa to 12.77 for Series IIIc. F_{max} of 8.70 does not reject homogeneity of variance but does approach significance. This high variance ratio is due to the "lexicon" or Series IIIc which has three times the variance of any other set.

The Newman-Keuls test separates hostile TBM into two classes. All tests using the pointer are superior at the .01 level to the triangle of Series I tests and the plus sign of Series IIIc. Errors follow a similar trend.

If the lexicon set is removed from the analysis, F_{max} drops to 3.11 and fails to reject homogeneity of variance $F_{max\ .95}(9, 9) = 9.45$. The two class divisions remain, with the pointers superior to triangles at the .01 level. When the cases are reduced to the six sets using the pointer, set IIIa is superior to all others at the 5 percent level. This is the only set which has no other open straight-line form within its code.

"Unknown"

The "unknown" targets were represented by a square in Series I, an open octagon in Series II, intersecting arcs in Series IIIa and b, and a closed triangle (exactly equivalent to the pointer with apex down), in set IIIc. F_{max} of 7.24 does not reach a significant level. The variances are quite irregular with differences unrelated to symbol form.

The Newman-Keuls comparison of means divides this group into only two classes with some overlap. The entire pattern suggests that the data were not suitable for this procedure. "Unknown" targets are next considered within their shape categories.

The intersecting arcs of IIIa and IIIb have mean scores of .760 and .886 minutes respectively. Pearson product moment r between the two tests is +.916. The standard error of the difference between the two means, correlated data, (44) is .047 giving a t-score of 2.68. These differences are significant between .01 and .025 with the advantage for set IIIa. Since the sets differ only in the hostile AST target, any differences must be associated with this symbol. In IIIb the plus sign presents four symmetrical open areas. While these areas are rotated 45^{0} from the open sections of the intersecting arcs, there is apparently some interference within this five-symbol structure. The square of IIIa is more desirable for rapid recognition of the intersecting arcs.

Sets of Series II used an open octagon for the "unknown" symbol. Size variations between the circle and diamond were present in the series, with the circle relatively smaller progressing from a to c to d. Set b held to the size of a, but substituted an oval for the half-circle used in other sets of the series. Analysis of variance of the unknown symbols for these four sets gives an $-F_{max}$ of 2.53. (F_{max}95 (4, 9) = 6.31). Total times vary from 6.74 for set b to 8.26 for set d. The Newman-Keuls test divides into two classes with set IIb superior to others at the .05 level. This set also shows the fewest errors on the open octagon. The interference of the diameter of the half-circle is again suspect as it was in Experiment III.

All sets of Series I used a square for the unknown target. Total times vary from 9.92 for set d to 11.96 for set b. F_{max} = 2.40 and does not reject homogeneity of variance F_{max}95 (3, 9) = 5.34 . The Newman-Keuls test shows set d superior to b and c at the .05 level. This difference is attributed to the accidental reduction in circle size described above.

Discussion of Individual Symbol Study

Circle

The circle has been discussed totally as a friendly AST. Results show the circle is best when relatively smaller than other symbols. An ellipse within the code degrades performance on the circle. The presence of a square results in some degradation, but it is minimized if the square is larger than the circle. There is some evidence that the intersecting arcs of a 90° diamond of the same size also cause an interference effect.

Half-Circle

The upper half-circle with enclosing diameter proved to be an excellent symbol. Performance on this target was degraded by presence of the open octagon and possibly by the triangle. Maximum efficiency with this target was obtained in combination of the circle with half-circle diameter at least twice the diameter of circle, pointer with apex horizontal, intersecting arcs and either the square or plus sign. Within this complex the diagonal of the square should be related to the diameter of the circle in an 8:5 ratio.

Ellipse

The ellipse was used in only two sets. In both instances performance was inadequate with elongated times and increased errors. The circle in both sets was probably the major contributing factor, and there is some evidence of interference with the diamond. Since the circle appears to be an ideal target in terms of time, errors and generation by current equipment, the ellipse was not studied further.

Diamond

The diamond proved a generally poor target in terms of times and errors. It is very inferior when combined with a triangle of nearly equal apical angle. When a pointer, or open triangle of strongly different apical angle is present, performance is still far from ideal.

Pointer

The pointer, or open triangle, with about 45° angle is an ideal target in either horizontal or vertical rotation. It can be used with the circle, half-circle, 90° diamond, square, plus sign or intersecting arcs with little degradation. This symbol, like the circle and half-circle, should be considered in any code set.

The six pointers used in the various sets have been subjected to analysis of variance. F_{max} of 2.44 is not significant (F_{max} .95(6, 9) = 7.80. The times ranged from 5.89 for IIIa to 7.66 for IIa. Newman-Keuls testing gives IIIa an advantage over the remainder at .01 level of significance. There are no other significant differences. This symbol is good in both times and errors. It may be used with a circle, half-circle, 90° diamond, open octagon, plus sign or intersecting arcs. It may also be used with an ellipse if the major axes of the two symbols are 90° apart. The ideal combination within our five-symbol sets is IIIa, which includes no other open straight-line forms.

Square

The square was present in all of Series I and in IIIa. Analysis of variance shows an F_{max} of 3.83. (F_{max} 95 (3, 9) = 5.35) and fails to reject homogeneity of variance. Times vary from 7.57 for IIIa to 11.96 for Ib. Errors are low and about equal. The Newman-Keuls test gives IIIa superiority at the .01 level. Set Id is superior to other sets of Series I at the .05 level.

In the two poorest sets, the diameter of the circle and diagonal of the square held a 7:8 ratio. In Id the ratio was 6:8 and in IIIa 5:8. The size relative to the circle seems very important for the square.

Half Octagon

This symbol is discussed under "unknown" targets. Performance was best when the half-circle with enclosing diameter was omitted. Since the half-circle appears to be an ideal target, further tests were omitted. This octagonal form is also undesirable because of degradation on the CRT. Its use is not recommended.

Intersecting Arcs

The intersecting arcs are also discussed under the "unknown" target heading. It is possible that size differences would further improve this form within the recommended codes. Using it with a plus sign or X should probably be avoided. This symbol has minimal effect on the circle, half-circle, pointer and square. It is the best fifth symbol in our studies to date. Further experimentation seems advisable here.

Triangle

The triangle was used as a hostile TBM in all sets of Series I and as the "unknown" target in IIIc. Its performance was poor in both time and errors in all cases. In Series I the presence of the diamond could explain poor performance. In IIIc there is no diamond and no other linear enclosed form, but the pointed design of the segmented oval may be the interference factor. In this set the apical angle and size of the triangle were identical to the pointer which tested as superior in other sets. In IId the pointer is paired with an ellipse with no evidence of interference. In this case, the target was a true ellipse with its major axis vertical to contrast with the pointer's horizontal major axis. Similar design changes might improve the triangle in IIIc.

When the four triangles are subjected to analysis, F_{max} of 3.09 fails to reach significance ($F_{max .95}(3, 9) = 5.34$). The test times vary from 11.37 for IId to 11.92 for IIb. Differences are not significant by the Newman-Keuls test. The triangle gives little promise as a code symbol because of its generally poor times and large error components. This symbol also degrades rapidly to a blur on the CRT, where the open form degrades only in a partial filling of the apical angle. While further experimentation on the triangle might be pursued, there is little encouraging data to support new designs.

Plus Sign

The plus sign appeared in IIIb and IIIc. Total times were 8.03 for IIIb and 12.77 for IIIc. The Pearson product moment r is .680 (for 95% confidence, N=10, r=.632). The index of forecasting efficiency is .266. Comparison of the means using the correlated data formula gives a t score of 5.10 and is significant at less than the .01 level (for 9 degrees of freedom a two-tail t test requires only 3.25 for .01 significance). This correlation is lower than generally observed in our data (.80 to .93). It seems probable that some factor other than the subjects' relative speed is influencing time performance. The large number of errors on IIIc can be attributed to the presence of a highly similar form (the X) in this set. This interference factor apparently affected subjects unequally. Our data would suggest rejecting the use of these two symbols in the same code.

Summary

The circle, half-circle and 45° pointer are excellent symbols within the symbol complex used in these experiments. Relative sizes are important and should conform to the design of IIIa. The pointer may be appropriately oriented with its major axis vertical or horizontal, with the choice related to other symbols within the code.

The square is probably the best choice for a fourth symbol. It should be relatively larger than the circle, with the radius of circle and diagonal of square in a 5:8 ratio. The square will probably lose some effectiveness if combined with a diamond or triangle. The current tests did not include the square in combination with a plus sign or X. If these symbols are added to a code, they will require testing.

For the fifth symbol the intersecting arcs hold a slight advantage. It is possible that this advantage could be increased with size changes. The symbol loses some of its effectiveness in combination with a plus sign and would probably be quite unsatisfactory with an X.

The diamond and triangle should probably never be used regardless of angle difference and they should definitely not be used in the same code. These symbols have poor discriminability under the best conditions and they degrade rapidly on a CRT.

The ellipse should also be avoided, since it interacts with circles to slow processing time and increase errors in both symbols. The ellipse might be an excellent symbol in a code without the circle or diamond, but the advantages of the circle are great enough to make this choice of dubious value.

The plus sign and X should probably never be used together; however, the plus sign is satisfactory with the 45^{0} pointer. The X was not tested with the pointer.

A study of the remaining simple forms (Table 8) which may be easily generated on a CRT failed to suggest other symbols which might be expected to fit well into a discriminable code. All have features of strong similarity which could be expected to produce problems. Forms from Table 8 which might be worthy of further study are the double ellipse and its parts (#9, #10, and #13 of the table), the anchor (#18), and atom (#21). Any of these symbols might be used for the "unknown" target with the four hostile forms of either IIIa or IIIb and discriminability could probably be maintained by enlarging their size.

Our studies gave no evidence concerning advantages or disadvantages of either linear or alphanumeric modifiers. The modifiers were considered here only in terms of interaction or interference with basic forms. The potential advantages of modifier types in learning and information content should be investigated.

While the logical lexicon is the poorest in terms of time and errors, there may be advantages in its grouping into hostile and friendly meanings. This possibility is investigated in Experiment VI.

EXPERIMENT VI - GROUPING

Our experiments had been based on the theory that five basic symbols should be highly discriminable within a code complex. Using time required and errors made in locating symbols as a comparative measure within and between sets, we had formulated a few tentative rules for designing a discriminable code. Applying these rules in the two HEL designs reduced time and errors. The best HEL design proved highly superior to the logical lexicon.

While the lexicon gave the poorest test performance, this set had been designed on the theory that a strong familial resemblance was desirable within the friendly and hostile meanings. Dr. Hugh Bowen, who designed this code, felt that the basic information was "friend," "foe," or "unknown." He stated that a hostile plane or missile presented a threat and that the type of threat was secondary information.

HEL codes had been designed on the theory that five categories needed to be differentiated. We had considered a missile, whethe friendly or hostile, as the most important information on the display. Missiles move more rapidly. Decisions on their deployment, threat, vulnerability and destruction must be made quickly. The fact that TBM targets appear at infrequent intervals and small densities also pointed to the need for using the most salient symbols for these categories. Familial forms were included as a learning and retention aid, within the friendly and hostile meanings. Familial resemblance was descriptive rather than perceptive, since all five categories were important.

The difference in the doctrine behind the two designs represented two entirely different conceptions of the radar operator's task. Since we really know very little about the eventual use of information on the PPI, it seemed advisable to run additional tests within the grouped-meaning concept.

The codes representing the two extremes on performance were selected for this study. The best HEL design, IIIa represented a code with a good figure-ground reversal on all symbols. While no meanings had been assigned in previous testing, the anticipated use included a weak familial resemblance. The circle and half-circle were to represent the friendly AST and TBM respectively. Their counterparts within the hostile meaning were straight line forms, the square and pointer. The unknown target, intersecting arcs, consisted of two half-circles and might be considered as fairly closely related to the friendly symbols.

The lexicon, IIIc had been designed with closed straight-line approximations of curved forms as friend, crossing straight lines as hostile and an enclosed straight-line form for unknown. These groupings were logical and could be easily explained. Experiment VI was designed to compare the two information doctrines using the symbol sets representing the extremes of our code batteries. Since learning advantages could mask performance trends, naive subjects were selected for this study.

Subjects

Subjects were casual troops awaiting assignment. The age range was 19 to 23. Since none of these men had ever participated in an experiment, they were moderately apprehensive. Their education and technical background was representative of the average raw recruit. Skills were probably below the level required for radar operators. While acuity was not measured, all subjects had passed a visual acuity test on entry physical within the previous two months. Distance acuity scores of at least 20/30 are thus assured.

Subjects were generally interested in the experiment and quite cooperative. One individual was eliminated early in the test sequence because of wandering attention. Ten subjects participated in the total experiment.

Procedure

Subjects were given a short description of the radar operator's task. Trial runs on two randomly selected test sheets oriented them to the test material, but there was no attempt to bring them to a performance plateau. Instructions were to locate and mark targets as rapidly and accurately as possible. There was no additional attempt at establishing time or error "sets."

Testing covered two individual tasks. The first procedure was identical to Experiment V and required location of individual targets in the two sets. A rest period followed completion of these test runs. In the second procedure subjects were asked to locate a "family" of symbols. This was the only experiment with meanings assigned to the symbols.

Subjects were numbered consecutively as tested. Fatigue orders presented IIIa first for subjects 1 through 5 and IIIc first for subjects 6 through 10. The two individual symbol runs were presented prior to the "familial" runs in all instances. Symbol presentation continued in orderly rotation from subject to subject.

Scoring on times and errors followed the original design.

Results

These subjects were slower, less accurate and more variable in performance than the groups who had been trained to a plateau. Performance trends confirm earlier findings but symbol and code difference are less exaggerated.

Total times for location of individual symbols are 43.18 minutes for IIIa and 57.22 for IIIc (contrasted with 34.40 against 55.63 in Experiment V). Subjects again tend to hold relative speeds fairly constantly during the test session. Total time on IIIa versus IIIc correlate at $r = +.912$. Differences in total time on the two series remain significant ($P < .01$) with the t ratio (correlated data) = 11.70.

Series IIIa has 29 errors against 79 in IIIc (contrasted with 10 and 66 in Experiment V). Differences give an X^2 of 8.13, representing significance at $P < .01$.

The Newman-Keuls procedure divide the symbols of IIIa into two groups differing at the .05 level. The two TBM symbols, pointer and half-circle remain superior to the circle, square and intersecting arcs. The total time increase of 8.78 minutes (10 subjects, 5 runs) over the earlier group is almost evenly divided between the five symbols. While errors are 2.64 times greater than found in Experiment V, distribution among symbols follow the trend of the earlier study.

Performance on IIIc matches the earlier experiment more closely with 1.59 minutes total increase in time and 1.2 times the errors of experiment V. In this instance, changes are less regular. The triangle shows improved accuracy coupled with a time increase, the X has seven times the errors of the earlier test with times also elongated. The three remaining symbols closely approximate results of Experiment V. The Newman-Keuls procedure separates the symbols into three classes with the circle and ellipse most desirable, the X and plus signs poorest and the triangle intermediate.

All findings tend to lend weight to Experiment V results. Subjects are generally proportionately rapid or slow, accurate or inaccurate.

Grouping of symbols in the second task is superior on IIIc. The circle and ellipse of this set require a total subject time of 11.34 minutes with only two errors while the circle and half-circle of IIIa had a total time of 13.13 minutes with six errors. Correlation approaches zero at +.014. Time differences are significant at the .05 level.

Hostile symbols follow the same trend. The plus sign and X of IIIc require 12.33 minutes with 12 errors as compared with 14.65 minutes and 22 errors on IIIa. The -.296 correlation does not approach significance. Time differences are again significant at the .05 level.

Familial likenesses are greater in IIIc and these symbols do result in good performance when friendlies or hostiles are grouped. However, the entire test battery must also include an unknown target. When grouped hostile, grouped friendly and single unknown targets are combined, IIIc has a total time of 34.37 minutes and 22 errors as compared with 36.99 minutes and 22 errors on IIIa. Correlation of total subject times approaches zero at +.056. While the lexicon series shows a slight time advantage, differences in times and errors are well below the .05 level of significance.

Discussion

The set designed on logical and familial association of forms is unquestionably poor when the five categories are to be identified. Only the Series I targets are not significantly superior in time or errors.

Sets IIIa and IIIb designed on cues from earlier test series are consistently superior with times and errors significantly below all other codes tested.

When the best and poorest sets were repeated with a naive subject group, the lexicon again proved less satisfactory. Differences are smaller but retain significance at the .01 level.

The lexicon had been designed on the theory that groupings within the friendly-hostile dimension should be permissible. For this reason the naive subject group was retested on the two sets with their task oriented toward the lexicon doctrine. In this case meanings were assigned to the symbols and only friendly, hostile and unknown test runs were made.

The lexicon shows dramatic improvement under these conditions. Grouped hostile and friendly symbols are now superior to the best HEL series. When the unknown target, which completed the five symbol code, is considered a part of the total performance, the two sets are essentially equal.

If we are correct in our assumption that each of the five target classes must be identified rapidly and accurately, the two HEL designs are the best codes tested to date. If the real problem is simply sorting into three classes, the lexicon is equally satisfactory and future studies should lean toward advantages in learning the "objectives" of the two codes.

It is difficult to justify a five-symbol code for three target categories. If this doctrine is correct, the possible advantages of reducing to three symbols must be considered.

EXPERIMENT VII - MEANING WITHIN CODE CONTEXT

We had found that the discriminability of a symbol was strongly affected by the presence of other forms in the same code. It seemed reasonable to suspect that any meaning associated with a form might also vary with the total code context. Since test materials and subjects were available, we designed a simple intra-set meaning experiment.

Procedure

Confusion test sheets presented the various forms of a set in a realistic distribution and were ideally suited for a study of symbol meaning with a code complex. While 10 different code sets were used in our experiments, there were only six basic form sets. One of these sheets was randomly selected for each of the six form codes.

Experimental packets consist of a cell matrix response form and copies of the six code displays. Target categories were listed across the top, grouped as in the heading of Table 11. Code sets were identified along the left side of the matrix.

Subjects

Two of the Human Engineering classes at these laboratories participated in this experiment, providing 37 subjects. Fifteen of our original subjects were also used. Following a lecture on the problems of coding information for an air-defense display, these groups were asked to help us identify the best choice of meaning for symbols of six proposed codes.

The experimenter gave each subject an experimental packet and explained the basic design of each code set. He emphasized that the sheets demonstrated only the general appearance of the coding alphabets and that target position should not be considered as a threat evaluation. He then asked the subjects to study the displays and sketch their recommended coding symbols in the cells of the matrix.

This procedure was completed rapidly with only a few questions. Subjects were then asked to indicate the code that seemed most suitable.

The experiment sparked considerable interest and a rather spirited discussion. There was general agreement on the fact that friendly and hostile categories each called for symbols that paired easily. This meant that the unknown meaning was assigned to the "odd-ball" symbol within each set.

Results are tabulated in Table 11.

TABLE 11

Intra-Set Meaning Survey
N=52

		FRIENDLY		HOSTILE		UNKNOWN
		AST	TBM	AST	TBM	
SERIES I	○	30 **	6	7	4	5
	⌓	6	23 **	8	7	8
	◇	3	6	12	25 **	6
	Δ	8	10	16	12	6
	□	5	7	9	4	27 **
SERIES II a, c, d	○	34 **	4	4	3	7
	⌓	5	28 **	10	6	3
	◇	3	6	21 **	13	9
	Λ	6	6	12	23 **	3
	∪	4	6	5	7	30 **
SERIES II b	○	33 **	4	7	1	7
	⬯	5	32 **	4	6	5
	◇	3	6	19 **	16	8
	>	7	6	17 *	20 **	2
	∪	4	4	5	9	30 **
SERIES III a	○	32 **	3	5	5	7
	⌓	3	24 **	12	10	3
	□	8	6	15	11	12
	>	6	12	14	19 **	1
	⧖	3	7	6	7	29 **
SERIES III b	○	30 **	8	6	2	6
	⌓	4	25 **	10	12	1
	+	10	5	17 *	9	11
	>	5	9	13	23 **	2
	⧖	3	5	6	6	32 **
SERIES III c	○	29 **	2	7	3	11
	⬯	5	27 **	3	11	6
	X	2	8	11	14	17 *
	+	11	7	17 *	9	8
	∇	5	8	14	15	10

* 05 significance level
** 01 significance level

Results

With 52 subjects and five meanings, a chance distribution of choices would call for 52/5 or 10.4 assigned to each meaning category. This would reduce to 10.4 within a single category versus 41.6 outside that category. This one degree of freedom design for a chi square test of significance reduces to:

$$\frac{d_1^2}{10.4} + \frac{d_2^2}{41.6} = X^2$$

where d_1 = assignments within category - 10.4
d_2 = assignments in other categories - 41.6
and $d_1 = d_2$

With one degree of freedom (one-tail test) $X^2 = 5.0$ is significant at $P = .05$; $X^2 = 8.1$ is significant at $P = .01$. Substituting these values in the above equation we find that the .05 level is reached with 16.8 assignments and the .01 level requires 18.6 choices. On Table 11 selection at these levels have been indicated as * and ** following normal conventions.

Selections for the two friendly categories are clear-cut and follow our suggested meanings. There is a similar trend in selection for the unknown target in all except set IIIc.

Hostile targets as a class are less meaningful to our subjects. The diamond and pointer have a strongly hostile meaning in all uses. Choice of the pointer as a hostile missile is significant. The diamond is more strongly hostile than either the square or plus sign of the HEL designs. The lexicon is not strongly meaningful outside the friendly meanings.

In choosing the best symbol code, three subjects had no preference. Choices were divided as follows: nine subjects preferred Series I, three chose Series II symbols with the half-circle, four chose Series II with the ellipse. The two HEL designs drew 27 votes, with 15 for the set with a square and 12 for the plus-sign grouping. Six choices went to the logical lexicon.

Tests of significance on this population would be doubtful validity, since there is no logical reason for grouping the small populations. Preference trends lean in the direction of the HEL designs.

Discussion

This experiment lends further weight to our earlier experiments on symbol meaning. It also points up the fact that we have been quite successful in selecting friendly forms. Hostile symbols need further study for ideal selection.

CONCLUSIONS AND RECOMMENDATIONS

Coding methods for radar displays are aimed at enhancing information. Any code which does not provide an advantage in time and accuracy is an inadequate substitute for raw radar returns. Our studies have been aimed at defining the factors necessary for designing a symbolic code which improves the rapid and accurate assimilation of available information.

The current studies at HEL have been directed at recognition of symbols in a mixed display, representative of an air-defense picture. Our findings lead to fairly strong conclusions:

1. Discernibility, or pure visibility, of forms, is not an adequate measure for selecting symbols to code mixed information. Two or more highly discernible forms may interact with resultant poor discriminability.

2. Any experimental method which presents symbols individually cannot demonstrate interaction between symbols. Sorting techniques are not suitable for code selection.

3. Experiments using black-on-white drawings representative of a coded, five-dimensional PPI display suggest the following tentative rules for code design:

a. Symbols should differ strongly in shape. Variations of a single form family such as the circle and ellipse are not desirable.

b. Redundant cues such as size difference may be advantageous.

c. Characteristics which are enhanced by a unique search method add to the saliency of an individual symbol in a code complex.

d. If several basic symbols are to be grouped within a major classification, a familial resemblance may be desirable. Absolute discrimination of these basic forms requires that the resemblance be descriptive rather than perceptive. If absolute discrimination is not required, a single symbol should be adequate.

f. The most satisfactory five-dimension code in the current studies

(Series IIIa) results in an average locating time of 0.80 seconds combined with an average error rate of 0.44 percent. The poorest code (Series IIIc) requires an average average locating time of 1.34 seconds with 2.64 percent errors. This advantage reduces time to 59 percent and errors to 16 percent.

4. Further experiments using actual CRT displays are recommended before final standardization of radar symbols. A variety of phosphors and ambient illumination levels should be included.

5. Learning studies should be conducted to select ideal methods for increasing the informational value of the basic codes. Modifiers added to the basic symbols could confuse the total picture. A trade-off between the advantages of total information in a single symbolic unit and clean symbols with auxiliary read-outs for additional information must be considered.

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APPENDIX A

Questionnaire Following Series I

You have just completed a test which represents some of the problems a radar operator may have if he is given display information in symbolic coding. Each shape represents an individual target class and the various modifiers could offer additional information such as speed or priority.

Since the operator will be working rapidly with a large amount of information, the codes must be kept simple to remain useful. We would appreciate your help in defining problems. Please answer the following questions, explaining your reasoning. We would also appreciate any comments that come to your mind.

1. Did you find this test difficult? ______________ Why? ______________

____

2. Which of the four sets seemed easiest? ______________________

   Which did you find most difficult? ______________________

3. Did you notice any patterning of targets? ____________ Did you try to find a pattern as you searched? ______________________

4. Which shapes were easiest to locate? ______________________

5. Were any shapes especially difficult? ______________________

6. Can you suggest changes that would make a task of this type easier? _____

____

____

7. Do you think of anything that might make location of targets excessively difficult? ______________________

____

PLEASE ADD FURTHER SUGGESTIONS OR COMMENTS.

APPENDIX B

TABLE 1B

Statistical Pattern for Time Analysis

Series Ib, N=20, k=5

Analyses of Variance

Source of Variation	Sum of Squares		Degrees of Freedom		Mean Square	F
Between People		4.2618		19		
Within People		4.4233		80		
Shape	3.4485		4		.86213	67.20**
Residual	0.9748		76		.01283	
Total		8.6851		99		

** $F_{.99}(4, 76) = 2.19$

Newman-Keuls Test of Differences

Shape		Half Circle	Circle	Square	Triangle	Diamond
	Totals	16.67	19.06	24.63	24.87	26.14
Half Circle	16.67	-	2.39**	7.96**	8.20**	9.47**
Circle	19.06		-	5.57**	5.81**	7.08**
Square	24.63			-	0.24	1.51
Triangle	24.87				-	1.27
Diamond	26.14					-
*$q_{.95}$(r, 76) N M S resid.			1.43	1.72	1.89	2.01
**q .99(r, 76) N M S resid.			1.90	2.16	2.32	2.43

$F_{max} = \frac{.0697}{.0472} = 1.48$ [F_{max} .95(5, 19) = 3.71]

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13. ABSTRACT

This report covers continued studies toward standardization coding symbols for an information display. Experiments were directed toward locating "the most readily discriminated five-symbol code complex" as measured by errors and location times.

Experiment I attempted to simplify testing procedures by using a card sorting task. The same five-symbol code was presented as a black-on-white simulated display in Experiment II. Results were not comparable and the simulated display was used in further experiments with a variety of codes.

Legibility and association values of individual forms varied with the population of shapes within the code complex. Experimental results led to general recommendations for code design. Further studies are anticipated.

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