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PERCEPTUAL DISCRIMINABILITY AS A BASIS FOR SELECTING MILITARY SYMBOLS

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FOREWORD

At present, the Army has a standard symbol set (FM 21-30) for use in portraying critical information on graphic battlefield displays. Because this symbology does not include all concepts that are required and some alternative symbols would be better to use than others, there is currently a need for guidance in both future symbology development and for modification of the existing symbol set. The goal of this research was to develop human-factors criteria for choosing among alternative symbols for use in tactical displays. The specific criterion developed was an index of the perceptual discriminability of alternative candidate symbols from symbols already included in the FM 21-30 symbol domain. The relationship between similarity ratings and symbol descriptors was studied using a multiple-regression procedure, where the similarity ratings constituted the variable to be predicted and the symbol descriptors constituted the predictors. This procedure was carried out separately for each of two sets of descriptors (primitive attributes and configural attributes) to determine which type of attributes best predicts the inter-symbol similarity ratings. An equation from the results was developed that would enable a symbol designer to derive an estimated "discriminability-index" for any given candidate symbol to be included into the symbol domain.

From the regression analyses of the inter-symbol similarity-rating matrix, it was concluded that symbols are judged more or less similar on the basis of the number of shared versus unique configural attributes (an "X," a triangle), as opposed to primitive attributes (no. of lines, 90° angles, etc.). About 70% of the variance in the similarity ratings could be accounted for on the basis of the configural attributes, whereas only about 25% of the variance could be explained on the basis of the primitive attributes. In addition, an easy-to-use discriminability-index formula was derived from the regression analysis involving the configural attributes. This formula was used to predict the results of an experiment involving the search for specific symbols embedded in an array of the 20 sample symbols. The predictions were confirmed, lending validity to the index equation.

It is suggested that indices obtained from a formula such as the simple one developed here could be used as part of the basis for choosing among alternative candidate symbols for inclusion in the FM 21-30 domain. Of course, other factors must be considered such as the degree of association of the symbol with the concept to be portrayed.

CONTENTS

INTRODUCTION

At the present, the Army has a standard symbol set (FM 21-30) for use in portraying critical information on graphic battlefield displays. It has become apparent that this symbology does not include all concepts that are required, ~~(Landee, Samet, & Gellman, 1980);~~ and of course, there may be some alternative symbols that would be better to use. Thus, there is currently a need for guidance in both future symbology development and for modification of the existing symbol set.

A major goal of this research is to provide human-factors based criteria as a basis for selecting among candidate symbols for inclusion in an existing symbology data base (the Army's conventional symbols, FM 21-30). In choosing a candidate symbol to represent a particular military concept, at least two factors must be considered: (1) the meaningfulness of the symbol, i.e., how well does the symbol portray its referent; and (2) the discriminability of the symbol, as reflected in the speed and accuracy of detecting and/or identifying the form, in relation to the existing symbol domain. It is not within the scope of this research to study symbol meaningfulness. Symbol discrimination is not the only basic perceptual/cognitive task that is a primitive of the more complex military tasks involved in graphic display usage. Logically, it is a precursor to several other behavioral-task primitives, such as search, comparison, and multiple-symbol pattern recognition. It should therefore be given primary emphasis in a research effort, as suggested by Williams and Teichner (1979).

The discriminability of a given symbol in isolation can be hypothesized from a limited amount of literature which addresses the psychophysics of form perception, and also from somewhat controversial Gestalt principles. A brief overview of this literature and theory is presented below. Unfortunately, the discriminability of a military symbol within the FM 21-30 domain cannot be evaluated at present from existing literature, and therefore, this document includes a description of an empirical study designed to assess the discriminability of candidate symbols relative to symbols currently in use in FM 21-30.

A good first-order approximation to the psychological complexity of a symbol is the total number of discrete parts that a figure contains (Attneave & Arnoult, 1966). For example, Attneave (1957) reported that 80% of the variance in the ratings of complexity of forms examined in isolation could be explained by the number of angles or curves in the form contour (e.g., number of symbol elements). Thus, one obvious criterion for symbol selection is symbol <u>simplicity</u> (number of elements).

In addition, a number of criteria for symbol selection can be suggested from the Gestalt laws of figural "goodness." Easterby (1970) has suggested such criteria for symbol selection. First, a symbol is hypothesized to be more perceptible if the figure-to-ground relationship is made clear. This can be accomplished by (a) avoiding the use of line forms in symbol construction that are used as standard terrain indicators, and (b) using solid forms whenever possible. Empirical support for the latter suggestion has been provided by Yoeli and Loon (1972), but there could be a discrimination problem created in using overlapping forms of this type.

Another criterion for symbol selection is figural unity. Although the placement of boxes, and other general forms, around basic unit symbols in conventional Army symbology has been criticized as *providing redundant* information that contributes to symbol confusability and display clutter, such outlines may serve a useful purpose in defining the symbol as a physical whole. The placement of additional information outside the basic symbol boundary could violate the principle of figural unity, however, since such information could conceivably blur the boundary, especially when symbols appear close together. Although no single general form (e.g., circle, rectangle, triangle) has been shown to be inherently most discriminable (see Hemingway, Kubala, & Chastain, 1978, pp.2-4 to 2-8 for a review), Casperson (1950) has demonstrated that the manipulation of certain attributes of each general form could enhance discriminability. For triangles and circles, the best measure of symbol discriminability is the area; for rectangles and diamonds, the best measure is the length of the longest dimension; for stars and crosses, the best dimension is the perimeter.

Other relevant Gestalt principles include closure of lines (i.e., open forms should be avoided, such as the conventional symbols for engineer units (horizontal E) in FM 21-30), and continuity of lines (i.e., interrupted lines should be avoided, such as the conventional symbol for signal group (lightning bolt) in FM 21-30). With respect to these principles, complete figures have been shown to be more discriminable than incomplete figures (Dardano & Donley, 1958); and arcs have been shown to be more easily perceived than a series of connected straight lines (Gaito, 1959).

It should be noted that suggested principles of perceptibility alone cannot dictate symbol selection; and that certain symbols, such as the lightning symbol for signal group, could have a degree of meaningfulness that more than offsets the violation of the Gestalt laws. When the principle of continuity is violated, the issue can be raised as to the discriminability of the specific kind of angles used. In this regard, Taylor (1963) has shown that visual acuity is best for straight lines that are oriented horizontally and vertically; and the bulk of empirical evidence suggests that 90° angles have lower thresholds for detection than do oblique angles. These findings complement Attneave's (1955) discovery that the symbols that are most likely to be remembered are symmetrical around the spatial axes of the horizontal and the vertical. Thus, the symmetry of a form is one final Gestalt principle of figural "goodness" that could be adopted as a criterion for symbol selection.

In summary, to insure optimal symbol discriminability, the following criteria could be applied to symbols to resolve symbol conflicts:

(1) Simplicity - a minimum number of symbol elements is desirable, consistent with the following principles.

(2) Figure-to-ground relationship - forms clearly identifiable from background (i.e., terrain and other symbols) are desirable.

(3) Figural unity - a clearly defined perimeter with few elements external to the basic symbol shape is desirable.

(4) Closure - a minimum of open elements is desirable.

(5) Continuity - a minimum of disrupted lines is desirable.

(6) Symmetry - symmetry of form about the vertical and horizontal axes is desirable: right angles are more desirable than oblique angles.

The selection of one candidate symbol over another cannot be carried out optimally without a careful accounting of the symbol domain in which the candidate symbol is to be used (Easterby, 1970). Identifying the symbol attributes that are most influential in affecting inter-symbol discriminability seems basic to any reasonable effort to resolve symbol conflicts. It is proposed here that consideration can be given to the

FM 21-30 symbol domain in assessing the potential discriminability of candidate symbols, and that the standards for accomplishing this can be determined empirically using the methodology outlined below.

METHOD

The methodology used here is based on the following assumptions:

(1) The more similar a new symbol is perceived to be to existing symbols, the less discriminable the new symbol will be. An assumption is made that these symbols are discrete forms in current use, not artificially constructed images.

(2) Knowing the attributes by which people judge the similarity of existing symbols will allow symbol designers to generate new symbols using other attributes, resulting in highly discriminable symbols. These attributes are assumed to be "generic" or "primitive" forms within symbols.

Thus, the approach was to:

(1) Assess the perceived similarity among a sample of symbols.

(2) Determine which symbol attributes lead to the perceived similarity among symbols.

(3) Construct and validate a formula for quantifying a symbol's perceived discriminability.

The approach was implemented using the following five-step procedure. First, the symbol domain was defined (FM 21-30), and a representative sample of 20 symbols from the domain was selected for use in the empirical investigation outlined below. The symbols were selected to provide a wide variety of symbol configurations. Perhaps a more comprehensive, yet more costly approach would have been to choose a large set of symbols for study on the basis of their frequency of occurrence across various symbologies and tactical situations. Since this was an exploratory, prototypical study, this comprehensive approach was not taken.

Second, each symbol in the symbol set was defined in terms of primitive symbol attributes, such as number of lines, arcs, 90° angles, etc., and also in terms of configural symbol properties, such as an "X" or an "oval." It is possible that a symbol viewed as a unit cannot be adequately described by its primitive parts, such as the number of straight lines. Therefore, examination of higher-order symbol parts, such as an "X" or an "oval" might prove more useful in accounting for performance data. These primitive elements have been used in a previous study and although somewhat arbitrary, provide a useful starting point to determine the relationship between structural elements and performance.

The third step was to determine which symbol attributes predict the inter-symbol perceived similarity. This was accomplished with a step-wise multiple-regression procedure, where the similarity ratings constituted the variable to be predicted and the symbol descriptors constituted the predictors (frequency of attribute occurrence). This procedure was carried out separately for each of the two sets of descriptors (the primitive attributes and the configural attributes) to determine which type of attributes predicts the inter-symbol similarity ratings best. The two types of descriptors could not be combined for analysis since (a) they represent two different levels of abstraction, and (b) the primitive elements involve a precise measurement of each primitive symbol attribute (e.g., counting the number of lines, etc.) whereas configural elements simply involve presence or absence (1 or 0).

The fourth step was to develop an equation from the results that would enable a symbol designer to derive an estimated "discriminability-index" (quantitative estimate of the inherent detectability of a given symbol from the specified domain) for any given candidate symbol to be included into the symbol domain. This equation, which would provide an objective criterion for symbol selection that is easy to apply, takes the following form:

$$D_c = \sum_{i=1}^{i=k} (W_i \cdot n_i - \overline{n}_i)$$

Where D_c is the discriminability index for the candidate symbol, W_i is the standardized regression weight in the symbol domain for the i^{th} attribute, and $\overline{n}_i$ is the average numerical value in the symbol domain on the i^{th} attribute. Thus, D_c provides an index of how dissimilar the candidate symbol is from the "typical" symbol in the existing symbology. The fifth and final step was to validate the derived discriminability-index formula in terms of human-performance data. To reiterate, the purpose of this initial effort was to explore the efficacy of this type of statistic and to apply it to human performance.

Participants. The participants were 24 undergraduate volunteers from the introductory psychology course at the University of California at Los Angeles. The subjects participated in groups of size two to six.

Materials. A representative sample of 20 symbols from the conventional Army symbology (FM 21-30) was selected for use in this investigation. It was decided that symbol elements external to the basic symbol shape would not be considered in this study, since to do so would require an unmanageable number of sample symbols. The symbols were chosen from three military categories: combat, combat support, and combat service support. An effort was made to include a wide variety of symbol characteristics. The 20 symbols used here are presented in Appendix A along with a description of the primitive attributes of each symbol. A second set of symbol attributes was constructed based upon configural properties of the symbols, and this set is presented in Appendix B. This set is different from that shown in Appendix A in that attention is given to how the primitive symbol attributes tend to form more complex configurations.

Procedure. Each participant was given a booklet containing instructions for the similarity-judgment task and 190 pages of symbol pairs representing all pairwise comparisons among the 20 symbols studied. The subject's task for each pair of symbols was to rate the similarity of the pair on a scale of one to five. The order in which the pairs appeared was randomized across subjects; and the average time taken to complete the task was 35 minutes. The instructions and a sample rating sheet are provided in Appendix C.

RESULTS AND DISCUSSION

In this section, the results of the two separate regression analyses outlined above are presented where the intersymbol similarity ratings are to be predicted from a comparison of primitive symbol attributes (number of lines, number of 90° angles, etc.) among symbols and from a comparison of configural symbol attributes (an "x", an oval, etc.) among symbols. Each analysis was carried out to determine how well each type of attribute set accounts for the similarity ratings (the percent of variance accounted for), and to derive a discriminability-index formula. Following the discussion of these analyses, an experiment is described that evaluated the validity of the index formula adopted.

Primitive Symbol Attributes

For this analysis, the log average similarity rating for each of the 190 pairwise comparisons of the 20 symbols was used as the criterion in a step-wise multiple-regression procedure. The log transformation was applied to this variable because its distribution was skewed and leptokurtic. The nine predictors of the similarity ratings were absolute difference scores obtained by subtracting the nine pairs of values in the attribute set (see Appendix A) for each pair of symbols. Thus, the rationale was that any two symbols given a high average similarity rating would have similar values on the attributes in the attribute set (i.e., small absolute difference scores). As an example, the log average similarity rating for the first two symbols listed in Appendix A was to be predicted by the following nine difference scores: 0, 4, 1, 0, 20, 8, 2, 0, 0.

The results of the step-wise multiple-regression procedure showed that absolute difference scores on a combination of four symbol attributes provided a significant prediction of the similarity ratings. These four attributes, in the order of their entry into the multiple-regression equation, are: (1) number of lines in the external symbol shape, (2) number of straight lines in the internal symbol shape, (3) number of alphanumeric elements, and (4) number of arcs. Difference scores on no other attributes, when added to the equation, significantly increased the percent of variance accounted for (p > .05) in the similarity ratings. Thus, the remaining attributes in the original attribute set were excluded from further consideration in this analysis.

Although the predictive power of the above four variables was significant, $F(4,185) = 14.55$, $p < .001$, the difference scores on these attributes accounted for only 25% of the variance. However, a discriminability-index formula can be derived from the initial analysis in a straightforward manner as follows.

It is desirable that values on the four symbol attributes identified above be different for a candidate symbol than for the average symbol in the existing symbol set. To the extent that these values are different from a candidate symbol compared against the sample of 20 symbols used here, that symbol can be expected to be discriminable from the existing symbol set. In this manner, the expected discriminability of one candidate symbol can be indexed and compared to that of another, and decisions regarding symbol conflicts can be made on the basis of the comparison. An estimate of the relative importance of each of the four symbol attributes to the overall discriminability of a symbol is provided by the absolute values of the standardized regression weights from the multiple-regression procedure discussed above. Using these weights, an equation for computing a discriminability index for a candidate symbol c is as follows:

$$D_{\underline{c}} = .37(|\text{No. lines in external shape of } \underline{c} - 3.75|) + .21(|\text{No. straight lines in internal shape of } \underline{c} - 3.40|) + .21(|\text{No. alphanumeric elements in } \underline{c} - 0.25|) + .25(|\text{No. arcs in } \underline{c} - 0.85|)$$

A candidate symbol with a higher discriminability index would be the preferred symbol to use.

Configural Symbol Attributes

For this analysis, the log average similarity rating for each of the 190 pairwise comparisons of the 20 symbols was again used as the criterion in a step-wise multiple-regression procedure. This time, 20 predictors of the similarity ratings were obtained by subtracting the 20 pairs of values in the configural symbol attribute set (aggregates of primitives) (see Appendix B) for each pair of symbols. It is, of course, the aim of this analysis to account for a greater percentage of the variance in the similarity ratings than was possible with the primitive elements. The results showed that 12 of the predictors were significant independent sources of information about the similarity ratings (as determined by tests of significance for increases in R^2, $p < .05$). The rectangular shape accounted for 14% of the variance, while 11 other configural properties accounted for an additional 5% each, on average. Thus, 67% of the variance in the similarity ratings could be accounted for in all on the basis of the configural properties. This represents a marked advance over the variance accounted for when primitive symbol elements were considered (25%).

Since 12 configural attributes out of 20 were found to be important, and 11 of these 12 each accounted for nearly an equal amount of percent of variance, it seemed appropriate to summarize these results into a form that would perhaps be more manageable. One potential methodology in this regard has been offered by Tversky (1977). This method basically suggests that the perceived similarity of two forms is a function of the number of elements that they have in common, and also the number of elements that are held uniquely by only one of the forms. Thus, an attempt was made to predict the similarity ratings in the present experiment from both (1) the number of configural attributes held in common by two symbols, and (2) the number of configural attributes held uniquely by only one symbol in the pair.

The results of this regression analysis showed that 65% of the variance could be explained simply on the basis of the number of configural attributes that two symbols held in common. An additional 5% of the variance could be explained through consideration of the number of unique configural attributes in a symbol pair. Thus, the twelve predictors from the configural attribute set can be summarized in the form of two predictors: number of configural attributes held in common and number of unique configural attributes.

From this result, a discriminability-index formula for evaluating a candidate symbol c with n configural attributes is as follows (i refers to the ith configural attribute [f the candidate symbol]). This procedure is analogous to comparing the candidate symbol to each of the 20 symbols in the sample symbol domain.

$$\#\ \text{common attributes} = \sum_{i=1}^{n} (\text{no. of the 20 symbols in the sample symbol domain having configural attribute } i).$$

$$\#\ \text{unique attributes of } c = \sum_{i=1}^{n} (\text{no. of the 20 symbols in the sample symbol domain not having configural attribute } i).$$

unique attributes of sample domain = 54 - # common attributes, since there are 54 instances of attributes in sum comprising the 20 symbols in the sample domain (see bottom of last page of Appendix B).

Taking the standardized regression weights from the multiple-regression analysis outlined above,

$D_{\underline{c}}$ = (.07) [# unique attributes of $\underline{c}$ + # unique attributes of sample domain] - (.31) [# common attributes].

For example, consider once again the three candidate symbols shown in Figure 1. Candidate symbol number one has two configural attributes: a rectangle and a tombstone shape. The former attribute is held in common with 11 of the 20 symbols in the sample symbol set (see Appendix B), whereas the latter is not held in common with any of the existing 20 symbols. Thus, the "number of common attributes" for candidate symbol one is 11. The value of "# unique attributes of $\underline{c}$" is (20-11=9)+(20-0=20)=29. The value of "# unique attributes of sample domain" is 54-11=43. Therefore, $D_{\underline{c}}$ for candidate one is (+.07)[29+43]-(.31)[11] = 1.63. For comparison, the value of $D_{\underline{c}}$ for candidate symbol two is given by (+.07)[47+41]-(.31)[13] = 2.13. This latter value also holds for candidate symbol three since both two and three are composed of a rectangle, alphanumerics (this method does not discriminate the number of different alphanumerics used in a symbol), and one configural attribute not contained in any of the symbols in the sample domain. Thus, this methodology predicts that candidate symbols two and three are equally desirable and that both are preferable over candidate symbol number one. Positive results from tests of predictions such as this one would provide validation for the discriminability-index equation. Work toward this goal is described below.

Validation of the Discriminability-Index Formula

For purposes of evaluating the discriminability-index formula that was based on configural symbol attributes, eighteen candidate symbols were chosen to be studied in a controlled validation experiment. These eighteen symbols are presented in Appendix D along with their respective derived discriminability indices in the middle column. The symbols were chosen to provide a wide range of discriminability values. Further, to illustrate the use of the formula, three groups of symbols were embedded in the candidate symbol set, where each group is composed of three alternative representations of the same concept: symbols 1, 2, and 3 all denote combat electronic warfare intelligence; symbols 4, 5, and 6 all denote air defense; and symbols 7, 8, and 9 all denote an aviation POL depot. As can be seen through inspection of the middle column, certain symbols in each set are predicted to be more discriminable from the existing sample symbol domain than others. Thus, the resolution of symbol conflicts such as these can be offered in terms of the discriminability indices and specific predictions were evaluated in an experiment described below.

In addition, the entire set of 18 candidate symbols can be divided into two distinct groups: nine symbols comprising a high-discriminability group (symbols 7, 8, 9, 13, 14, 15, 16, 17, and 18) with a median index of 6.63, and nine symbols comprising a low-discriminability group (symbols 1, 2, 3, 4, 5, 6, 10, 11, and 12) with a median index of 1.63. The high discriminability symbols are, of course, predicted to be the preferred ones. Thus, several predictions were generated regarding the outcome of a human-performance experiment involving these symbols in the context of the sample symbol domain.

The experimental procedure was as follows. A 2' x 3' magnetic board was used to display the 20 symbols in the sample domain from Appendix B in a random array. A battlefield background was drawn on the board with a black grease pencil; otherwise the background was white. Embedded within the array of symbols on each trial were two instances of one of the 18 candidate symbols to be evaluated. This symbol was also presented on a card that was shown to the subject before the trial began. The board was covered with a large sheet of paper until the subject had thoroughly studied the card. The subject's task was to find both instances of the candidate symbol and to pick them from the board using one hand. The time to complete this task, which was recorded with a stopwatch, was taken as a measure of the discriminability of the candidate symbol in the context of the sample symbol domain. One trial was conducted with each candidate symbol yielding 18 trials per subject in all. The spatial arrangement of the 20 symbols from Appendix B, as well as the positioning of the two instances of the candidate symbol, was randomized across trials. The two instances of the candidate symbol were always separated by 14 inches. This was done to control for proximity effects in finding the two targets across trials. In addition, the order of testing the candidate symbols was randomized across subjects.

Nine subjects who were unfamiliar with Army symbols were used in the experiment. The median time to complete the search task for each candidate symbol across subjects is presented in the right-hand column of Appendix D. Attending first to candidate symbols 1, 2, and 3, which are alternative representations of the same concept, it can be seen that symbol 3 has the shortest median search time, whereas symbol 1 has the longest median search time. This pattern of results is as predicted by the discriminability-index equation. That is, the symbol with the largest discriminability index was found to require the shortest search time. Inspection of symbols 4, 5, and 6 reveals an analogous pattern, again supporting the predictions of the discriminability-index formula. Finally, symbols 7, 8, and 9 also constitute three alternative representations of a single concept; but, this time, the discriminability-index formula predicts that symbols 8 and 9 should be equally easier to discriminate from the symbols in the sample symbol domain than symbol 7. The confirmation of this prediction is also apparent from inspection of the median search times.

Symbols 10 through 18 have been arranged such that they are ordered from least discriminable to most discriminable; and, with the exception of one value, the median search times are in fact inversely related to the discriminability indices. The one anomaly is symbol 10. It is perhaps significant that the letters used to draw this symbol were larger than those used in the symbols in the sample symbol domain. Such a variation could have made symbol 10 easier to locate than was predicted. Overall, however, the nine symbols with the highest discriminability indices had an average median search time of 2.44 sec., whereas the nine symbols with the lowest indices had an average median search time of 3.12 sec. Thus, symbols with higher discriminability indices required less time to locate [$t(16)=3.11$, $p < .01$] as predicted. In correlational terms, 50% of the variance in the median search times could be accounted for in terms of the discriminability indices ($r=.71$). On the basis of these results, we conclude that the discriminability-index formula that was derived on the basis of configural symbol attributes has a reasonable degree of validity.

Sample Use of the Index Formula

Given confirmation that the discriminability-index formula based on configural attributes is a valid one for quantifying the perceptual discriminability of some symbols, a nontechnical approach for its practical use was developed. It must be acknowledged, however, that at the current stage of this research, two assumptions must be accepted in using the formula in its present form as a general tool. One implicit assumption is that the FM 21-30 domain of symbols will, in fact, provide the base for a standard symbology of the future; and the other is that our sample of 20 symbols from FM 21-30 constitutes a representative sample from that symbology.

Step 1. The generation of alternative candidate symbols might proceed from an inspection of different symbologies already in existence; or the symbols could be created from scratch with consideration given to the meaningfulness of the form and/or the principles enumerated in the introduction to this report. In any case, the procedure described in steps 2-6 can be used to evaluate the symbols to be compared.

Step 2. After you have specified the candidate symbols, the first step in selecting one of them is to list the configural symbol attributes that make up each of your alternative candidates. The list for each candidate should be exhaustive; that is, all parts of a candidate symbol must be contained in its list. This step is a subjective matter to a degree, but any ambiguity can usually be cleared up by gathering opinions from 2 or 3 other persons. Be sure to decompose each of your candidate symbols into a set of configural attributes, such as an "x," an oval, etc., and not into primitive attributes, such as number of straight lines, etc. For a comparison of examples of these two types of elements, compare the set of descriptors shown in Appendix A (primitive attributes) with that shown in Appendix B (configural attributes).

Step 3. In Appendix B, all of the configural attributes necessary to construct the 20 sample symbols from FM 21-30 are shown across the top of each page. The purpose of Step 3 is to compare the configural attributes contained in each of your candidate symbols with the configural attributes contained in each of the 20 sample symbols. This is to be done as follows for each of your candidate symbols. Suppose that one of your candidate symbols is composed of a circle (outside shape) and a diamond (inside the circle). As can be seen at the bottom of the last page of Appendix B, a total of 3 of the 20 sample symbols contain a circle for an outside shape, whereas none of the 20 sample symbols contain a diamond shape (a diamond element is not even listed across the top of the page). Therefore, the sum across the two configural attributes making up your candidate symbol is 3+0 or 3. This value is called $\underline{c}$ and will be used in Steps 4, 5, and 6.

For purposes of comparison, suppose that you have an alternative candidate symbol which is composed of a circle (outside shape) with a smaller filled-in (blackened) circle inside it. Again using the totals on the last page of

Appendix B, a total of 3 of the 20 sample symbols contain a circle for an outside shape, and 2 of the sample symbols contain a filled-in circle. Thus, for this alternative candidate symbol, the value of c is 3+2 = 5.

Step 4. For each of your candidate symbols, multiply the total number of configural attributes making up the candidate symbol times 20, and subtract c from the product. Call this value uc. For the example in Step 3, the candidate symbol composed of a diamond inside a circle had 2 configural attributes with a value of c equal to 3. Thus, uc for that candidate equals (2x20)-3 = 37. The alternative candidate symbol composed of a filled-in circle inside a circle also has 2 configural attributes but had a value of c equal to 5. Thus, uc for this alternative candidate equals (2x20)-5 = 35.

Step 5. For each of your candidate symbols, compute (54-c) and call this value us. In the example, the candidate composed of a diamond inside a circle has us = 54-3 =51, whereas the candidate composed of a filled-in circle inside a circle has us = 54-5 = 49.

Step 6. For each of your candidate symbols, compute the discriminability index (D_c) as follows:

$$D_c = (.07)(us + us) - (.31)(c)$$

For the candidate with a diamond inside a circle, D_c = (.07) (37+51) - (.31) (3) = 5.23.

For the candidate with a filled-in circle inside a circle, D_c = (.07) (35+49) - (.31) (5) = 4.33.

Step 7. Compare the discriminability indices among your alternative candidate symbols. The symbol with the highest index is the preferred one based upon the predicted discriminability of that symbol in a tactical display. In our example, the symbol composed of a diamond inside a circle is preferable to the one composed of a filled-in circle inside a circle.

IMPLICATIONS FOR FURTHER WORK

The goal of this research was to develop a methodology for choosing among alternative symbols for inclusion in FM 21-30. Specifically, a formula was derived for predicting the discriminability of a candidate symbol when placed in the context of FM 21-30 symbols. This formula, which is easy to apply, was found to account for 50% of the variance in symbol search times in a laboratory task. Thus, the method clearly has promise, but we feel that there is a considerable amount of work left to be done. This work falls into three main categories.

Perfection of the Instrument

With 50% of the variance in search times left to be explained, there are factors affecting performance other than the number of configural symbol attributes held uniquely and in common with FM 21-30 symbols, and these factors must be identified. It does seem clear from the present work that configural symbol attributes hold greater promise than primitive attributes in predicting discriminability. Thus, further work also needs to be carried out concerning how to identify a configural attribute (e.g., is a box divided into fourths to be viewed as a cross and a box, or as four small boxes). Studies of this problem are being performed at present (van Tuijl, 1980).

Generality of the Instrument

As noted earlier, we are concerned about the representativeness of our sample of 20 symbols as a surrogate for the FM 21-30 symbol domain. Ideally, we would have performed a comprehensive examination of most symbols contained in FM 21-30, taking into account the relative frequency of use of each symbol in typical tactical displays. The generality of the present formula or future formulas could be enhanced by making predictions concerning the outcomes of experiments conducted previously which involved the FM 21-30 symbology.

Development of Guidelines for Symbol Design

Theoretically, if we know what symbol attributes are currently being used and which are being used frequently, then symbol designers might be encouraged to rely on other attributes. In other words, the application of results like those reported here need not be restricted to post-design evaluations of symbols; but rather, some a priori guidance might be offered. From Appendix B, both the rectangular shape and the "X" shape would appear to be symbol attributes to be avoided since they occur most frequently in the sample symbol domain.

Ideally, from the perspective of discriminability alone, all attributes of a new symbol would be made novel to the FM 21-30 set, and the principles of perception enumerated in the introduction could guide (place limits on) such creativity. However, from a learnability point of view, similar symbol attributes are necessary to portray similar kinds of information. Otherwise, memory for the referents of the different symbols would rapidly become overtaxed. Thus, further research is required to identify and catalog symbol attributes which serve to signify salient symbol characteristics, perhaps across different symbologies. Work toward this requirement is proceeding at present (Landee & Geiselman, 1981). It is only the remaining symbol attributes which should be avoided if used too frequently in tactical displays.

One final note is that the design of a standard display symbology would necessarily be an iterative process. As additional symbols are accepted, the symbol data base for comparison with new symbols is altered. For example, at present, few tactical concepts are represented with verbal abbreviation; and therefore, such candidate symbols are highly discriminable from the existing symbols. However, the current trend to denote new concepts with alphanumerics will rapidly become an undesirable practice if used too often. Thus, when new concepts must be portrayed with alphanumerics, older symbols that include alphanumerics may have to be re-evaluated and changed. In this sense, the evaluation of symbols is a complex iterative process; and therefore, certain suggestions for symbol design are dependent upon current trends as well as upon past ones. Nevertheless, the present results suggest that at any one iteration, the selection of new symbols can be guided in part by a straightforward analysis of the physical attributes of the existing symbol domain.

REFERENCES

Attneave, F. Symmetry, information, and memory for patterns. American Journal of Psychology, 1955, 68, 209-222.

Attneave, F. Physical determinants of the judged complexity of shapes. Journal of Experimental Psychology, 1957, 53, 221-227.

Attneave, F., & Arnoult, M. D. The quantitative study of shape and pattern recognition. In L. Uhr (Ed.), Pattern recognition, New York: John Wiley & Sons, 1966.

Brown, L. T. Quantitative description of visual pattern: Some methodological suggestions. Perceptual and Motor Skills, 1964, 19, 771-774.

Casperson, R. E. The visual discrimination of geometric forms. Journal of Experimental Psychology, 1950, 40, 668-681.

Dardano, J. F., & Donley, R. Evaluation of radar symbols for target identification, Technical memorandum 2-58, U.S. Army Human Engineering Labs, Aberdeen Proving Ground, Maryland, March, 1958.

Easterby, R. S. The perception of symbols for machine displays. Ergonomics, 1970, 13, 149-158.

Gaito, J. Visual discrimination of straight and curved lines. American Journal of Psychology, 1959, 72, 236-242.

Hemingway, P. W., Kubala, A. L., & Chastain, G. D. Study of symbology for automated graphic displays, ARI Technical Report 78, U.S. Army Research Institute (Arlington, VA), May, 1978.

Landee, B. M., & Geiselman, R. E. Military symbology: A user community survey. Perceptronics Draft Technical Report, March, 1981.

Landee, B. M., Samet, M. G., & Gellman, L. H. User-elicited tactical information requirements with implications for symbology and graphic portrayal standards. Perceptronics Technical Report PFTR-1063-80-4, April, 1980.

Taylor, M. M. Visual discrimination and orientation. Journal of the Optical Society of America, 1963, 53, 763-765.

Tversky, A. Features of similarity. Psychological Review, 1977, 84, 327-352.

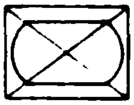
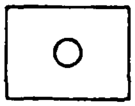
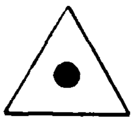
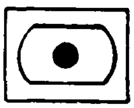
van Tuijl, H. F. J. M. Perceptual interpretation of complex line patterns. Journal of Experimental Psychology: Human Perception and Performance, 1980, 6, 197-221.

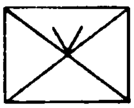
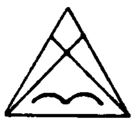
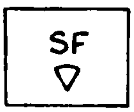
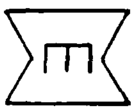
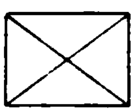
Williams, E., & Teichner, W. H. Discriminability of symbols for tactical information displays, Technical Report 79-1, U.S. Air Force Office of Scientific Research (Washington, D.C.), January, 1979.

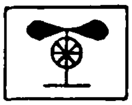
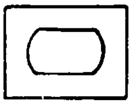
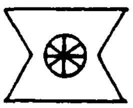
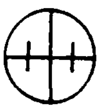
Yoeli, P. & Loon, J. Map Symbols and Lettering: A Two Park Investigation. European Research Office, January, 1972.

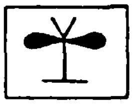
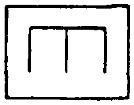
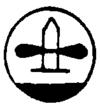
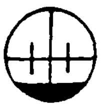
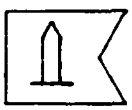
APPENDIX A

SAMPLE SYMBOL SET WITH DESCRIPTORS BASED ON PRIMITIVE ATTRIBUTES

	EXTERNAL	INTERNAL							
	SYMBOL SHAPE (NO. LINES)	NO. STRAIGHT LINES	NO. FULL CIRCLES	NO. ANGLES 90°	NO. ANGLES OTHER	NO. QUASI ANGLES	NO. ARCS	NO. FILLED ELEMENTS	NO. ALPHA-NUMERICS
	4	4	0	0	20	8	2	0	0
	4	0	1	0	0	0	0	0	0
	3	0	1	0	0	0	0	1	0
	4	2	1	0	0	4	2	1	0
	4	2	0	0	12	1	2	0	0

	EXTERNAL	INTERNAL							
	SYMBOL SHAPE (NO. LINES)	NO. STRAIGHT LINES	NO. FULL CIRCLES	NO. ANGLES 90°	NO. ANGLES OTHER	NO. QUASI ANGLES	NO. ARCS	NO. FILLED ELEMENTS	NO. ALPHA-NUMERICS
	4	4	0	0	14	0	0	0	0
	3	2	0	4	8	1	2	0	0
	4	2	0	0	1	2	1	0	2
	6	4	0	4	0	0	0	0	0
	4	2	0	0	12	0	0	0	0

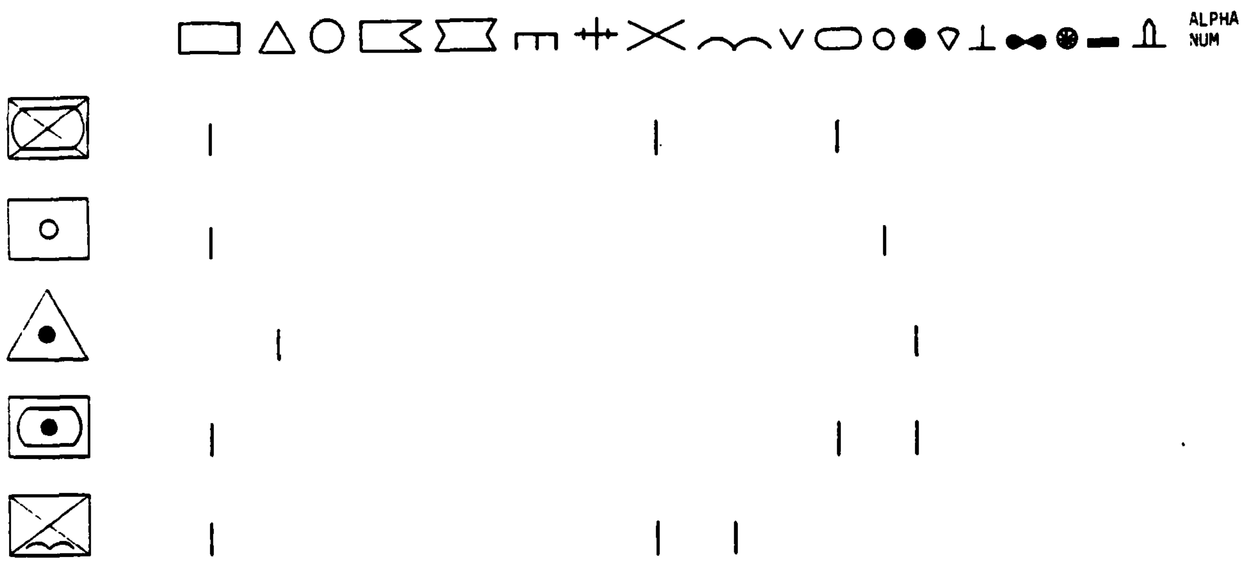
	EXTERNAL	INTERNAL							
	SYMBOL SHAPE (NO. LINES)	NO. STRAIGHT LINES	NO. FULL CIRCLES	NO. ANGLES 90°	OTHER	NO. QUASI ANGLES	NO. ARCS	NO. FILLED ELEMENTS	NO. ALPHA-NUMERICS
	4	7	1	2	13	20	2	2	0
	4	2	0	0	0	4	2	0	0
	5	1	0	2	2	0	0	1	3
	6	4	1	0	8	16	0	0	0
	1	4	0	12	0	8	0	0	0

	EXTERNAL	INTERNAL							
	SYMBOL SHAPE (NO. LINES)	NO. STRAIGHT LINES	NO. FULL CIRCLES	NO. ANGLES 90°	OTHER	NO. QUASI ANGLES	NO. ARCS	NO. FILLED ELEMENTS	NO. ALPHA-NUMERICS
	4	6	0	2	7	4	2	2	0
	4	4	0	4	0	0	0	0	0
	1	8	0	4	15	8	2	3	0
	1	5	0	14	0	10	0	1	0
	5	5	0	4	3	0	0	0	0

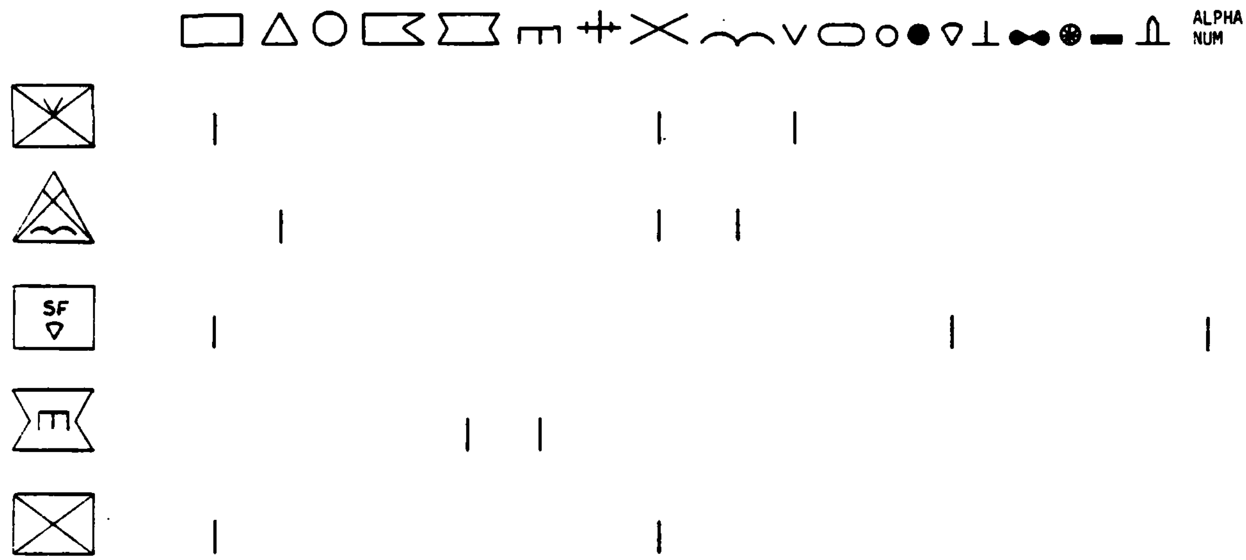
APPENDIX B

SAMPLE SYMBOL SET WITH DESCRIPTORS BASED ON CONFIGURAL ATTRIBUTES

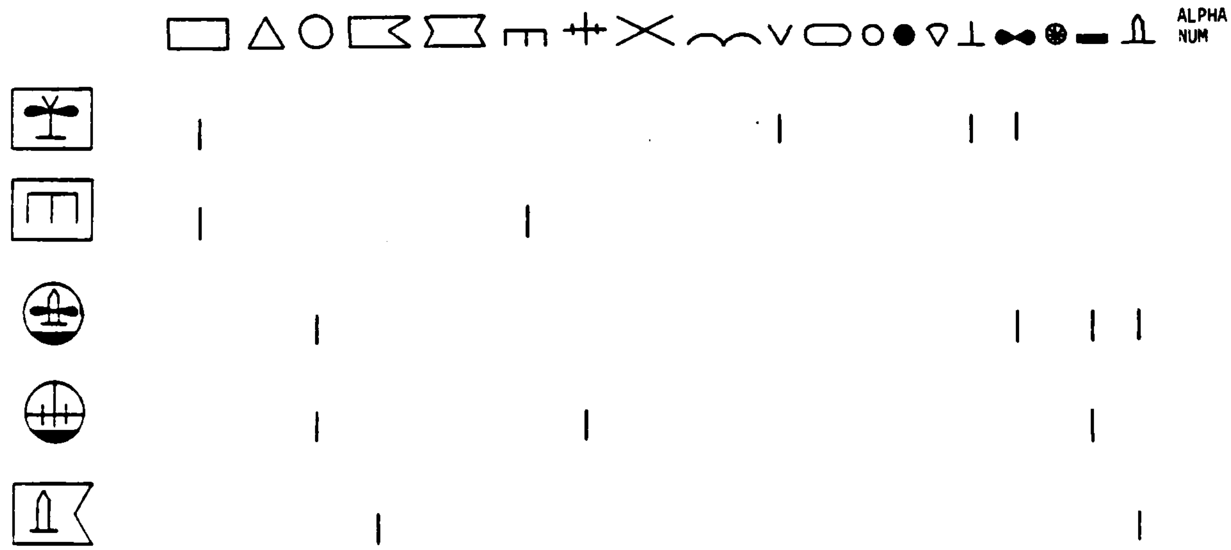
Configural Attributes



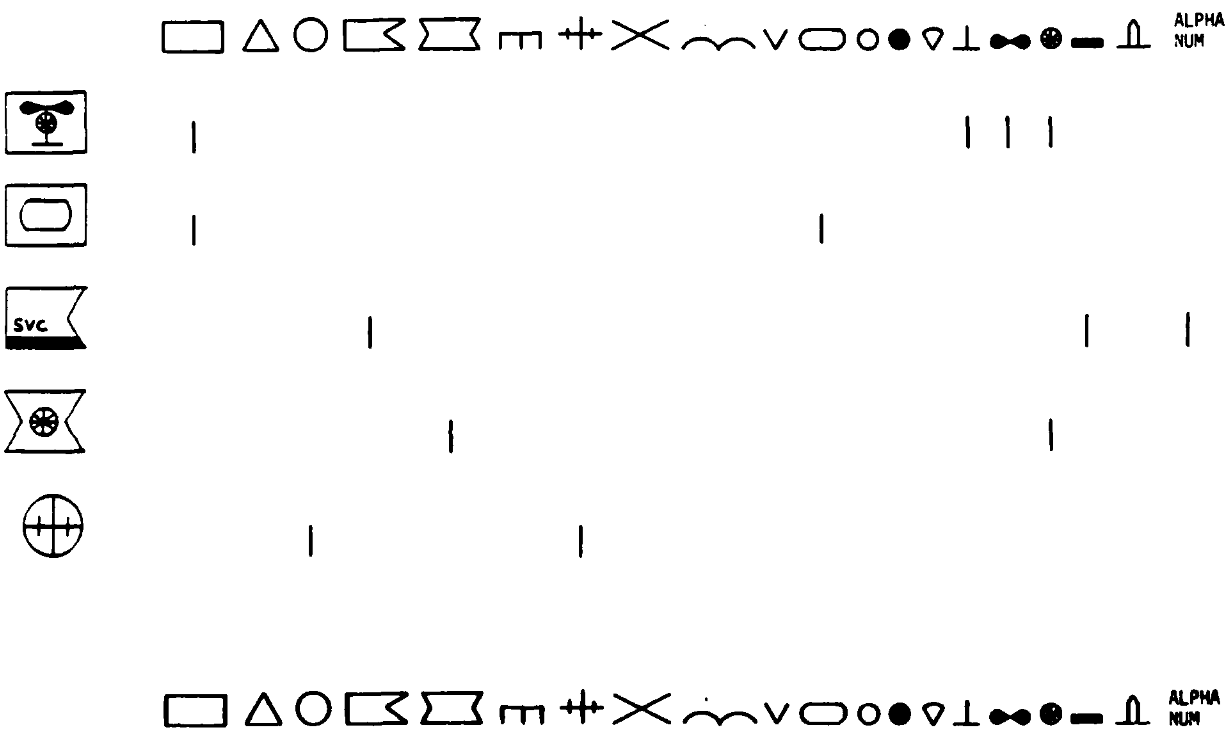
Configural Attributes



Configural Attributes



Configural Attributes



totals = 11 2 3 2 2 2 2 5 2 2 3 1 2 1 2 3 2 3 2 2

grand sum across all configural properties = 54

APPENDIX C

INSTRUCTIONS AND SAMPLE RATING SHEET FOR SYMBOL SIMILARITY-RATING TASK

INSTRUCTIONS

The purpose of this experiment is to determine the physical similarity of different symbols to one another. These symbols are being considered for use in displaying information on a TV system.

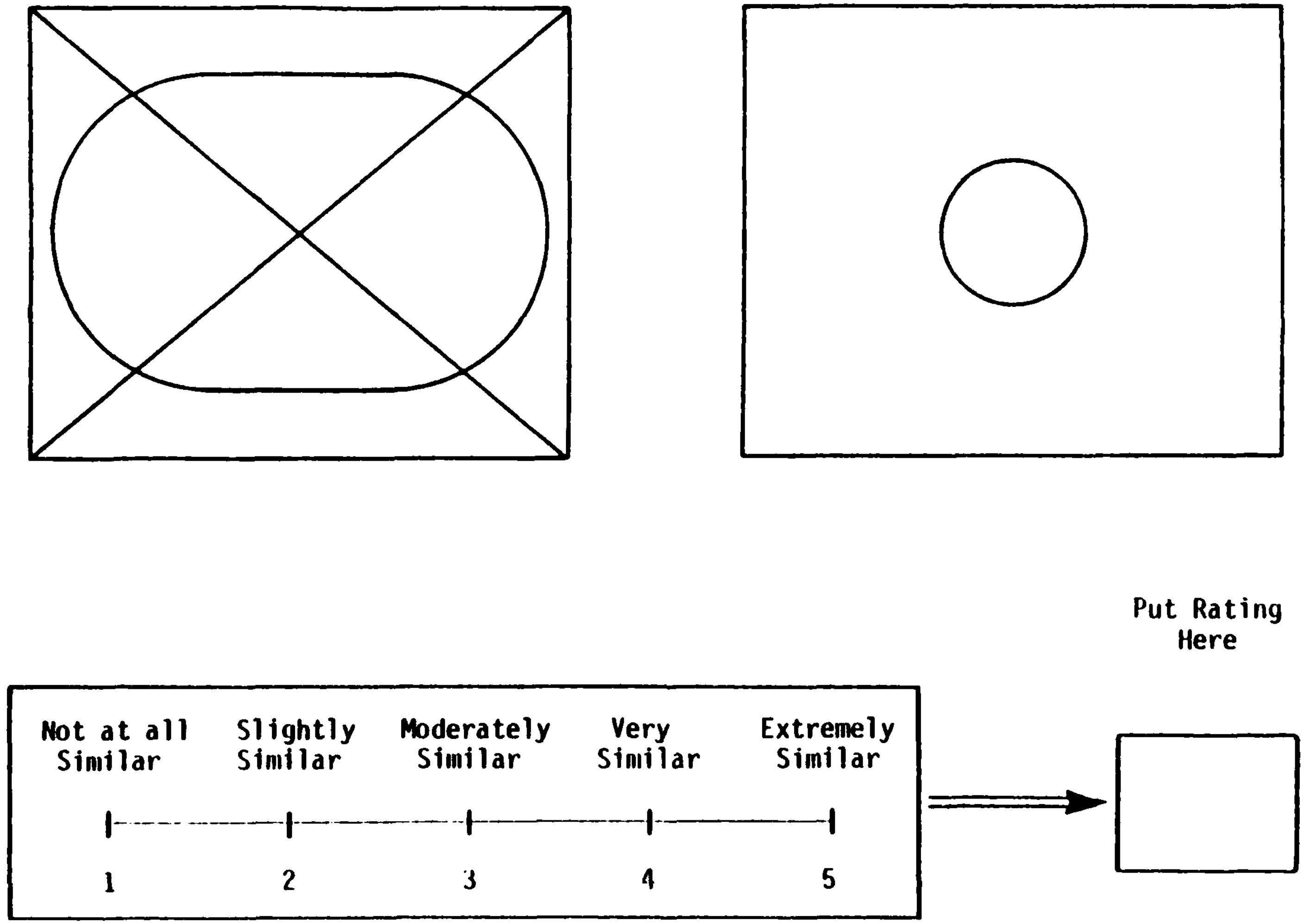
On each of the pages in this booklet, you will see two symbols, side by side. For each page your task is to rate the physical similarity of the two symbols using the following 1 to 5 scale:

1 - "not at all similar"
2 - "slightly similar"
3 - "moderately similar"
4 - "very similar"
5 - "extremely similar"

As an example, the following two symbols should be given a 1 since they are not at all similar:

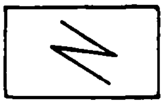
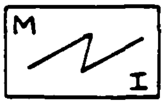
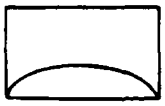
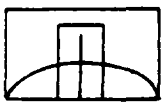
The following two symbols should be given a 5 since they are extremely similar:

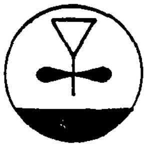
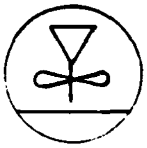
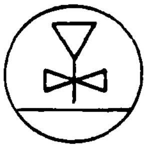
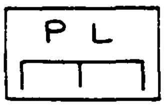
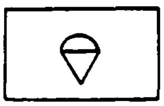
Please do not spend a lot of time on any one page; just look at the pair of symbols and immediately make a rating of 1, 2, 3, 4, or 5. Put the rating in the box provided. Do not skip any pages and please do the pages in order.

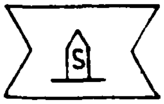
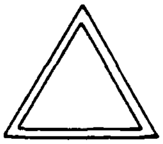
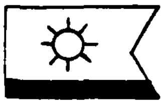
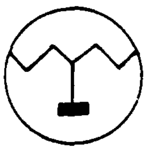
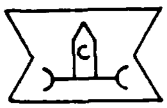

Put Rating
Here
Not at all Similar
Slightly Similar
Moderately Similar
Very Similar
Extremely Similar
1
2
3
4
5

APPENDIX D

CANDIDATE SYMBOLS USED IN THE VALIDATION EXPERIMENT

	CANDIDATE SYMBOL	DISCRIMINABILITY INDEX (Dc)	MEDIAN SEARCH TIME
1		0.73	3.03
2		1.63	2.61
3		2.13	2.39
4		1.63	3.68
5		2.13	2.93
6		3.03	2.59

	CANDIDATE SYMBOL	DISCRIMINABILITY INDEX (Dc)	MEDIAN SEARCH TIME
7		5.33	3.08
8		8.03	2.29
9		8.03	2.34
10		0.73	3.04
11		1.23	3.94
12		1.63	3.83

	CANDIDATE SYMBOL	DISCRIMINABILITY INDEX (Dc)	MEDIAN SEARCH TIME
13		5.28	2.69
14		5.68	2.67
15		5.73	2.47
16		6.63	2.12
17		6.68	2.21
18		7.58	2.11