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COLOR AND SHAPE CODING FOR FREEWAY ROUTE GUIDANCE

Vol. III. Appendices A and B – Literature Review and Laboratory Studies

March 1978

Final Report

Prepared for

FEDERAL HIGHWAY ADMINISTRATION

Offices of Research & Development

Washington, D. C. 20590

Foreword

This report presents the results of laboratory and field tests of a unique color and shape coded guidance system which offers promise as a supplement to conventional guide signing at problem freeway interchanges. The effects of five color/shape coded systems on erratic maneuvers, lane placement and speed of vehicles traversing the test interchanges are discussed. Guidelines for system installation and use are reported.

The report concludes that the color/shape coding concept as applied to freeway route guidance results in sufficient benefit to merit further development and testing. The reported information will be of interest to researchers concerned with highway guide signing and routing information.

Copies are available from the National Technical Information Service (NTIS), Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161. A small charge is imposed for copies provided by NTIS.

Charles F. Scheffey
Director, Office of Research

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16. Abstract

The purpose of this research effort was to develop and field test a unique color and shape coding system which offered promise as a supplement to conventional guide signing on problem interchanges. Following a review of the technical literature, a series of laboratory studies was conducted to empirically identify the most appropriate color and shape combinations for symbol signs. The symbol signs were used in various ways in the design of five color/shape coded route guidance systems which were installed and subjected to field evaluation on problem interchanges.

With the exception of the initial system evaluated, all other systems resulted in operations and safety benefits as evidenced by a statistically significant reduction in erratic maneuvers and a significant improvement in other operational measures.

It was concluded that the color/shape coding concept as applied to freeway route guidance results in sufficient benefit to merit further development and testing of such systems.

This volume presents the literature review (Appendix A) and a detailed description of the laboratory studies and results (Appendix B).

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

Page

INTRODUCTION

This report in its entirety documents an effort to develop and field test a unique color/shape system that offered promise as a much-needed supplement to conventional guide signs for freeway and route guidance. The backdrop, against which the project was conceived, encompassed a great deal of both accident and traffic research literature which argued rather convincingly that color, shape, and color/shape codes were effective information carriers. The literature provided ample evidence that color/shape coded information could generally be processed very rapidly under a variety of conditions. Additional impetus for the project stemmed from the fact that there are a number of freeway interchanges throughout the country that are difficult to sign via conventional means, either because the interchange is unique and violates driver expectancy or because the interchange is complex and results in information overload for the driver. In either case, the consequence is driver uncertainty which is frequently manifested in the commission of erratic maneuvers and ultimately in increased turbulence in the traffic stream in the vicinity of the interchange. Faced with this problem and the potential for a solution via application of color/shape coding, Mr. King Roberts and other staff members of the Office of Research and Development, Federal Highway Administration, conceived a system which through the provision of rapidly processable information (for both route guidance and path control) would facilitate the driver's task in traversing unusual or complex freeway interchanges. More specifically it was felt that coded information appearing on or added to existing sign panels, and/or on the roadway surface, could help the driver to more quickly and easily identify the lane he should occupy prior to and within the interchange to reach his desired exit.

The effectiveness of any such system is, of course, predicated upon the driver's ability to recognize or build an association between his desired route (or destination) and the color/shape symbol signs which are presented as a supplement to the conventional signing information. Once this association is made, the driver needs only to search for and follow the symbol signs, thereby reducing the information loading in the vicinity of the interchange. A further advantage of the symbol signs when they are used to supplement existing delineation in the vicinity of the exit gore and ramp is the provision of specific rather than general information regarding the exit and confirmatory information on the ramp.

It is important to note that the system developed and tested is intended to be used only on problem interchanges where conventional signing treatments have been shown to be or are expected to be inadequate due to unusual geometrics either in kind or complexity. That is, the system begins and ends within a problem interchange and there is no intention, at present, to utilize the system to aid the driver in long term route following

The project was initiated with a review and synthesis of the academic and traffic research literature applicable to the development and use of the color/shape system. This synthesis is provided in Appendix A of the report. Following the literature review, a series of five laboratory studies were conducted.

The purpose of the laboratory studies was to provide an empirical basis for choosing the color/shape (C/S) symbols to be used in the subsequent development of the system to be field tested. Since the conceptual objective of the C/S system was to provide supplemental guidance information at problem interchanges on a spot basis rather than for long term route guidance involving the entire highway network, a large number of different symbols was not required. Based upon the assumption that even the most complex interchange (or even two adjacent problem interchanges) would not require more than eight route choices, the objective of the laboratory studies was to identify two sets of four symbols which would be best suited to the system. Since the colors were restricted to those currently identified in the Manual of Uniform Traffic Control Devices as "unassigned", the first two studies were designed to identify the most appropriate shapes. The third study was designed to investigate the role of background and direction of contrast as related to visual target (symbol) location. The fourth study was designed to select the best format for the symbol signs. The fifth study, conducted in an outdoor environment, was designed to determine the best color/shape combinations to be used in the field tests. The detailed documentation and results of the studies is presented in Appendix B.

APPENDIX A

LITERATURE REVIEW

OPERATIONAL TRAFFIC LITERATURE

The purpose of the present study is to develop a color/shape route guidance system for applications to freeway interchanges. This literature review is directed towards those factors concerned with the perception of highway signs within the constraints of the study. The operational or developmental traffic literature is discussed separately from the more basic, research literature to establish a clear definition of the concerns of the present study as they relate to the highway. The treatment of the research literature will follow the same outline as the discussion of the highway literature. In dealing with separate studies, the review will consider the methodology of each in the initial discussion; studies of methodology relevant in the evaluation of a color/shape route guidance system will be considered in a separate section of the review.

Color

Color has long been used in highway signing because of its relatively high visibility and its effectiveness as a code. Present application of color must be considered in the development of the color/shape system to control for learning effects and to ensure that redundancy does not impair the use of color as a code. Ferguson and Cook (1967), in a study of driver's awareness of sign colors and shapes, found that most of the subjects questioned did not know the intended meaning of the colors: green, orange, blue, and white; but red and white combination was recognized and given their appropriate meaning. These findings suggest that drivers are confused about the present usage of color and that color is not being used effectively as a code. A set of about 12 easily identified and equally differentiated colors were sought for use in color coding for highway information systems. At present, the MUTCD (1971) defines red, black, green, blue, yellow, white, orange, and brown as already assigned for specific purposes. Purple, strong yellow-green, light blue, and coral comprise the rest of the revised MUTCD set and they currently are unassigned as to general meaning. Robinson (1967) in his discussion of color in traffic control included grey and buff instead of light blue and coral as unassigned colors in an earlier suggested set of 12 colors. There are differences between the 1967 set and the 1971 MUTCD set in the specifications of the other colors as well. The assigned colors could possibly be used if it could be demonstrated that the color/shape coding signs to be used were not confusable with the present application of those colors; i.e., a red diamond could be used against a blue background if it was not found to be confused in practice with a stop sign.

Several authors have considered how the physical properties of vision relate to the visual driving task. In considering color coding, it is first important to note that approximately 8% of the male population and 1% of the female population possess some significant form of color blindness or color weakness. This is most frequently classified as either protonopia or deutoranopia. In protonopia, an individual does not perceive the red end of the spectrum as readily as "normal" individuals, while with deutoranopia, an individual is less sensitive to the green midsection of the spectrum. True monochromatic vision ("color-blindness") is found in a very small portion of the population; individuals with monochromatic vision cannot discriminate at all among hues of the same brightness. Thus about 6 to 8 percent of the population will have to depend on other dimensions of coding, like shape, in the information seeking task.

The coding potential provided by color must often be supplied by other means, such as brightness contrast, to provide high visibility. Other color vision deficits are to be found in peripheral vision, where there are few color receptors (cones), and in the elderly, where both color sensitivity and width of peripheral vision are decreased. Schmidt (1967), in his review of the variables in the visual driving task, considers color vision in a discussion centered on a comparison of green and red. The various wavelengths across the visible spectrum require varying amounts of radiant energy to be visible. Furthermore, these requirements vary for photopic (day) vision and scotopic (night) vision. Schmidt points out that red wavelengths require more energy than the green wavelengths of the spectrum in order to be visible. Thus green should be more perceptible than red of the same power across a broad range of light levels. The difference between the two colors is more accentuated at night vision levels. This accenting is a function of the Purkinje phenomenon. At night, sensitivity to the colors of the red end of the spectrum decreases more rapidly than sensitivity to the violet end colors. The change in sensitivity occurs because cones, which are most active during the day, are most sensitive to colored light at 555 nm while rods, the mediators of night vision, are most sensitive to light at 510 nm. Thus as night approaches, a shift in sensitivity occurs. Using the knowledge of differential energy requirements and of the Pukinje shift, a general outline for colors most easily perceived at day and night levels can be obtained. A general order of visibility based on these curves would be:

1. For photopic vision, yellow would be most visible followed by green, orange (both green and orange require essentially the same amount of light), blue, violet, and red (some reds require more energy than some violets).

2. For scotopic vision, green would be most visible, followed closely by blue, then yellow, violet, orange, and red. It must be noted that within each color name area of the spectrum there are wide variances in energy requirements so that one wavelength of a color might be more visible than the wavelength of another color, even though the above rating lists the latter color as more visible than the former. Also, it should be clearly understood that many more variables other than the requirements for energy effect visibility; for instance, learning can contribute to the visibility of one color or different materials might affect the visibility of different colors. In

addition, few lamps produce "pure" colors. The mixing of white light with a hue makes it more visible while it still appears distinctly colored. Richards (1958) affirms that at night vision levels red appears darker and blues brighter than the same colors in daylight. He also points out that with lowered color sensitivity and lowered visual acuity, signs must be larger (five times as much areas as with daylight levels), must be reflectorized, and must have a greater brightness contrast (six to twenty times greater than higher light level requirements).

Most of the experiments evaluating color in highway applications were done considering color against the background of the sign. Four studies considered the relationship between legend color against the sign background as it affected visibility; color of the surrounding environment was not accounted for. In a study of wrong-way driving, Hulbert (1963) considered four different signs: white letters on black background, black letters on white background, white letters on red background, and a fourth sign with white letters and slash on a red circular background. 35-mm film segments were made of an off-ramp which was made up to look like an on ramp; each segment presented a different sign. Undergraduate student subjects first "drove" a ten minute trial run on the UCLA Driving Simulator and then "drove" the 60-90 second test film. Afterwards, each subject was asked for general information, impressions of simulation, and indirectly his reactions to signing. Speed, steering wheel turns, and brake and accelerator applications were taken. The results of the study indicated that the white-on-red signs were more effective and were detected earlier. It should be observed, however, that the superiority of the white-on-red signs might be in part a result of the novelty effect, given that the white-on-black and black-on-white signs are used more frequently than the experimental white-on-red signs. There may also be a stereotype effect contributed by red, which depends on the prohibitory meaning from use in stop signs.

A 1961 experiment by Decker considered further color combinations on signs. In the first of two studies, Decker compared a blue-white format, against a white-on-green format, using legibility distance as a measure. Legibility was examined for three conditions of illumination: daylight, and low and high beam headlights at night. It was found that legibility for the two color combinations was equal for the daylight conditions but that the blue-on-white combination was legible at a significantly greater distance than was the white-on-green combination for the night conditions. The earlier discussion on Schmidt's article indicated that blue and green should be of nearly equal visibility at night levels of illumination, and that green would be more discriminable at day levels of illumination. These apparent discrepancies between Schmidt's findings and Decker's can be accounted for by pointing out that the more discriminable color combination (blue-on-white) is a dark on light or positive contrast, while the other color combination (white-on-green) is a negative contrast, light on dark; there have been fairly consistent findings in both the scientific and the traffic literature which indicate that a positive direction of contrast generally has greater visibility than a negative contrast.

Decker's second study (1961) evaluated diagonally striped warning signs, which are used on Virginia highways, for daytime visibility. The design of these signs varied according to stripe width and color combinations. The study found the black stripe on white background combination to be most visible, followed closely by the black stripe on yellow background combination, with the red stripe on white background not easily discerned. These findings are partly in contradiction with Hulbert's (1963) study in which the negatively contrasted white-on-red sign was more effective than both the negatively and positely contrasted black and white signs, while Decker found the positively contrasted red-on-white sign to be less visible than the positively contrasted black stripe on white background sign. These differences can be explained as the result of either population stereotype, a novelty effect, or the interaction of the two effects. Hulbert's study compared new experimental signs (the white-on-red) against the standard signing while Decker compared signs which are used on the highway; this would perhaps contribute a novelty effect. Hulbert also used white-on-red signs in an application which is appropriate to the normally coded use of red, that is, in a stop or prohibitive situation (MUTCD), while Decker compared signs which share the same coded meaning.

Still further data on color combinations within a sign are provided by a study done by Birren (1957). Birren examined different color combinations on an octagonal sign for legibility distances during the day and at night. Legibility distances for daytime illumination rank: black-on-white, first, with 404 ft (123 m); white-on-red with 361 ft (110 m); black-on-yellow with 358 ft (109 m); black-on-yellow with 358 ft (109 m); and white-on-green with 358 ft (109 m). Birren's results generally seem to concur with Decker's findings; it must be pointed out, however that the general superiority of the positive (dark on light) contrast over the negative (light on dark) contrast is being challenged in that Decker finds the positively contrasted red-on-white sign less visible than black-on-yellow, while Birren finds the negatively contrasted white-on-red sign more legible than the black-on-yellow sign.

Birren's (1957) results for nighttime legibility distances are as follows: the black-on-yellow combination was the most legible at 341 ft (104 m); the white-on-green combination was second at 337 ft (103 m) then followed the black-on-white combination at 316 ft (96 m); and the white-on-red combination was least legible at 312 ft (95 m). Signs were legible at night at 88% of the daytime legibility distance. Across levels of illumination, Birren's findings indicate a basic reversal in legibility. The two least legible signs by day (black-on-yellow and white-on-green) become the most legible at night, while the most legible by day (black-on-white and white-on-red) become the least legible at night. This result can probably be attributed to the greater brightness contrast of reflectorized signs at night. This finding illustrates a basic paradox in highway signing: those variables which perform well in one highway condition perform poorly in another. This paradox suggests strongly that signs must be evaluated and implemented for specific situations if optimal results are to be obtained using practical devices.

The findings of a fourth study by Hanson and Dickson (1963) will be mentioned in part here (considered in the next section in more detail). The Hanson and Dickson study provides values for six colors (red, yellow, white, international orange, fluorescent yellow-orange, and fluorescent red-orange) presented as 0.01 sq ft circular targets against three background colors (white, tan, and olive-drab). Detection and recognition distances were obtained. The two fluorescent colors were the prime subject of the study; they introduce another variable to the consideration of colors: fluorescent pigments, through a light-conversion process unique to their specie, reflect more than 100% of the incident visible light falling on them. With their high brightness, they are highly visible and the mean recognition ranges for fluorescent targets are significantly better than those of conventional colors. The findings (see Table 1, page 9) also demonstrate that the recognition distance varies directly with the darkness of the surrounding environmental background, regardless of direction of contrast on the sign. The positive contrast advantage does hold true for mean detection distances, if the fluorescent colors and the international orange color are disregarded because they contribute special brightness factors. With mean recognition distance, the positive direction of contrast may be interacting with color-contrast effects. Recognition is dependent on color, whereas detection is dependent on contrast effects. The studies by Decker (1961) and by Birren (1957) used legibility as a measure of visibility; legibility may have the same visual requirements as detection in regards to contrast. If the results of Hulbert's (1963) study and Birren's findings on the white-on-red sign are discounted because of other effects, a number of conclusions can be made about sign color combinations. The superiority of the positive (dark on light) contrast effect was upheld. Forbes (1969, to be considered later) also points out the importance of brightness contrast over color contrast. The studies by Decker and by Birren both demonstrated that black-on-white and black-on-yellow combinations were highly visible during daytime illumination. Black-on-yellow and blue-on-white show good visibility under conditions of night illumination, with white-on-green showing superiority over the black-on-white combination. The Hanson and Dickson (1963) study demonstrated, for mean detection distance, that the following color combinations are effective: international orange on white background (613 ft, 187 m), red-on-white background (611 ft, 186 m), white-on-tan background (693 ft, 211 m), yellow-on-olive-drab background (825 ft, 251 m), fluorescent red-orange on olive-drab background (671 ft, 205 m), white-on-olive-drab background (847 ft, 258 m), and fluorescent yellow-orange on olive-drab background (789 ft, 240 m). In considering the variables that contribute to a color/shape guidance system, it must also be recognized that the studies by Decker, by Birren, and by Hanson and

Table 1. Mean Detection and Recognition Ranges of 0.01 sq ft circular targets

TARGET	Range (ft)					
	Both Days		Overcast		Clear Sunny	
	Detec	Recog	Detec	Recog	Detec	Recog
White Background:						
Yellow	400	240	394	234	406	246
Fluorescent red-orange	572	346	591	340	592	352
International orange	613	182	589	183	636	180
Red	611	134	602	143	630	125
White	143	87	142	87	144	86
Fluorescent yellow-orange	504	363	494	356	513	369
Tan Background:						
Yellow	490	317	486	320	493	314
Fluorescent red-orange	479	347	526	345	432	346
International orange	479	249	472	250	486	247
Red	528	204	515	207	542	203
White	693	442	655	437	730	446
Fluorescent yellow-orange	521	413	525	418	517	407
Olive Drab Background						
Yellow	825	391	781	381	866	400
Fluorescent red-orange	671	490	663	489	678	491
International orange	420	296	408	293	431	299
Red	319	230	309	225	329	234
White	847	499	813	509	881	488
Fluorescent yellow-orange	789	549	767	542	810	555

Dickson are essentially measuring pure legibility, which allows the subject unrestricted viewing, while for the purposes of the color/shape system glance legibility which involves a limited amount of time, is perhaps the most appropriate measure.

In considering sign color against the surrounding environment, three studies from the traffic literature are available. Forbes et al. (1968) conducted a series of experiments in the 1960s on factors in highway sign visibility. Each of the studies used essentially the same method (see Forbes, 1969). Stimuli were presented through a two-channel projection tachistoscope onto a screen. One channel of the tachistoscope presented a highway scene while the other channel projected the same scene with simulated signs; stimuli were varied through the second channel. Subjects reviewed the projected image while performing an auxiliary task which was intended to introduce loading in simulation of the driving task. The auxiliary task required the subject to relight one to four lights in the matrix of 12 small lights located in front of the subject corresponding to where the road would be. These lights were relit with buttons controlled by the left hand. With presentation of the simulated signs the subject was to respond, indicating which sign he saw "first and best". This measure was decided on because it best eliminated effects introduced by viewing angle and individual variations in eye movements. Time to perform the auxiliary task and the number of times each sign was reported as "first and best" were recorded as dependent variables. In the 14th of the series experiments, Forbes examined the visibility of signs against colored highway environments with size, shape, and brightness effects controlled. The seven sign colors were black, dark green, blue, a saturated green, a brilliant red, yellow, and white. These colors were viewed against typical highway environments: dark-green trees, a yellow-brown hill, blue-gray cliff and day-snow. These are fairly representative of the variation in highway background as measured against Hanson and Woltman's (1967) recording of sign environments on Interstate highways. As can be seen in Table 2 (page 11), there are wide variations in the backgrounds along interstate highways. Against his four environments, Forbes' results indicated that the brightest colors were "seen best" most frequently. The average percent "seen best" increased nearly linearly with the log of brightness (measured with the Spectrum Prichard photometer). The exceptions to this finding are the red, yellow, and black signs. It was suggested that here hue contrast added to the effect of brightness contrast and modified the result. The ordering of colors seen first and best is as follows: yellow, brilliant red, white, the saturated green, blue, dark green, and black. Differences introduced by the color of the background environment were minimal. These findings were validated closely in an outdoor observation which was intended to check the laboratory results. The outdoor reservation measured perception distances for 400 advertising signs and 82 highway signs along a standardized highway route.

Table 2. Backgrounds of Signs - Overall Totals

Background	Number of Signs and Percent of Total					
	Overhead		Shoulder		Combined	
	No.	%	No.	%	No.	%
Sky	603	35.8	174	7.3	777	19.1
Trees						
Dark green	180	10.7	752	31.8	932	23.1
Bright green	15	0.9	106	4.5	121	2.9
Grass						
Tan	23	1.4	152	6.4	175	4.3
Green	11	0.7	91	3.8	102	2.5
Building	123	7.3	98	4.1	221	5.4
Advertising signs	38	2.3	119	5.0	157	3.9
Road	9	0.5	74	3.1	83	2.0
Bridge	333	19.8	295	12.4	628	15.6
Sand	2	0.1	46	1.9	48	1.2
Dark Hill	77	4.6	154	6.5	231	5.7
Sky and Building	29	1.7	6	0.3	35	0.9
Sky and Bridge	109	6.6	56	2.4	165	4.1
Sky and natural						
Dark	127	7.5	171	7.2	298	7.3
Light tan	2	0.1	4	0.2	6	0.1
Bright green	-	-	27	1.1	27	0.7
Red rock	-	-	8	0.3	8	0.2
Grey rock	-	-	40	1.7	40	1.0
TOTALS	1681	100	2373	100	4054	100

Odescalchi (1960) reported two experiments on sign conspicuity. The second experiment gives findings which essentially support Forbes' results. In his second experiment, Odescalchi evaluated five colors for signs: yellow with a reflectance of 56%; red, 13%; green, 10%; blue, 3.8%; and black, 2%. Each color was presented on panels of varying sizes to be compared with a white (88% reflectance) panel of fixed size. Subjects were asked to fixate on a gray panel, which separated the two colored panels, and judge which of the two panels was more easily detected. From this data, Odescalchi obtained a measure of how much larger (or smaller) than the white panel the colored panel had to be in order to be equally conspicuous. The results give the following rank order of conspicuousity: yellow can be 8% smaller than the white panel; red only 7% larger; blue, 24%; and black having to be 125% larger than the white panel to be equally conspicuous. These results agree with Forbes' results with one exception; Forbes' data indicated that white should be less visible than the red. This difference is explained by pointing out that Forbes specified that his red was a brilliant red; it may be assumed then that the red Odescalchi evaluated was less bright.

A third study by Hanson and Dickson (1963) was conducted to evaluate the visibility differences between fluorescent pigments and high visibility conventional pigments. Conventional pigments absorb some of the light they receive, reflecting the rest; fluorescent pigments augment the normally reflected light by converting light from the near ultraviolet, blue, and green areas of the color spectrum to add to its own reflecting wavelength. At the same time, fluorescent pigments are limited because of a shorter life than most pigments (33% of the original brightness is lost by yellow-orange in 2 years, and red-orange in 2.5 years). In their study, Hanson and Dickson compare fluorescent red-orange and yellow-orange with red, yellow, white, and international orange. These colors were viewed as 0.01 sq ft circular targets against three different colored panels (3 ft x 4 in): white, tan, and olive-drab. Three time periods were used: noon, 3:00 PM, and 6:00 PM, and two different sky conditions: clear and solid overcast. Colored targets were presented in a random sequence. The subjects approached the stimulus in a car at 5 mph to determine both the detection distance and the recognition distance. Results showed that the fluorescent yellow-orange was recognized first and at the greatest viewing distance for both viewing conditions (time and weather). With the sole exception of a white target on a tan background fluorescent yellow-orange had the greatest recognition range for all targets and backgrounds studies. On an olive-drab background, the fluorescent yellow-orange had a recognition range 3.8 times greater than international orange at 6:00 PM, and 2 times greater at noon. In comparison with conventional yellow, recognition distances for fluorescent yellow-orange were 1.6 times as great at 6 PM and 1.3 times as great at noon. The study also found that the detectability distances for conventional pigments were reduced more than those for fluorescent yellow-orange in the overcast condition. Under selected conditions, some conventional colors were slightly more detectable or recognizable than fluorescent yellow-orange. Overall, however, this yellow-orange had consistently higher performance than the conventional pigments. It seems clear then that, except for a pigment's limited life, fluorescent yellow-orange might be a candidate for the color-shape guidance system. Table 1 gives the mean detection and recognition distances for all colors tested. If the fluorescent pigments and international orange are barred from consideration, the results of the Hanson and Dickson (1963) study are in agreement with findings of Forbes (1969) and Odescalchi (1960) for detection distances, but not for recognition distance. Forbes ranked yellow over white; with the Hanson and Dicson findings on detection distances the order is reversed. Hanson and Dickson, after analyzing their comparison by background color data, concluded that contrast ratio is of primary importance in determining the rank order of detection ranges with color contrast and target luminance participating to a lesser extent. This finding is in accord with Forbes' findings on brightness (to be discussed later) and is also in agreement with the contrast effects cited in relation to the studies by Decker (1961), Hulbert (1963), and Birren (1957). If the results of all three studies are compared for similar measures (Forbes and Odescalchi compared with Hanson and Dickson's detection range), the following order is obtained: fluorescent yellow-orange, yellow, white, fluorescent red-orange, brilliant red, international orange, saturated green, blue, dark green, and black. Fluorescent red-orange, brilliant red, and international orange can't be ranked because there are no similar measures.

It is conceivable that the color/shape route guidance system will utilize media other than signs to carry the color/shape code. Taylor and Datta (1971) conducted a study on the delineation potential of colored pavement. The informational content of delineation is essentially based on the contrast between one color or brightness and another color or brightness. The study primarily centered on a measure of color contrast called the chromaticity vector, which is a measure of the differences in two spectral curves. This measure was found to be correlated with a subject's ability to differentiate colors. Four colored pavement samples (red, orange, yellow, and green) were used in the study; some samples were made with both clear and color-coated beads. The study was performed in a lab with samples being evaluated for six variables: (a) pavement color, (b) type of lighting, (c) effect of rain, (d) bead size and type, (e) angle of incidence for light source, and (f) wear and weathering. Both a physical (reflectance) measurement and human subjects (distance to identify color) were used. Different combinations of colors were examined for contrast under four different lighting sources. The combination identified at the greatest distance is orange and green pavement under hucalox lighting; the worst is orange and red under the same lighting. In wet conditions, contrast approaches zero since the water reflected the incident light rather than the different surfacing materials underneath. The effectiveness of reflective beads is also dependent on their color. Overall, it was determined that, with the proper selection of materials and lighting, changes of up to 100% may be made in the distance at which colors can be correctly identified. None of the results on color combiantions are directly comparable to studies previously discussed.

There are questions about the traffic literature's present status in regard to color. One crucial question is: What is the interaction between the color combination within a sign and the sign's color against the surrounding environment? It also seems clear that terms used to describe attributes or visibility must be clearly defined and agreed upon. The relationships between factors like legibility, recognizability, and others must be worked out so results may be generalized correctly from one study to another and so that, in accounting for these relationships, we might approach the formulation of optimum sign colors across situations. Comparisons between studies could be made more critically if experimenters specified standardized values (like the Munsell notations) for their sign colors. Presumably, future work aimed at highway information systems would avoid using colors which are only slightly different from the 12 colors established in the MUTCD (1971).

Brightness

Brightness must be considered as essentially the most important factor in the visibility of a highway sign. Forbes (1969) concluded that brightness contrast factors were of the greatest importance for sign visibility; color contrast was also important but secondary. Experimental work in applied areas other than traffic signing also indicates the importance of brightness. Citing a 1944 study by Eastman, experimenters Baker and Grether (1954) pointed out that the highest color contrast possible produces a visual acuity equivalent to that produced by a brightness contrast of 35%. In another study, Gustafson (1960), using luminance reflective values for Federal Standard colors, found that errors in discriminability increased as brightness contrast decreased without regard to hue contrast. Returning to Schmidt's (1967) discussion, it can be recalled that visibility is a function of the reflective efficiency of different colors. Essentially then, as Forbes (1968) points out, it is the bright colors which are "seen best" more freuqently. Hue contrast interacts with brightness contrast but it is the color's brightness value which chiefly effects visibility. Brightness contrast in a color/shape system serves to enhance or minimize attention value and legibility while hue contrast ensures or minimizes the recognition of a color code.

Because brightness is of such importance to highway sign visibility, factors effecting brightness which are relevant to the color/shape route guidance system should be mentioned. Much of the work in the traffic literature is directed towards night visibility since brightness becomes more crucial at night when visual acuity is lowered. Most of the highway studies have dealt with such factors as sign position, both with respect to the pavement and the vehicle; different conditions of illumination, like headlamps with and without ambient light; and the reflective characteristics of signing materials. The literature reflects the infinite variation possible for each of these factors. Rather than consider each study in depth, only articles on the factors relevant to sign brightness will be cited and summarized briefly. Straub and Allen (1955, 1956, and 1971) have studied the factors which are crucial to the relationship of sign brightness and legibility. Their first study (1955) considered night visibility factors: sign brightness, level of illumination to which the eye is adapted, characteristics of sign letters, and contrast direction in both field and laboratory experiments. Also discussed was irradiation which occurs when a driver, whose eyes are adapted to a fairly low level of illumination, encounters a sign of much higher brightness. For signs of high brightness, irradiation can be reduced by narrowing the stroke width of white letters or widening the stroke width of black letters. Essentially this study was directed towards answering the question, "How bright should a sign be?". The 1956 study of Straub and Allen was intended to answer the question: "How bright is a sign of a certain material in a given highway situation?". In that paper, a method for calculating the brightness of a reflective material for a given distance and placement is described. Through this method the effects of sign position relative to the pavement, reflective material type, headlamp type, and vertical and horizontal curves were discussed. It must be pointed out that the state of the state of the art in signing materials has advanced dramatically in the past few years so that the two older Straub and Allen studies should be consulted for their explanation of brightness and legibility relationships rather than for the values given for specific signing materials. In the more recent study, Straub and Allen (1971) sought to determine letter heights which would satisfy nighttime legibility requirements. A computer program was developed which calculated required letter heights for a given legibility distance using published empirical data relating brightness to legibility. Minimum letter heights required for road distance up to 2,000 ft (610 m) are given in the article. In the final discussion of their findings, the authors pointed out that signs must be implemented individually because of the wide variance in road conditions.

A 1967 study by Allen et al. offers findings more relevant to the needs of the color/shape route guidance system. The study dealt with the relationship between sign luminance (brightness) and legibility over a wide range of ambient conditions. The results show that a sign of low brightness is seen better under low ambient illumination while a bright sign is seen better with high ambient light. This suggests that the brightness values of signs should be altered to suit the conditions of the illumination. For the color/shape guidance system, it would be necessary to ascertain whether the color/shape code could still be recognized despite brightness differences within a sign series. A significant finding of the study was that light letters on a dark background sign had superior legibility in comparison with dark letters on a light background sign; the difference for this finding was not uniform but varied slightly with sign luminance. This seems to contradict the positive contrast effect (i.e., dark on light would be superior to light on dark) discussed in the previous section. Studies mentioned earlier in the color section demonstrated the validity of the positive contrast effect for day conditions. It is possible that the negative contrast effect is superior to the positive contrast effect at night levels of illumination. A final finding of the Allen et al. (1967)

study was that high contrast (100% contrast) legends were read at a distance 12% farther away than the lower contrast (75% contrast) legends. Youngblood and Woltman (1971) examined the brightness values of contemporary guide-sign facing materials and listed luminance readings. A more recent study by Levin (1974) considered the luminance level of signs in relation to ambient light conditions, the characteristics of sign facing materials, and the uniformity of sign face luminance; formulas for some relationships are given.

Each of these studies demonstrates that the number of variables relevant to visibility at levels of night illumination is great. It is also clear that individual values for the relationships between these variables are complex. This complexity and wide variation is reflected in the highway environment. More work in the areas of brightness legibility at night levels of illumination must be done before specific guidelines for the manipulation of night visibility factors can be applied widely.

The saliency of brightness for visibility is perhaps more meaningful in terms of brightness contrast. Forbes' (1969) studies of highway sign visibility found, as earlier stated, that brightness contrast was the primary effect on target visibility with color contrast being an important but secondary effect. In one of many experiements (using the same methodology as described earlier) Forbes et al. (1968a) found that the darkest and largest signs were seen best against a day-snow background. It was also found that the dark, small signs were seen "best" more frequently than the bright, large signs against a day-snow background. This finding demonstrates clearly the primary importance of brightness contrast. Against a dark-night background, it was found that the brightest of four blank signs was seen "best" more frequently. Forbes et al., in the same (1968a) study, also introduced the variable of legend-to-sign-background brightness by adding large bright letters and symbols to the simulated signs. Brightness contrast increased as the sign backgrounds were darkened behind letters of constant brightness. This enhanced the attention or target value of the darker signs. It was found that higher letter-to-sign-background contrast opposed the effect of greater sign brightness against a dark-night environment and contributed to the effect of a dark sign against a bright-day environment. The direct relationship between brightness contrast and visibility was demonstrated when visibility decreased as sign-letter brightness decreased with the sign background. Forbes suggests that these findings indicate that silhouette seeing is important for attention value when signs are seen against a bright background. It is clear that more must be known about brightness contrast and how within-sign contrast interacts with sign-to-background contrast.

In another study, Forbes et al. (1968b) looked at the visibility of four green interstate signs, varied for brightness, in environments of dark-green trees, a yellow-brown hill, and a blue-grey cliff. Forbes found that the brightest sign was seen best against the dark-green trees. While both the brightest and darkest signs were seen well, the darkest sign was superior, evidently because there were both dark and light elements in the blue-grey background. These results clearly support the validity of the brightness contrast effect. It was in this same study that Forbes examined the seven different colors (black, dark green, blue, saturated green, a brilliant red, yellow, and white) in the three background environments mentioned above, plus a day-snow background. It was found not only that the brightest colors were "seen best" most frequently but also that the average percent "seen best" increased in an almost linear fashion with the log of brightness. It was also concluded that hue contrast effects did show an effect for the red, yellow, and black signs.

General conclusions on the effects of brightness may be summarized as follows. It was determined from the Allen et al. (1967) study that a sign of low brightness was seen better in low ambient light conditions while a sign of high brightness was seen better in high ambient light conditions. While this may appear to contradict the findings by Forbes et al (1968a) of an almost direct relationship between brightness contrast and visibility, it seems more likely that Allen's results are a function of the light adaptation level of the eyes. The earlier findings on the positive effect of positive contrast on visibility at day levels of illumination may perhaps be reconciled with the findings of Allen et al (1967) to the contrary for night levels of illumination. The answer may be forthcoming when the interaction between within-sign brightness contrast and sign-to-background contrast is more fully understood. Forbes' overall findings indicate, first, that brighter signs are generally seen better than darker signs, but indicate secondly that visibility or attention value is a function of brightness contrast.

Shape

Very little extensive work has been attempted by traffic researchers on visibility and shape despite the continued use of shape as a code in highway signing. At present, the MUTCD (1971) lists the octagonal shape (exclusively for stop signs), the equilateral triangle shape with one point downward (used for yield signs only), the round shape (applied to railroad crossings and used as the shape for civil defense markers), and the pennant shape (used for the no passing zones) as being reserved for specific applications. Other shapes are being used in broader applications, like the diamond shape (warning sign), the rectangular shape with long dimension vertical (used for regulatory signs), rectangular shape with long dimension horizontal (generally used for guide signs), the trapezoidal shape (used for recreational area guide signs); and the pentagon shape with the point up (used for school advance and crossing signs). Few of these sign meanings are likely to be clear to drivers as Ferguson and Cook (1967) have demonstrated in their study of driver awareness of sign colors and shapes. They found that generally only the signs which required an active rather than a passive response were recognized; drivers consistently remembered the meaning of only the octagonal shape, the inverted equilateral triangle shape, and the circle shape. These findings are relevant to the color/shape route system in that they emphasize the importance of building adequate associations between the sign shapes used and their application. The use of shapes as codes in signing in addition to color can enhance recognizability because of its being a redundant code. Shape as a code becomes even more crucial for those individuals who have color blindness. A remaining distinction for color/shape coding is that the shape is the "message" rather than the exterior boundary shape surrounding a distinctly separate (redundant) message. This implies greater attention will be paid to the shape in a route marking context.

Aside from making contributions to the coded meaning of a sign, shape can aid in enhancing the visibility of a sign. A study by Hills, Freedman, and Goldsmith (1972) considered the effects of the design of Interstate direction signs on visual performance. Recognition distances were recorded for sixteen designs under lab conditions and six others under field conditions. The designs were constructed with square and pointed ends and contained arrows, chevrons, and other pointed symbols. Results showed that the pointed signs gave markedly superior recognition distances for the identification of individual direction. Among the shapes, the chevron (with 70° angle) produced the greatest recognition distances in distinguishing both the direction indicated and the symbol used. Recognition distances for chevrons tended to be greatest for angles ranging from 70° to 120°.

Both the pointers and the chevrons could be applied to the color/shape guidance system at decision points, and this may insure greater sign visibility and good response at those points. Before these elements can be introduced to the system, it must be determined whether or not their addition would contribute to confusion in the driver's visual task. A final finding of the Hills et al (1972) study was that a white border around the sign's edge enhanced the effect of the directional pointers. This conclusion implies borders on all sign shapes are desirable to enhance visibility.

Two studies on a curved stop sign have been run by Nelson and Ladan (1972) and Ladan and Nelson (1973). These studies were based on lab findings that showed that a two-dimensional object having a flat surface does not communicate its spatial plane accurately; the conventional flat sign face leads to confusion of reference. The distortion of shape in a curve sign evidently communicates the spatial plane and its reference more efficiently. In the first study (1972), a flat, elliptically-shaped red sign labeled "stop" was compared to a curved sign with the same dimensions with the bend around a vertical axis. (The ellipse was used instead of an octagonal shape to reduce the stereotype effect.) In all test runs, the curved sign was demonstrated to be superior in terms of communicating its spatial plane and reference. The authors suggested that the curved stop sign could be especially beneficial if applied to situations with less than ideal conditions like: (1) night, rain, or fog conditions; (2) emergencies or situations not likely to be familiar to the driver; (3) in unstructured locales; and (4) special circumstances. A second study by Laden and Nelson (1973) demonstrated essentially the same results for a dynamic traffic situation in which nine angles of orientation, four vehicle velocities, and the interaction of these factors were studied. It is evident that both of these studies suggest that sign shapes might be communicated more efficiently if they were curved. This knowledge could be applied to the signing used in a color/shape route guidance system.

A comprehensive study of the effects of sign design on visual performance was conducted by Markowitz et al (1968). A signal detection technique was used. Stimuli were presented to subjects on a screen through the use of a projection tachistoscope. Subjects were to indicate which sign from a set of signs was presented on each trial. When this method was compared with a field method using a helmet equipped with a visor which allowed periodic viewing of the signs it was found that the relative recognizability of individual signs varied across the two methods: Two or three of the most recognizable signs in the field study were among those least recognizable as determined by the lab study. The results indicated that obtuse-angled figures and circles were ranked lowest on an index of recognizability. The triangle was the best recognized shape, followed by the trapezoid and the pennant. The shapes with the poorest values of recognizability were the octagon, the pentagon, the square, the diamond, and the circle, with the circle and the octagon easily confused.

Markowitz et al. (1968) also compared color shapes against black and white shapes finding a different rank order for detectability of shapes across the two media. For instance, the triangle, which was the most detectable when black and white, was ranked fifth when colored. Shape recognizability also seemed to depend in part on color. Considered across all shapes red was found to be the most recognizable color, with blue and green being least recognizable. Other studies on color, cited below, argue that yellow should be ranked as more visible than red; a finding which contradicts Markowitz's finding of high detectability for red. This difference could also arise as a result of the interaction between color and shape; the studies cited previously examined color on a constant sign shape. When color shapes were compared with each other for distinctivity (a measure of the discriminability of one colored shape display with other colored shapes), the most distinctive were ranked by color/shape combinations. Those found to be least distinctive were the yellow hexagon, trapezoid, circle, and pennant. It is interesting to note that yellow was rated high on recognizability but lwo on distinctivity; this finding means that yellow is highly visible presented alone, but easily confused with other color shapes when presented among other color shapes. Markowitz's results also showed that the positively contrasted color/shape had superior visibility over the negatively contrast color/shapes. The differential effects of color on sign shape recognizability should be more completely worked out. At present Markowitz's results show that the best recognized color/shape combinations were the red square, the yellow circle, the blue pennant, and the green pennant. The most distinctive shapes were the red bar, octagon, square, and pentagon; the blue bar and pennant; and the green bar and octagon.

One final area that should be considered briefly in a discussion of the use of shapes in highway signing is the work on symbol signing as compared to word signing. Signs using shapes as codes can be compared to those signs which convey a message through pictorial representation. It is important to note that the shape coding of interest in this review is in the context of a signing system. Color/shape signs differ from symbol signs in that symbol signs are generally used singly rather than repeatedly in a sequence. King and Tierney (1970) evaluated the glance legibility of symbol signs in comparison to word signs. They utilized a motion picture technique to present signs for 1/3, 1/6, 1/9, and 1/18 of a second. Word signs commonly used in the United States were compared with symbols from both the Canadian Pan-American and Quebec-United Nations symbol systems. The signs were presented in black and white. A matching technique was employed which required the subject to match a briefly presented stimulus with one of a set of nine signs which were presented previously; the percentage of correct matches was used as the dependent variable. The symbols from both symbol sign sets were found to be more legible despite shortened exposure durations while verbal signs became less legible.

Another study by King and George (1971) presented the same signs as used above through a tachistoscope slide projector, except that the signs were colored instead of black and white. Subjects saw signs for 1/3 or 1/18 second and were required to match the sign seen with one of a previously presented set of nine slides. A delay of 5 to 10 seconds followed each presentation. An interference task was given to one group of subjects during the delay period. The results indicated that symbols are slightly more legible than verbal signs with legibility being much greater when the interference task was used. The results were somewhat less dramatic than those found for the earlier King and Tierney (1970) study. One speculation for this change across the two studies is that color, which was present in the King and George (1971) study but not in the King and Tierney study (1970) may have an overall detrimental effect. As Markowitz et al. (1968) pointed out, the perception of shapes is partly dependent on color. This effect was found to affect the shapes differently.

An earlier study by Cameron and McGill (1968) evaluated speed control signs, both verbal and symbolic. Time to classify the signs was used as the primary measure. Again the symbol signs were found to be superior. These three studies on symbolic signing generally indicate that symbol signs would be useful in high-pressure situations where great demands are placed on the driver's perceptual and information-handling capacities. This is directly relevant to the color/shape guidance system.

The work done on shape signing has a number of implications for the development of a color/shape guidance system. Markowitz et al. (1968) reported that, when color was not considered, obtuse angled figures and circles were very poorly recognized but that the was recognized best, followed by the trapezoid and the pennant. Markowitz's results demonstrated that the visibility of shapes was differentially affected with interaction with color. Ladan and Nelson (1973) and Nelson and Ladan (1972) suggest that curving the signs will enhance their usability. Hills et al. (1972) found that pointed signs perform better as directional indications than square signs and that white outlining around a shape increases its visibility. Work on symbolic signing suggests that greater improvements in glance legibility and efficiency will be obtained with color/shape signing.

Size of Symbols

The effectiveness of the color, shape route guidance system will depend in part on the size of the symbols as they are viewed in their operational settings (i.e. PMD or posted on overhead sign). The size of these symbols must conform to the visual requirements of the driving population. It is estimated that "normal" visual acuity (1 minute of arc or smaller in resolving power) is found in about 72.8 percent of the U.S. adult population (including individuals with lens corrected vision). Of the remaining 27.2 percent of the population 22.2 percent meet at least the most common licensing minimum requirement of 2 minutes of arc resolution (6/27, 20/40). The final 3.2 percent probably constitute a portion of the population which cannot be reasonably accounted for in most practical signing systems.

Jacobs, Johnson, and Cole (1975) compared alphabetic traffic signs with symbolic traffic signs for visibility under conditions of both normal and reduced visual acuity. The authors of the study concluded that the symbolic traffic symbols studied were identifiable at about twice the viewing distance at which alphabetic legends were readable. When ranked in the order of 50 percent threshold legibility distances the 16 symbolic traffic signs used in the study were grouped compactly varying from threshold distances of 200 m (656 ft) to 350 m (1148 ft); the one exception to this grouping was the crossroad symbol sign which chould be identified at about 500 m (1640 ft). The alphabetic traffic signs, on the other hand, varied from 250 m (820 ft) to 80 m (263 ft) for 50 percent identification distances. Other conclusions, important for road guidance considerations were that the variations between subjects was not significant and that there was no significant difference between the 50 percent identification distances for signs without the standard border and for those with the standard border. The results of the study also indicated that the symbolic signs are identifiable at about twice the distance of alphabetic signs regardless of variations in visual acuity conditions. For a sign to have a 0.95 percent probability of correct identification at a given distance it must be approximately 1.7 times larger than the size required for a more compact sign. The ratio of change can be as low as 1:2. Overall the results of the Jacobs et al. study indicate the advantage of symbol signs over alphabetic signs and provide some guidance for determining sign size.

Symbol sign size requirements can be roughly approximated by generalizing from current size requirements for alphabetic road signs. At present, the common understanding is that for each millimeter of height, 0.6 m. of legibility distance is obtained (50 ft [15 m] per inch of letter height). Using this rule, a 100 mm (4 inch) letter would be legible at a distance of 60 m (197 ft), for the driver with the 20/40 visual acuity, if the symbol were 100 mm (4 inch) in dimension. However in light of the results of Jacobs et al. (1975) this ratio would be conservative. In the context of the color shape route guidance system, the symbols used will probably become identifiable at even greater distances as drivers become familiar with the sign symbols.

Color Coding Systems

Traffic researchers have implemented systems which use color to mark or delineate a path in highway interchanges or intersections. In many of these studies, the initial components in the system are signs which provide guidance to a specific destination contiguously with a particular color code; this serves to build an association for the driver between the color code and the specific destination. Later in the system, color is applied at crucial points to guide the driver. Color has been applied on pavements, in delineators, and on raised pavement markers. The color coding systems are discussed here because they considered methodologies, intersystem component relationships, and road conditions relevant to the study of color/shape route guidance system. The evaluation of these sytems has been performed using a before and after design. A field site is chosen (on interchange, or a left turn intersection); traffic counts are taken, as well as measures of erratic maneuvers and directional constancy; the system is then implemented and later it is evaluated by determining whether there are changes in values of the measures taken previously.

One of the earliest studies of color coding for highway use was Fitzpatrick's (1960) study on the use of color coding for night guidance. In the study, both exiting and merging ramps as well as the through lane of an interchange were coded with high intensity reflective colored materials. A yellow (to denote caution) beaded reflective material was applied to the traveled surface of on-ramp terminals and merging zones. Yellow post-mounted delineators (PMDs) were posted on either side of the ramp and beside the merging zones. To provide contrast to the yellow, a blue reflective surface was applied to the deceleration lane and exit ramps; blue PMDs were also posted. Pertinant guide signing for exits was given blue bakcgrounds (2-mile and 1-mile advance guidance signs were on conventional green); the standard warning sign series for merging areas was retained. The silver through lane delineation and standard green guide signs was also retained. The coding was visible to all traffic. Luminance readings were taken for the pavement under high beam illumination at night. At 100 ft (31 m) the reflective blue roadway provided 6 ft-L luminance while the yellow pavement provided 40 ft-L luminance compared to the untreated surface which returned 0.8 ft-L. This increase in luminance markedly increased the contrast ratio between the road and the surrounding environment. The study did not consider the traffic's response to the coding.

Anderson and Pederson (1963), working out of guidelines provided by their earlier 1959 study, investigated the application of a color system to a highway interchange. While the first study had used blue exclusively for exits and yellow for entrances, the 1963 study intermixed the two colors for exits so that blue was applied to some exits while yellow was applied to others. These exits were compared against uncoded exits which served as controls. Yellow was used exclusively for entrance ramps. The color treatment was applied to reflectorized edge lines, delineators, and sign backgrounds. Using a before and after design, before data were taken in the months of June, July, and August of 1962 while after data were taken in June and July of 1963. The data recorded were: approach speeds by lane, lane placement, volume by lane, vehicle classification by lane, points of exit and entrance, exiting speeds, and measures of erratic maneuvers. Day and night observations were made. Roadside interviews were conducted in October 1963. Questions were intended to elicit information about the driver's response to the system without specifically directing his attention to the system. The results indicated that yellow and blue had differential effects: the blue resulted in significantly faster speeds and later exits than on the control exit, while the yellow produced slower speeds and earlier exits. The driver interviews proved to be a poor measure of driver awareness of the system. After a one-year exposure to the system, only 25% of the drivers mentioned the color when asked whether they had noticed anything different [even though 75% used the interchange more than once weekly]. In response to a direct question about the color system, 64% replied that they had seen it. These results tend to indicate that the drivers had a "conscious indifference" to the system. The use of yellow in exiting areas probably introduced a stereotype caution response, causing the slower exit speeds and the earlier exits.

Some time later, Roth and DeRose (1965) of the Michigan State Highway Department conducted a pilot study to evaluate a color coding system which consisted of edgemarking, delineators, and signing. Following the lead of the previously mentioned studies, Roth and DeRose chose blue for exits, yellow for entrances, with white for the through lane. This system was applied to two freeway interchanges which were designed as two-lane ramps from two-lane highways; each of the roadways then split, with a left hand exit and the through road to the right. Driver confusion arose from the left hand exits and the presence of an upstream curve in the through road which was misleading as to its destination. Edgemarking for the exit ramps was applied in a 8-in, high-intensity reflectorized blue stripe on the left side and along the right side of the exits. A 4-in, high-intensity reflectorized white stripe was applied in essentially the same manner to the through lane. Entrance ramps for the opposing traffic were coded yellow. Delineators were mounted on posts parallel to the edgemarking. Three-inch white delineators were posted along the thruway; 4-inch by 10-inch plaques of yellow and blue were posted at their respective ramps. New exit and directional signs were erected with blue backgrounds.

The signing in this study was different from the Anderson and Pederson (1963) study in that advance directional signs were coded blue. The earlier presentation of the blue color on the signs in association with the other blue markings presumably served to strengthen the code meaning to the driver. A number of pure sign changes (legend changes or removal of previously existing signs) were implemented with the color system's implementation.

Vehicle movements and erratic maneuvers were recorded for both before and after the color system installation. Drivers were also interviewed after the system was applied. The before recording was done in July 1963, and the after measurements were taken in October 1963. A reduction of traffic volume across data collection periods, resulting from the drop-off in summer tourist traffic, motivated the experimenters to compare traffic on the basis of per 1000 vehicles. Observations were made for both daytime and nighttime traffic. The study showed a 38.2% reduction in erratic maneuvers at one site with a reduction of 33.5% at the other for combined day and night counts; this reduction was highly significant. The results also showed that drivers were getting in proper lane positions for the exit movement earlier, apparently correspond to the beginning of the blue color. Increased use of the left lane of the exit ramp also was observed. Data for the nighttime observations were not sufficient to support conclusions. The data did indicate the generally positive effect of coding.

The results of the interview were summarized, with 86.2% of the daytime familiar drivers and 93.5% of the nighttime familiar drivers reporting that the system was beneficial with 82.5% of the daytime unfamiliar drivers and 90.6% of the nighttime unfamiliar drivers feeling it was a benefit. For driver awareness of the blue coding similar percentages were reported for both groups. In general, the study indicates a positive effect arising from the implementation of the color coding system.

The Michigan Department of State Highways also conducted a later study (Roth 1970) based on the previous study. The same color treatments were applied to 18 interchanges on a 40-mi (64-km) section of rural freeway. Diamond, loop, and connector ramps were coded for the northbound direction only. Erratic maneuvers and general observations were taken for both night and day periods in a before and after design (before: July 6 - July 20, 1965; after: August 23 - September 3, 1965). An interview was conducted also. Accident counts were reviewed for one year before and one year after. Erratic maneuvers were reduced significantly for the after period; good improvement was seen on all ramps except the diamond ramp. Results for the interviews showed that for those who used the freeway once a year or less, only 66% of the day drivers as opposed to 83% of the night drivers knew the code's meaning. The review of accident data showed that there were three times as many accidents on the southbound side (the side not coded for the study) as compared to the northbound side. These results could not be related directly to the color system. This study does give results favorable to the color coding system for several types of interchanges.

Taylor (1965) conducted a study by means of interviews to determine the public's response to a color system. The system was applied in essentially the same way as those cited previously. The author concluded that there was popular support for the color coding system.

The Oregon State Highway Department (1966) conducted a before and after study of the effect of color coding on night driving on interchange ramps. Blue was used as a code for exiting ramps and was applied in an eight-inch wide blue edge stripe; on delineators, mounted three to a post; to the background of signs; and to the chevrons of the gore area [the gore pattern alternated white and blue]. In this study, color coding: (1) resulted in a smooth exit path, (2) seemed to be most effective on ramps having the greatest distance between the beginning of the deceleration lane and the gore point, (3) had no effect on exiting vehicle speed, (4) had no definite effect on accident rates, (5) seemed to be most applicable to special problem areas.

The last study on a color coding system to be reported here was conducted by Taylor (1968) to evaluate the use of colored pavement as a control and guidance device through intersections with left-turn slots. Again, the design was a before and after study in which approach speeds, traffic flow patterns, and lane position were analyzed. In the after period, the left-turn lane was paved with green, indicating go, while the island was paved in yellow, indicating caution. Analysis of the data supported the conclusions that: (1) the introduction of colored pavements at left-turn intersections does not significantly reduce vehicle velocity, (2) for daytime traffic there is a more uniform pattern of lane changing exhibited with the colored pavement, (3) colored pavement has little effect on traffic patterns at night. The effect of the colored pavement probably was reduced at night because, unlike the Anderson and Pederson (1963) study, the color was not treated with reflective beads.

Overall, the studies on coding indicate color coding would have a positive influence for systems made up of such elements as coded advance and choice-point signing, pavement marking, edge line marking, delineators, and gore chevrons. High reflective materials are necessary to insure visibility at night. A few of the studies discussed had methodological problems; these problems will be highlighted here to help insure that the proposed evaluations do not fall prey to these same problems. One requisite of a sound design in traffic studies is that the after data should be taken for essentially the same time period, in the year, and for the same hours of the day as the before data. In this way spurious variables are not introduced; for instance, summer data often has more inexperienced tourists driving than is the case in the winter. Also, the time period between the two data collection periods should be sufficiently long that the after period is not measuring the novelty effect of the applied system as well as the system effect. It is also important that only changes specifically relevant to the system to be evaluated be applied for the after study; if a sign change is made over and above the system implementation, it may have an additional effect on traffic performance.

Often evaluations of systems are done utilizing driver interviewing techniques. These studies must avoid biasing the questions by telling the drivers that they just went through a new system. Telling a driver about a system may serve to remind him of cues he would not ordinarily heed or remember. If specific choices for answers are provided they should also give the driver opportunity to express further variations or elaboration. Subjects often are biased to answer yes instead of no if these are the only choices, even though they may be wholly indifferent to the system. These points must be taken into account for the formulation of specific methodology for evaluating a color and shape route guidance system.

Diagrammatic Signing

Brief mention should be made of the work on diagrammatic signing as one of the few modern attempts to improve the driver's guidance task through major new concepts of signing. Since the color/shape guidance system is to address the same area of concern, the results from diagrammatic signing studies may be used as a benchmark against which the color/shape system can be compared. The two systems are similar in that they involve a learning process upstream of a difficult area. The driver is prepared in a relatively low pressure area to cope with a high pressure area later. This earlier preparation is to serve to minimize the driver's confusion at a choice point. The two systems are different in that the diagrammatic signing usually requires a more complete initial learning process. The color/shape coding system creates an association in the driver between one symbol and one destination. In the color/shape guidance system, the driver only need know one symbol's "meaning" to be able to take advantage of the later presentations of that code which are presented at crucial decision points. On the other hand, the driver following diagrammatic signing must carry a complex visual or spatial image in his head which must later be translated into actions appropriate to the real situation.

Diagrammatic signing essentially involves a graphic presentation of a roadway situation, like an interchange. The design of the sign can be varied in many different ways (i.e., orientation or perspective of view). It is perhaps in part because of the wide variations in design that diagrammatic sign studies have shown varying effects. A 1972 study by Eberhard and Berger used a laboratory projection technique to evaluate five sign concepts and six interchange types. Their results demonstrated significantly greater performance for diagrammatic signs at collector-distributor and multiple split ramps. The graphic guide signs as opposed to the conventional signing, received higher preference ratings with the conventional signing least preferred. This difference in preference may be wholly or partly due to a novelty effect. Gordon (1972) evaluated diagrammatic signing in comparison with conventional signing for a freeway cloverleaf intersection, a lane drop, a multiple split ramp, a left ramp downstream of a right ramp, two right ramps in quick succession, and a major fork. Conventional signs were found to be slightly more effective overall than diagrammatic signs. This result may be explained in part as a result of the drivers' extensive previous experience with conventional signs. Hanscom (1972) found diagrammatic signs to be generally more effective than conventional overhead signs on a heavily traveled highway: weaving maneuvers in the gore area decreased; partial weaves increased, with vehicle hesitations and stopping or backing reduced; accident records showed a 35% reduction during 11 months. In a study by Roberts (1972), one type of diagrammatic signing (without lane lines) showed a significant reduction in unusual maneuvers over conventional signs for an interchange. When this first type (without lane lines) was compared with a second type (with lane lines), the results favored the second type with a reduction of unusual maneuvers shown for the second type. Interestingly, the first type showed significantly more unusual maneuvers for a second data (August 1969) period as compared to the first (July 1969). No explanation was given for this difference. A later study by Roberts (1975) experimented with 22 interchanges. Ninety-four diagrammatic signs replaced 120 conventional signs. Results: (1) conventional signs produced a lower critical maneuver rate than diagrammatic signs for a split or parallel roadway, (2) for cloverleaf interchanges, diagrammatic signs effected a lower rate of stopping or backing maneuvers but a higher rate of exit gore weaving maneuvers, (3) diagrammatic signs at right-hand T-ramp exits approached by either one auxiliary lane or a regular deceleration lane produced a lower rate of stopping or backing maneuvers as well as fewer or the same number of exit gore weaving maneuvers.

The most methodologically sound study of diagrammatic signs is one conducted by BioTechnology, Inc. and reported by Kolsrud (1972). The author points out that in any field study of the relative effectiveness of various types of route guidance signing, the design of the study must accommodate the following factors: the proportion of familiar and unfamiliar drivers; a possible novelty effect of the signing changes on familiar drivers; and the fact that a large proportion of familiar drivers may mask any effects of the signs on unfamiliar drivers, particularly when measures other than erratic maneuvers are employed. The designs of the previously discussed studies did not accommodate all of these factors, whereas the design of the BioTechnology, Inc. study (Kolsrud, 1972) did so by using an appropriate acclimation period, observation, and classification of local and non-local drivers, etc.

The results of this study showed that drivers require more time to read and interpret information on diagrammatic signs in comparison with conventional signs. Also, it was found that as the graphic component on the sign increases in complexity there is a commensurate increase in driver interpretation time. This led to the conclusion that simple graphic designs must be used. Their results clearly indicate that diagrammatic signs will produce a benefit to driver performance at interchanges where traffic must exit to the left of the through route, including major forks where exiting traffic must take the left fork and interchanges where there is a single left exit and where there is a left exit in combination with a right exit.

The wide variations in diagrammatic sign design and in the results of the studies make it somewhat difficult to make any final assessment of the merits of diagrammatic signing. However, the BioTechnology, Inc. study (Kolsrud, 1972) is assumed to be the most accurate assessment since the methodological problems which may have affected the results of the other studies were accounted for in the design of this effort.

Additional Methodology

The methodologies already discussed involved either lab studies with slide or film projection methods or field studies which usually evaluated signs on the basis of either legibility and detection distances or changes in driver performance. The studies to be considered in this section have variations in methodology appropriate to study of a color/shape route guidance system that have not been discussed elsewhere in this review.

Bhise and Rochwell (1973) applied more advanced technology -- an eye marker camera -- to the task of evaluating highway signs. Their method determined how well the eye movements of a driver matched the characteristics of a highway sign or situation. In this way, a measure of how much information the driver acquires is obtained. Data were collected on the eye movements of drivers under field situations involving more than 400 different Interstate highway signs and they were analyzed by computer. The eye movement data provided quantitative information on the driver's sign-reading characteristics. It was found that drivers take several glances at the sign rather than concentrating continuously on it. The authors concluded that the eye marker was a useful tool for the evaluation of highway signing with the evaluation measure being related to characteristics of the signing, the driver, the highways, and the traffic situation.

The methodology as given in the Rochwell and Bhise (1973) study could be applied to evaluating specific signs in the color/shape route guidance system but changes in the methodology would be necessary to make the method appropriate for the needs of a system evaluation. Since the color/shape route guidance system involves the learning of a code for application to a later series of signs the methodology must be altered so that it can evaluate the effect learning the code has on the processing of later signs. To demonstrate effectiveness, the color/shape guidance system would have to show a reduction in the number of eye movements as the driver progresses through the system so that, at the later points in the system, only a brief glance would be required to recognize a coded sign.

One study by Dewar and Ellis (1974) compared three methods of evaluating traffic signs. The first method required subjects to classify signs according to type and to identify the sign's meaning while driving towards the sign at 30 and 50 mph (48 and 80 kph) under normal conditions; classification and identification distance were recorded. The second method involved a reduction of signs to one-third size. The same measures were taken as for the first method with subjects driving at 17 mph (27 kph) which is roughly one-third the top speed of the previous method; this reduction in speed was to compensate for the reduced sign size. The third method was a lab study in which the signs of the first two methods were presented via slides; reaction times to classify and identify the signs were recorded. The results showed that the three measures were closely related, with performance on individual signs highly correlated across the three measures. It is also interesting to note that performance was better for symbolic signs that for verbal signs. The second method, involving sign and speed reduction, was the unique variation for this experiment. Such a reduction has benefits in that it reduces material costs and complexity in the experiment.

Case, Hulbert, and Wojeck (1965) developed and tested a simulation device which presents drivers with a series of highway signs while they are performing a tracking task. Three configurations of freeway-to-freeway interchange signs were presented on a paper roll which was moved through the machine towards the subject who viewed the scene through an aperture. The driver's reactions were studied as they "drove" a freeway-to-freeway configuration using a streering wheel control. The study gave results for specific sign formats.

A study by Desrosiers (1965) evaluated another lab technique in comparison with commonly used field research methods. A film technique was compared against a field driving technique for legibility distance; signs for both methods were at one-third scale. In the field, study subjects drove at 20 mph (32 kph) toward the sign (to simulate normal sized signs approached at 60 mph [97 kph]) and pressed a button when a target word was found on the sign. The lab technique was similar except that the film moved while the subjects sat. The results for both studies showed the same trends, with the mean-legibility distances 5 to 60 times as great for the field studies as for the lab test. These greater legibility distances may arise in part because the subject in the field test is able, by moving his head, to view the three dimensional real scene from a variety of different angles of orientation. It should be noted also that the effect of viewing angle was not controlled in the lab; some of the lab subjects had to view the screen from less than ideal angles. This possible source of variance was also uncontrolled in a study by Burg and Hulbert (1962) who used a film technique to evaluate test signs indicating a lane drop. The film was taken with a 16 mm motion picture camera mounted in the driver's position. The actual situation was filmed at 24 fps from a car moving at 35 mph (56 kph). A film of each test sign was shown to the subjects. After each sign, the lights were turned on and the subjects were asked for first impressions. The subjects were then asked to judge the quality of these impressions: clear and immediate, confused, obvious, complex, and/or slow in forming. After all signs were presented, the subjects were asked for personal preference. This method seemed to be highly subjective; the methodology would be improved if it was counterbalanced with more quantifiable measures or at least was evaluated with these measures. The measures of personal preference provided by this method offers a measure of the public's approval of particular signing concepts.

Each of the methods discussed above could be applied to the evaluation of signing appropriate for color/shape coding in route guidance.

BASIC RESEARCH LITERATURE

Apart from the work done for operational highway traffic purposes which is directly applicable to the concerns of the present study, there is the more basic research literature which has some bearing on the requirements of the present study. Often this literature is concerned with the development of theoretical concepts or models which seek to establish basic principles and relationships for the explanation of phenomena. In this review, much of the more academic work will be cited only briefly. Initially, the review will discuss those studies concerned with the use of color and shape as elements in a coding system. In later sections of the review, particular variables which effect the use of color and shape as codes will be considered.

Color and Shape Coding

Much of the work done on color and shape as elements of a code have utilized two-dimensional visual displays which are presented to the subjects; the subjects are required to identify (recognize), locate (search), count, compare, or verify the presence of one or more specified targets which are defined according to such various coding elements as color, shape, numeric symbols, flashing rates, etc. Hitt (1961) evaluated the various dependent measures mentioned and found, using factor analysis, that location and identification tasks are independent measures with counting, comparing, and verifying tasks sharing perceptual and processing aspects of each of these measures. Identification tasks are correlated with counting and comparing tasks (0.53 and 0.56, respectively), while location tasks are correlated with counting and verifying tasks (0.65 and 0.67, respectively). Counting tasks are highly correlated with comparing and verifying tasks (0.80 and 0.69, respectively), and comparing tasks show a high correlation with verifying tasks (0.73); all other correlations between tasks were low. These findings have important implications for comparing and generalizing the results of studies concerned with color and shape coding when these studies use different dependent measures. There are no traffic studies available that evaluate the visual guidance requirements as they relate to the dependent measures studied by Hitt (1961).

A number of studies supply information about the efficacy of various codes when applied to a homogeneous field (a field varying on only one dimension). The codes studied include: color, flashing rate, brightness, shape, numeric, and size coding characteristics. Hitt (1961), in his comparison of four codes across five dependent measures, found that: (1) a color code was superior to numeric, letter, and shape codes for location (search) task and superior to all but the numeric code for counting, comparing, and verifying tasks. Color was judged inferior to numeric coding on the basis of only slight differences in response time. (2) Color was found to be inferior to all other codes (numeric, letter, and shape) for the identification (recognition) task.

Processing times for seven symbolic codes were obtained by Alluisi and Muller (1958). The two numeric codes used were found to be superior to the three inclination codes (angular aspect of line segments) used which, in turn, were superior to the two remaining codes which were color and elipses of different axis ratios. In another study using processing time for codes as a measure, Krieg (1972) found that subjects processed color more effectively than form. Wedell and Alden (1973) found that for a "keeping track" task there was no difference between color and numeric symbols as codes. These two codes may be equally effective for the "keeping track" task because the task has processing components similar to those found with Hitt's location task but dissimilar to those components associated with Hitt's recognition task.

Harris, Kolesnik, and Teel (1964), in a study of wire sorting, found that color coding was superior to numeric coding for measures of both speed and accuracy. An early study by Eriksen (1952) found that when displays varied on only one dimension, color was superior to form for search time, while color and form were both superior to either brightness or size. A later study by Eriksen (1953) found that location time was quickest on visual displays that varied in hue as compared to those varying in either form, size, or brightness.

Newman and Davis (1962) examined the coding effectiveness of three colors, two brightness levels, three flashing rates, and a number of geometric symbols. They found that color coding leads to significantly shorter response times and fewer inaccuracies in both a searching and a decoding task. Counting based on a five-valued color code was found by Smith and Thomas (1964) to be faster and more accurate than counting using one of three shape codes.

Williams (1966) looked at the effect of target specification on the eye fixations of subjects searching a heterogenous field varying according to color, shape, and size. It was found that a high proportion of the fixations were on objects of a specified color, with a moderate proportion on objects of a specified size, and a lower number of fixations being centered on objects of a specified shape. Williams also found that when two or more target characteristics were specified, fixations were generally based on only one of those characteristics. Another study by Stone and Peeke (1971) found that for a matching task, color was a more effective stimulus characteristic than shape, while for a same/different judgmental task, shape was superior to color.

Generally, the studies reviewed indicate that the single characteristic most effective in visual display coding is color, even when compared across a variety of measures. The exception to this conclusion is numeric coding which was superior to color coding on all measures except location tasks. It should be noted however that, for the purposes of the color/shape route guidance system, numeric coding is not applicable. The reviews cited found shape to be superior to color in an identification task (Hitt, 1961) and in a judgmental task (Stone and Peeke, 1971). These findings suggest that shape coding would be more effective as a carrier for specific information, while color would better serve to blaze a trail for the driver; in this way color and shape coding might complement each other when combined into a single symbol.

Many studies indicate that color and shape coding dimensions when combined become more effective than either the color or shape coding alone. Eriksen in two studies (1952 and 1953) found that, in a search task with targets embedded in a heterogeneous field (field varying on more than one coding dimension) targets redundantly coded for both shape and color dimensions were located more quickly than targets defined by multiple or single dimensions varying across form, hue, brightness, and size. In his 1952 study, Eriksen also found that the location times for targets defined on two or three dimensions correspond to a weighted geometric mean of the single dimensions of which they were composed. A similar formulation was determined by Eriksen and Hake (1955) for a discrimination task; the discrimination accuracy of multiply defined stimuli could be predicted with reasonable results if the accuracy of each of the composite dimensions was known. With superior rates of performance being found for color and shape used as single coding dimensions, one would expect that they would be highly discriminable when used together. This conclusion is supported by Eriksen and Hake. It is interesting to include here the results of Garner and Creelman (1964) who found that, in a visual discrimination task, color and size combined were superior to either dimensions used singly. The authors pointed out, however, that their task required judgmental (they used the method of absolute limits) rather than perceptual discrimination.

Green, McGill, and Jenkins (1953) evaluated the effect of a partially redundant color code (a target is defined by two or more codes, not all of which are unique to that target but are shared with some of the other stimuli in the display). These codes were added to three-digit symbols. They found that, when a subject was told the color of a particular target number, search time was directly proportional to the number of symbols in the display that shared that color. When the subject did not know the target color, search time was proportional to the total number of symbols. Green and Anderson (1956) replicated this finding in a second study using two-digit numbers. In these two studies the partially redundant color coded target number (which may be likened to form) was located in significantly shorter times than the target number alone. As in the two studies by Eriksen (1952, 1953), Green and Anderson (1956) and Green, McGill, and Jenkins (1953) found that search time depends on the heterogeneity of the field: search time increased with increasing field heterogeneity. Newman and Davis (1962) reported that when color was used as a non-redundant code in addition to a geometric symbol code, significantly shorter response times and fewer errors were obtained in comparison to the coding dimensions of brightness and flash rate.

A study directed by Saenz and Riche (1974) evaluated the coding dimensions of color, form, and color and form combined. The redundant color/form code produced only slightly faster search times than color used alone; the form code alone produced significantly slower search times. Saenz and Riche pointed out that the information transmission value of a redundant code is dependent on the transmission effectiveness of the individual coding dimensions. This statement suggests that particular coding elements of color and shape dimensions could actually impair the effectiveness of either of the dimensions used alone. The formulations of Eriksen (1952, 1953) and Eriksen and Hake (1955) lend support to the formulation of Saenz and Riche. Eriksen (1952) has suggested a more specific function: that search times for redundantly coded dimensions are directly related to the weighted geometric mean of the search times of all the single dimensions. This formulation needs further verification.

Some understanding of the facilitative process involved in redundant color/shape coding is provided by Gunnerman (1975). Gunnerman suggests that a color detection mechanism serves to draw the form detection mechanism to the vicinity of the target with redundant dimensions. This hypothesis was deducted from his findings that a colored letter (form) in any given position was always more likely to be named, in a letter naming task, than a black letter in the same position. LaBerge and Brownston (1974) found this same result for a similar letter detection task. Gunnerman's suggestion seems to point to a focusing or attention effect provided by color. The Green, Jenkins, and McGill (1953) study and the Green and Anderson (1956) study mentioned earlier both found that search time for numbers coded with a partially redundant color code was directly proportional to the number of symbols which shared the target's color; these results lend support to Gunnerman's hypothesis.

It should be pointed out that Gunnerman's hypothesis implies serial information processing, in which a subject concentrates on one dimension at a time. Williams (1966), as previously mentioned, found that subjects generally fixated objects on the basis of only one of several target characteristics specified. This finding gives some support to the idea that redundant codes are processed serially. William's findings are seemingly contradicted by the results of a study done by Hawkins (1969) utilizing a task in which subjects had to identify pairs (varying along one or more dimensions) as the same or different. Hawkins concluded that stimulus dimensions are compared in parallel when targets vary according to size, form, and color. Hawkins also concluded that subjects cease processing information once they acquire enough to make a decision. In explaining the variance between Hawkins' study and that of Williams, it is important to note that Hawkins' conclusions are based on an examination of eye fixations, which is probably a more direct measure for practical applications, such as route guidance.

Viewed in the context of the color/shape route guidance system, these findings indicate that subjects first attend to one code which serves to focus attention on the second code. For purposes of the color/shape route guidance system, the first code ideally is color because of its superior performance in visual display tasks, and the second code is shape. In many cases, the driver may need to focus on only one coding dimension since it will supply all the information needed. Since color perception weaknesses exist, the shape must furnish most of the information needed for color-deficient observers, even though color is likely to be the dimension with the highest priority for observers with normal color perception. As Hawkins suggests, the driver terminates processing once all the information needed to make a decision is acquired.

The results of some of the studies cited above (Eriksen, 1952, 1953; Green, Anderson, and McGill, 1953; Green and Anderson, 1955) suggest that redundant coding, as it will be used in the color/shape route guidance system, becomes important when signs are presented against a complex heterogeneous field. The driver entering an interchange may be faced with a number of signs varying along each of the dimensions of color, shape, size, and brightness. Sometimes, he will need both shape and color codes to discriminate the crucial sign from others when the signs are similar along one or more dimensions. An example of this kind of sign is the Interstate sign which will share the same color and background shape with a number of signs which differ only in terms of the route number superimposed on the sign. Color serves, as suggested by Gunnerman (1975), to focus the driver's attention on just those signs that are green; the driver can then find the particular route number desired from that smaller set of Interstate signs with green backgrounds. This example and its logic can be applied also to the requirements of the color/shape route guidance system. Redundant coding is especially meaningful for the signing requirements of the color/shape route guidance system since about 8 percent of the population (Robinson, 1967) has color weaknesses to a significant degree, and will have to depend on the redundant shape code.

Interrelationships Within the Color and Shape Dimensions

Several studies (Eriksen, 1952 and 1953; and Saenz and Riche, 1974) indicate that the efficacy of redundancy coded targets depends on the efficacy of the individual dimensions. It thus becomes important to determine which particular elements of the color and shape dimensions are most effective. Color and shape will be considered first separately and then combined to determine which candidate shapes and colors would be most effective for use in the color/shape route guidance system.

Color

Several studies have determined that the normal observer can identify in an absolute sense only about nine colors (Conover, 1959; Halsey and Chapanis, 1951; and Baker and Grether, 1954). While this number may be increased dramatically through continuous practice (Hanes and Rhoades, 1959), it is probably reasonable to assume that, for the purposes of the color/shape route guidance system, the number nine imposes a limit on the total set of colors which can be used. The choosing of highly discriminable colors becomes important because of this limit.

Many of the studies on redundant color shape coding fail to offer specific information about the discriminability of the colors used. Those studies that do offer information about the discriminability of sets of colors will be cited along with other studies from the research literature which offer information on individual color effectiveness. Saenz and Riche (1974) found that the shortest search times were with yellow targets, with red having slightly longer times, followed by blue and then green. Subjects in the Saenz and Riche experiment reported that various target colors were confused with backgrounds of particular colors. Confusion occurred between green targets and green-yellow background objects, between red targets and yellow-red background objects, and between blue targets and blue-green backgrounds. These reported confusions arise because the subjects are unable to discriminate clearly and distinctly between the color pairs involved. A 1962 study by Smith determined that, in a search task, the colors white, orange, and red were more discriminable than green and blue. A study by Smith and Thomas (1964) found the same results, with yellow substituted for orange. Both these studies are reinforced by Saenz and Riche (1974).

Fenee and Rand (1931) evaluated different color test objects (red, orange, green, blue-green, and yellow) under conditions of high and low illumination. Under high illumination the rank order of visibility for these colors tested is: yellow, yellow-orange, orange, green, and red (blue and blue-green were not tested at this level). For the low illumination level the rank order of visibility was: red, orange, green, blue-green, and blue (yellow was evidently not tested at this level). The results of Fenee and Rand for high illumination levels generally concur with the results of the studies by Saenz and Riche (1974), Smith (1962), and Smith and Thomas (1964) with the exception that Fenee and Rand found green to be more discriminable than red, a finding which is not replicated by these other studies. More data on the perception of colors in low light levels is provided by Middleton and Mayo (1952) who found that purple has the highest threshold and yellow and green the lowest. Not enough information is provided by Middleton and Mayo for comparisons to be made with the study done by Fenee and Rand (1931). The articles reviewed in this section provide the following generalities. Under high illumination the rank order of colors for visibility is: yellow, yellow-green, orange, green, and red (red and green vary in position across studies); and under low illumination: red, orange, green, blue-green, and blue.

In a study evaluating the use of color coding for information location Shontz, Trumm, and Williams (1971) suggested that color coding was most effective when colors highly discriminable in peripheral vision are used. The study cited three colors which were highly discriminable in peripheral vision: 10 Blue-Green, 4/4; 5 Red, 4/14; and 2/5 Yellow-Red, 6/5 (Munsell notation). These colors may be relevant to the requirements of the color/shape route guidance system since drivers often perceive the presence of a sign first in their peripheral vision and the color cue may be important in the selection or rejection of a sign seen peripherally as the desired target.

Another area of concern relevant to the needs of the color/shape route guidance system is color discriminability. A number of colors are being used on the highway and the color/shape route guidance system requires that more be added. It is necessary to determine a total set of colors which are sufficiently discriminable from one another in use. Conover and Kraft (1958) have derived sets of colors for coding, insuring that each color is discriminable in an absolute sense from the other colors in the set. When eight colors are required they recommend the following (each is given with the Munsell Notation first followed by the Munsell production number): 1 Red, 999; 9 Red, 982; 1 Yellow, 946; 7 Green-Yellow, 960; 9 Green, 1099; 5 Blue, 1087; 1 Purple, 1135; and 3 Red-Purple, 1003. For a seven element code the following are offered: 5 Red, 1008; 3 Yellow-Red, 890; 5 Yellow, 1128; 1 Green, 1103; 7 Blue-Green, 1095; 7 Purple-Blue, 1133; and 3 Red-Purple, 1003. A six element code could be composed of the following: 1 Red, 999; 3 Yellow-Red, 890; 9 Yellow, 1131; 5 Green, 1101; 5 Blue, 1087; and 9 Purple, 1005. A code of five elements should be made up of: 1 Red, 999; 7 Yellow-Red, 884; 7 Yellow-Green, 960; 1 Blue, 1093; and 5 Purple, 1007. A code made up of four colors can be obtained by taking every second color from the eight element code; in this way maximum discriminability is assured. Conover and Kraft (1958) did not evaluate these codes to determine their visibility values, and there is no available work which does.

A study by Siegel and Siegel (1972) provides further data on human ability to discriminate between colors. Siegel and Siegel use a method of constant stimulus differences to obtain hue discrimination values for different wavelengths. They found that the greatest sensitivity to hue differences occurs around 480-500 nm in the blue-green region of the spectrum and again at about 570-585 nm in the yellow region for both the 1 ft-L (3.4cd/M^2) and 10 ft-L (3.4cd/M^2) levels of object luminance. Highly trained subjects also showed a third area of high sensitivity at 420-430 nm in the violet region for both levels. The areas of least sensitivity for both luminance conditions can be found at the extreme red end of the spectrum and at 530-550 nm in the yellow-green area. These findings cannot be compared with the findings of Conover and Kraft (1958) since they did not provide an explanation of how their highly discriminable sets were chosen. Siegel and Siegel (1972) also found that as stimulus luminance was lowered to 0.1 ft-L (0.3cd/M^2) more individual differences occurred, so that bands of greatest sensitivity were narrowed to 480-490 nm in the blue region and 575-580 in the yellow. At the luminance level of 0.1 ft-L discrimination sensitivity was distinctly reduced.

The findings of Siegel and Siegel (1972) are challenged by the results of a study by Thornton (1972). Thornton found that the most effective wavelengths for hue discrimination of objects illuminated by white light were near 450, 540, and 610 nm. The least effective wavelengths -- in the sense that they caused confusion -- were near 500 and 580 nm. In Thornton's study the most effective wavelengths fail to match those areas found in Siegel and Siegel's study to be the most hue sensitive areas while Thornton's areas of least effectiveness fall within those areas of greatest sensitivity cited by Siegel and Siegel. These differences may be a result of differences in illumination (i.e., color temperature) or in the measures used to obtain the results. Further study is needed to determine the differential effects of illumination on color discrimination. The findings of Conover and Kraft (1958) are perhaps most relevant to the needs of the color/shape route guidance system in that they offer sets of highly discriminable colors.

The research literature also indicates that color contrast, brightness, and brightness contrast are important variables affecting target visibility. With color contrast between a target and surround, the target color will be perceived as approaching that of the surround color. Judd and Eastman (1971) provided a comprehensive study of the target value of colored targets presented against color surrounds. The study offers visibility determinations for 263 combinations of target and surround colors which were obtained through the use of a "contrast threshold visibility meter". In a 1965 study, McLear examined the effect of brightness contrast and color contrast on the legibility of a dial. The results demonstrated that both color contrast and brightness contrast are dependent on the direction of contrast. A negative (light on dark) contrast seems to enhance the effect of color contrast. A negative (light on dark) contrast seems to enhance the effect of color contrast on target legibility relative to brightness contrast. On the other hand, a positive (dark on light) contrast degrades the effectiveness of color contrast but enhances the effect of brightness contrast. McLear felt that the negative color contrast should be reconsidered for application in coding dials.

The findings of McLear on brightness contrast are replicated in a study by Pain (1968) who examined brightness and brightness ratio for Munsell gray chips. His main conclusion was that brightness is the dominant variable in attention value but only in a positive contrast condition. Voss (1955) evaluated the effect of target brightness and target speed on tracking proficiency. Groups of subjects practiced tracking at one of six levels of target brightness: 697 mL, 6197 mL, .0697 mL, and .0028 mL (2571, 257, 25.7, .016, and .010 cd/M^2, respectively). Overall, the results indicated that target brightness affected tracking proficiency in a curvilinear manner. In general, the factors of target brightness, color contrast in a negative direction, and brightness contrast in a positive direction have been shown to be effective in enhancing target visibility.

Shape

While the studies cited on color visibility offer a diverse array of unreconciled findings and variables, studies of shape identifiability seem to have produced more cogent results. In this section, studies concerned with identifiability of shapes will be discussed, followed by a discussion of the factors which aid in making a shape more or less recognizable. Dependent measures used in these studies included sorting times and a number of threshold variables.

A diffusion model for predicting identification thresholds for shapes was introduced and tested by Bitterman, Krasukopf, and Hochbert (1954). This model, which is based on the Kohler-Wallach theory of figural after-effects, predicts that the identification thresholds of shapes will vary directly with the ratio of perimeter to area (P/A ratio). The smaller the ratio the more identifiable the shape. The diffusion model also predicts that the identification threshold will vary inversely with the magnitude of critical detail for figures with nearly equal P/A ratio (e.g., given an "X" and a "T" with nearly equal P/A ratio the model predicts a greater identifiability for the "T" because of its greater magnitude of critical detail). However, it must be noted that similar figures of different areas would have different P/A ratios since A varies as the square of P. Bitterman et al. (1954) tested the predictions of the diffusion model using a circle, a square, an equiangular diamond, an equilateral triangle, and block L, +, X, T, and H shapes of equal areas. They also used versions of the diamond and block X which were four times the size of the smaller figures. Using the log of the threshold luminance as a dependent measure, Bitterman et al. held that the data supported the predicted effect of P/A ratio; identifiability of shapes was better for smaller P/A ratios. Discrepancies that did exist in the data were felt to be support for the diffusion model's second prediction: shape identifiability suffered (i.e., had higher luminance threshold values) with less critical detail. Several shapes had nearly equal P/A ratios but had different magnitudes of critical detail; the shapes with greater detail had systematically lower threshold values for identification. These findings imply an interactive effect between P/A ratio and magnitude of critical detail.

A less theoretically oriented study by Casperson (1950) produced results which lend support to the diffusion model. Casperson examined the identification thresholds with respect to area, maximum dimension, and perimeter of ellipses, rectangles, triangles, diamonds, crosses, and stars. He determined that the percent of correct identifications was affected differentially across shapes by the manipulations of the three qualities. It was found that area was the best prediction of identifiability for ellipses and triangles, while maximum dimension was found to be the best predictor for rectangles and diamonds, and the best predictor for stars and crosses was perimeter. The rank order of shapes was: triangle, cross, rectangle, star, diamond, and ellipse.

A review of Casperson's data indicates that decreases in P/A ratio (within shape category) were directly related to percent correct identifications as would be predicted by Bitterman et al. (1954). Area and perimeter variation resulted from the attempts by Casperson to control for geometric similarity across shapes. A limitation of the P/A ratio was pointed out when Casperson, having manipulated perimeter and maximum dimension with area held constant, found that rectangles, crosses, and stars were more identifiable with increased P/A ratio. For diamonds, there was a partial reversal to this trend, with the percent correct increasing generally with a decrease in P/A ratio but falling slightly with the smallest P/A ratios.

This result was clearly counter to the results of Bitterman et al. (1954) and to the results of Casperson himself for geometrically similar shapes. On its face, this certainly cast strong doubts on the value of P/A for predicting identification thresholds for shapes if effects of the various manipulations on the magnitude of crucial detail are taken into account. As the P/A ratio increases with the perimeter of shapes of constant area, the size increases. The size increase seems to enhance the effect of critical detail of shapes even though the ratio of critical to noncritical details does not increase. The increase in size appears to combat the diffusion effect of Bitterman et al. (1954).

For non-similar shapes with the same shape category and having the same area, critical and non-critical details are not necessarily affected in the same way by changes in perimeter of maximum dimension. For example, based on Casperson's illustration, the magnitude of critical detail for crosses and stars would appear to be increased considerably as perimeter increases with respect to a constant area (i.e., P/A increases). On the other hand, the same type of manipulation of other shape categories, e.g., diamonds or ellipses, would appear to have limited effects on critical detail.

The differential effect of critical detail seems to be a major factor in Nielsen's (1969) findings for the identification threshold of regular polygons. Nielsen examined regular polygons of three, four, five, six, or eight sides. While Nielsen did not discuss P/A ratio it can be shown that P/A ratio decreases with increasing number of sides for figures of equal area. With larger numbers of sides, the lower P/A ratio would predict shorter identification distances of reduced identifiability. Nielsen found that the identifiability threshold distance did vary inversely with the number of sides. As the number of sides increase for regular polygons, the shapes approach a circle; the angles of fewer sided polygons are sharper and more jutting. Nielsen also suggested that discrimination of regular polygons is a function of the length of their sides. This explanation is in harmony with Casperson's findings. There it was suggested that as the P/A ratio increased for equal area figures (in the same shape category) the effect of critical detail was enhanced which increased identifiability.

P/A ratio and magnitude of critical detail can also be examined in relation to a study by Sleight (1952). The study sought to determine the relative discriminability of 21 different shapes each of which was inscribed in a circle with a diameter of one inch. This restriction is similar to the constraints imposed on highway signing, a sign shape must be inscribed in a given area. The shapes were evaluated using a sorting task with mean sorting time and mean selection order used as measures of discriminability. The ranks order correlation of these two measures was 0.79. The shapes are given in their rank order in Table 3. The groupings in Table 3 distinguish sets of shapes which differ significantly with respect to sorting times. Nielsen (1969) is supported by Sleight in that the discriminability of regular polygons was found to increase as the number of sides decreases; the most discriminable regular polygon was the triangle. With inscribed regular polygons, the area increases and the P/A ratio decreases with increasing number of sides. The results show that regular polygons are more discriminable with increasing P/A ratio or fewer sides. The P/A ratio of other shapes evaluated by Sleight cannot be determined without more information on the construction of the shapes. It seems apparent, however, that Sleight's most discriminable shapes often have the highest P/A ratio. The more discriminable shapes appear to have both more critical detail and greater P/A ratios.

Sleight's results are contradicted in part by a study of a visual display task by Smith and Thomas (1964). Smith and Thomas ranked their shapes for identifiability as follows: star, circle, semicircle, diamond, and triangle. In contrast, Sleight (1952) found the circle to have shorter sorting times than the star and the semicircle longer times than the diamond and the triangle. These differences may be a result of either task differences, field heterogeneity, or shape construction. Sleight's task required that each shape be discriminated from a more complex and varied field than that of Smith and Thomas.

Where the studies cited previously examined the relationship between shapes and identifiability, Fox (1957) has reported finding no relationship between the P/A ratio of shapes and their brightness contrast threshold for detection or recognition. Fox evaluated six shapes (circle, irregular shape, square, triangle, cross, and star) over combinations of three foveal sizes and three edge gradients. For detection, Fox reported that: (1) increase in stimulus size decreased detection threshold at a decreasing rate; (2) shape affected detection for the two larger sizes only; (3) decreases in the steepness of edge gradient were systematically related to increased detection thresholds. The first two conclusions for detection seem to be encompassed by the diffusion model's predictions for magnitude of critical detail. As size increases, so does the magnitude of critical detail (though critical detail is enhanced differentially across shapes with size increases).

For recognition thresholds, Fox (1957) reported that: (1) increases in stimulus sizes increased the frequency of correct responses; (2) stimulus shape was related to recognition threshold, with irregular shapes and crosses having higher thresholds in general; and (3) decreased steepness of the edge gradient systematically increased threshold for recognition. Again, the magnitude of critical detail seems to be an important factor in the identifiability as size increases.

For the relation between detection and recognition Fox reported that: (1) as stimulus size increases, recognition thresholds decrease

Table 3. Discriminability of Shapes (Sleight, 1952)

Group	Shape	Mean Sorting Time (0.01 min)	Rank by Mean Sorting Time	Rank by Mean Selection Order
A	Swastikas	11.4	1	1
	Circle	15.2	2	7
	Crescent	18.5	3	5
	Airplane	27.9	4	4
	Cross	29.1	5	2
	Star	30.4	6	3
B	Ellipse	40.0	7	14
	Rectangle	45.3	8	13
	Diamond	47.2	9	6
	Triangle	53.7	10	9
	Square	58.0	11	16
C	Heart	66.0	12	8
	Ship	70.2	13	15
	Semicircle	71.5	14	11
	Pentagon	73.4	15	18
	Trapezoid	77.3	16	17
	Shield	83.5	17	12
D	Octagon	94.7	18	20
	Double-concave	99.3	19	10
	Heptagon	103.2	20	21
	Hexagon	107.7	21	19

at a negatively decreasing rate with detection thresholds, (2) recognition thresholds were affected slightly more than detection thresholds by decreases in edge gradient, (3) the ranking of shapes on the basis of detection and recognition thresholds was essentially the same, and (4) familiarity with a shape apparently affected both detection and recognition thresholds: The unfamiliar irregular shape had higher thresholds than the more familiar shapes. Fox (1957) also stated that variations in area, perimeter, and P/A ratio did not adequately predict his findings. Despite this statement, Fox's results for geometrically similar shapes are close to those of Casperson (1950). As in the Casperson study, size increases were related to increased identifiability. Casperson (1950) cannot be compared with Fox (1957) since Fox does not report how the variables of area, perimeter, and P/A ratio were manipulated or how the shapes were constructed.

Generally, the findings on shape identifiability indicate that the salient predictors of identifiability are magnitude of critical detail, size, and, for regular polygons, the number of sides. Consistent effects of P/A ratio as predicted by Bitterman et al. (1954) are not found, but other variables like area, perimeter, and maximum dimension seem to interact in a complex way. For the purposes of the color/shape route guidance system, the amount of crucial detail, the size, and the number of sides should be considered. It seems that the magnitude of critical detail is affected by a number of other variables like size, number of sides, etc., but no straightforward rules for designing good shape codes yet exist. A listing of shapes by identifiability is provided by Sleight (1952). With the exception of the Smith and Thomas (1964) study and the study by Bitterman et al. (1950) the literature reviewed concurs with Sleight's findings. The Fox (1957) study indicates that decreases in edge gradient reduce the legibility of shapes for both recognition and detection thresholds. Fox also suggests that familiarity is a factor in recognition and detection.

In addition to the studies directed towards identifiability of shapes, a number of studies have looked at the variables affecting shape recognition. Deese (1960) investigated the complexity and regularity of shape contours as they affected recognizability. Deese used a set of shapes with regular contours which had all right-angle corners (concave or convex) and a set of shapes with irregular contours which had acute or obtuse angles in the corners. Each of these sets was divided into simple and complex groups on the basis of number of angles. In an initial experiment, subjects were required to pick a previously presented shape from a group of five shapes. Reaction times were longer for complex shapes (both regular and irregular). Errors varied according to the particular shape with simple-regular shapes having a higher number of errors than complex-regular figures. For complex figures, regularity had no effect on error rates.

It should be noted at this point that a later study by Kelly (1974) contradicts Deese's findings on the effect of stimulus complexity. Kelly found no effect for five levels of stimulus complexity on recognition performance. This divergence in findings may arise from either differences in complexity across studies or because Kelly examined complexity with an interference task placed between the initial presentation and the second test presentation while Deese did not. This explanation is supported by Kelly's findings in a second experiment in which stimulus characteristics were found to affect processing in a recognition task.

In his second experiment, Deese (1956) asked subjects to identify 1, 10, or 25 previously presented shapes from a display set of 25 shapes. The results showed that recognition was more accurate for shapes high in complexity when the set of shapes to be recognized was small (one) but was more accurate for shapes low in complexity when the set of shapes to be remembered was large (10 or 25). Deese's findings suggests that complex shapes take longer to recognize but, because they are uniquely defined in relation to the other shapes, they can be recognized more accurately when only a small number of shapes must be remembered. As the number of shapes to be remembered increases, the information processing limits become more influential, so that errors are more frequent with highly complex shapes.

A study by Goldstein (1961) finds that, if subjects are familiarized with complex shapes, these shapes appear less complex to the subjects. This suggests that the negative effect of complexity on recognition might be reduced through familiarization. If it is necessary to use complex shapes in the color/shape route guidance system, learning should be effective in enhancing their recognizability.

It should also be pointed out that Deese (1960) did not control for target/field effects. Dornic and Borg (1971) examined geometric shapes against different backgrounds also of geometric shapes which varied according to similarity to the target shape. Their findings demonstrated that the detectability of a target depends to a large extent on the degree of differentiation of the target from its surround. Further studies should control for similarity between target and surround.

While Deese (1960) did not find any particular differences between the irregular and regular sets of shapes for reaction time, Garner and Sutlift (1974) did find that greater pattern "goodness" in a shape resulted in faster encoding. Another attempt to quantify complexity in shapes is given in Atteneave's 1957 study. There, shape complexity is defined as the number of inflection points in the perimeter of the shape. Generally, the literature suggests that the optimum shapes for use in the color/shape route guidance system should be simple, regular, and dissimilar to sign shapes currently in use. If simple shapes are not available, the use of symbols depends to a greater degree on drivers learning to recognize more complex shapes.

Another area of concern in the color/shape route guidance system is centered on the effect of associations to shapes in recognition tasks.

Ellis (1968) considered the effect of verbal labels on subjects' shape recognition; properties of the labels were evaluated also. Subjects were given practice learning associations to random shapes. The associations varied in three ways: meaningful, relevant words; meaningful, irrelevant words; or non-meaningful irrelevant words. The results indicated that recognition performance depended primarily on the relevance of the association, while performance on an identification learning task depended on both response relevance and response meaningfulness. The author suggested that the verbal label serves both a confirming and a directing function in recognition and identification tasks.

While Ellis looked at the effect of verbal labels as associations to shapes, Donderi, Seal, and Covit (1973) examined the relationship between learned stimulus associations for shapes and visual discrimination. They concluded that learned stimulus associations for shapes do have an effect on the visual discrimination of these shapes.

Kelly and Martin (1974) investigated the recognition of random shapes which varied factorially along five levels of complexity and two levels of codability. Kelly found that verbal codability facilitated recognition performance. The study also showed that an interpolated activity following the initial presentation of stimuli affected later recognition.

The studies discussed above indicate that the use of associations paired with shapes has a positive effect on recognition performance. The use of verbal labels seems particularly important for the color/shape route guidance system: If a shape can be named it will help the driver locate the color/shape guidance sign. Also, if a shape can be named it can facilitate communication between the driver and a passenger or other person giving route information.

A number of studies considered the value of word associations for shapes. This concept will be considered here because of its possible impact on the process of choosing sign shapes which are highly nameable. As reviewed earlier, Ellis (1968) found that recognition performance for shapes depended primarily on the relevance of the associations which were paired with the shapes, while identifiability was found to be dependent on both response relevance and meaningfulness. Price and Slive (1970) found results similar to those of Ellis, using a recognition task. Their study was also concerned with the verbal processes that subjects use during acquisition and recognition tasks. The study found that the occurrence of verbal association on a recognition trial increased the probability that the subject would report having seen the shape before. With the occurrence of a correct association the probability that the subject would recognize the shape correctly increased to 0.98. These findings add credence to Ellis's (1968) conclusions that labels serve to direct and confirm the subject in a recognition trial. Price and Slive also found that, while both association value and label relevance affected the number of associations produced during the recognition task, label relevance had its main effect on the number of correct associations.

In another related study, Clark (1965) found that complex shapes are recognized more easily when they were easily encoded, though no effect of codability for simple shapes was found. It was concluded that simple shapes were stored visually while complex shapes were stored verbally or by associations. If this is the case, the development of the color/shape route guidance system should be concerned primarily with insuring that the more complex shapes can be coded verbally, and secondarily with insuring that the simpler shapes have labels to facilitate communication between the driver and others. Unfortunately, as Vanderplas and Garvin (1959) found, shape complexity seems to be inversely related to the production of associations for the shapes. Another study by Hall (1950) serves to confirm the results already cited. He found that the effect of names and titles on shape recognition performance varied with the relevance of the names and titles for the materials used.

The studies reviewed generally indicate that association value and label relevance are salient factors to be considered in choosing the particular shapes to aid in shape code recognition performance. It was also found that labels are most important for the recognition of complex shapes.

Color/Shape

While the preceding discussions were concerned with color and shape as separate dimensions, a few studies have been concerned with the two dimensions combined. In the review of the operational traffic literature it was pointed out that Markowitz et al. (1968) found that shape recognizability depends partly on the color with which the shape is presented. This effect could be partially a result of learned associations. A 1939 study by Dunker found that a form's identity affects the phenomenal hue of that form. This effect was attributed to "memory color". A later study of the effects of memory color on form identification by Miel et al. (1974) found that memory color induces a bias toward identifying the shape as a shape of the memory color. For example, a leaf green brings to mind a leaf despite the fact that the color is presented in the shape of a circle. No data are available in the research literature which give visibility values for particular color/shape combinations. Eriksen (1952, 1953); Green, McGill, and Jenkins (1953); Green and Anderson (1956); and Saenz and Riche (1974) have suggested, as previously mentioned, that a redundant code's visibility or detectability is a function of the visibility values of the particular shape and color. This finding can be applied to the development of candidate color/shape combinations for the color/shape route guidance system by combining the most visible colors and shapes cited in both the traffic and research literature. For those studies which examine the effectiveness of color/shape, candidates can be obtained by using the stimuli of the studies which found the greatest effect for color/shape coding. It appears that field evaluation of practical color/shape coding systems is still a necessary part of the selection process. The state of the art does not permit accurate prediction of the discriminability or identifiability of multidimensional symbols from a listing of their characteristics of components alone.

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APPENDIX B

LABORATORY STUDIES

STUDY I. NAMEABILITY AND CONFUSABILITY OF THIRTY SHAPES

This section covers the first in a series of three studies designed to select an optimum set of eight shapes from a previously chosen group of 30 shapes (see Figure 1). This set of eight shapes was to be used in a color and shape coding system aimed at improving driver guidance through complex highway interchanges. Important selection criteria for this set of shapes were felt to be high shape nameability and low shape confusability.

The nameability criterion was deemed important for two reasons. First, it was felt that communications between a "navigator" and driver must be as unambiguous as possible. The navigator could be another occupant of the vehicle providing real-time verbal information or could be someone providing prior verbal information about landmarks and other appropriate features, including the color and shape guidance system. Second, there was good reason to believe that having a specific verbal label (name) to serve as a mediator between the sensory experience of a shape and its later recognition might facilitate that recognition, especially when relatively long term memory was required. Four aspects of nameability were investigated. These were: (1) ability to produce a name for the shape; (2) concensus on the name for the shape; (3) number of names for the shape (because the larger the set of names, the greater the opportunity for lack of agreement and confusion with other shapes); and (4) low usage of the shape's name for other shapes.

The confusability criterion also had several aspects. One was low verbal confusability which was included among the important aspects of nameability. A second aspect, low perceptual confusability, was felt to be important for two reasons: (1) the small amount of time normally available for recognizing and acting on highway guidance information, and (2) the proposed use of the color and shape guidance system in locations where the information load on the driver was already high.

The strategy in this first study was to collect information about the nameability and confusability of 30 previously selected shapes in group sessions using paper and pencil methods. One outcome of this study was a ranking of the 30 shapes with respect to nameability. A second outcome was an indication as to which shapes were most likely to be verbally confused. The final outcome of this study was a four-by-four matrix of shapes such that the four shapes in any column (candidate set) were judged to be less like one another than the four shapes in any row (control set). The matrix of shapes was later used in studies two and three of this series. These later studies investigated the shapes' perceptual confusability in a visual search paradigm and the effect of providing redundant information on the time to visually search for a shape.

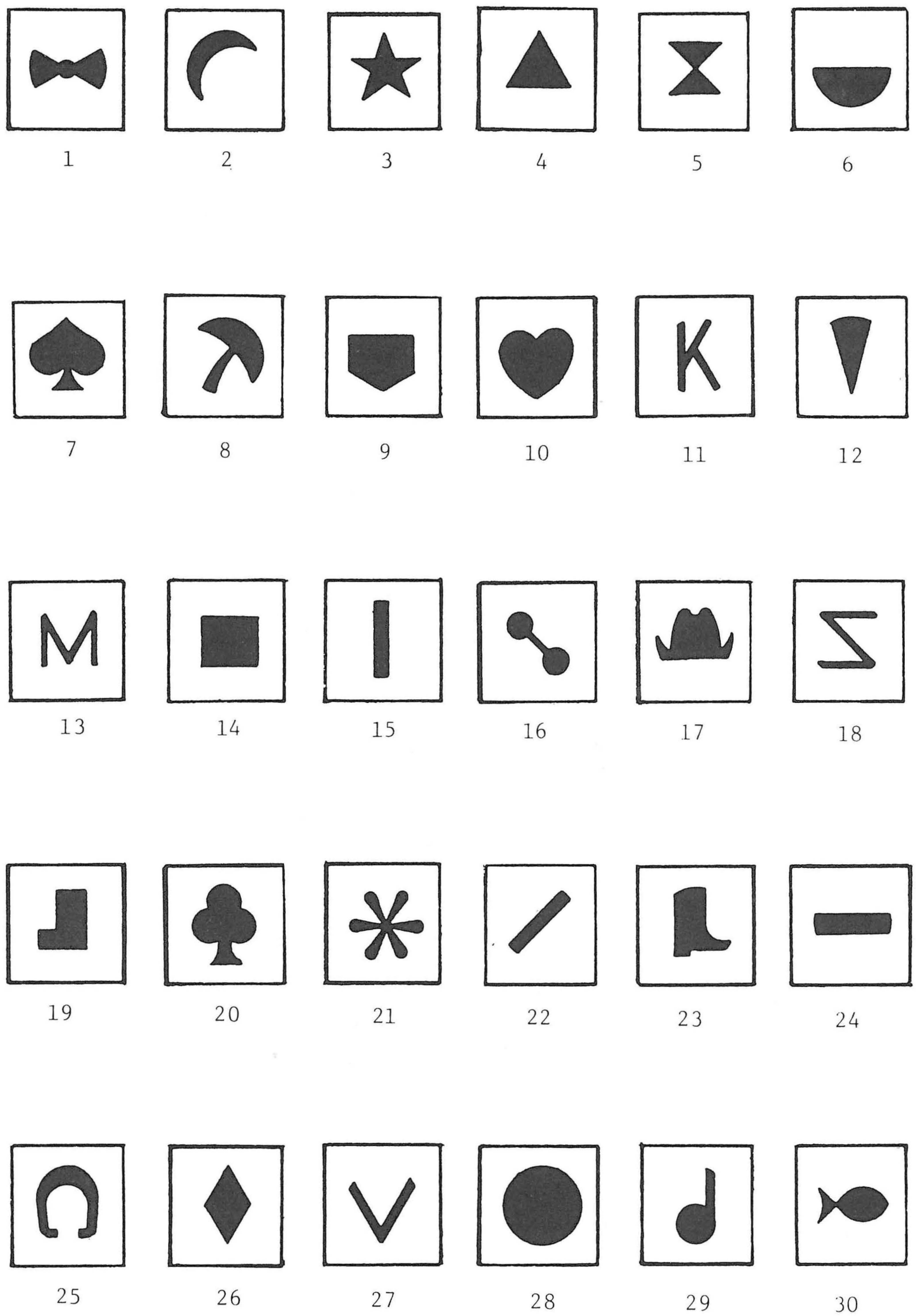


Figure 1. The 30 Shapes used in Study I

Method

Study one included three phases, each with its own paper and pencil task. Materials for the three phases were included in a single booklet given each subject at the start of a session. The booklet's first page explained that participation was voluntary, pledged confidentiality of individual performance, and gave a brief description of task and time requirements. Further participation was contingent upon this page being read and signed. Parental and appropriate institutional consent was also required for subjects less than 18 years old. The booklet's second page asked for the biographical data summarized at the start of the results section.

The remaining pages of the booklet comprised the stimulus materials for the three experimental phases of the study. Each page, depending upon the phase, included some or all of the 30 shapes. Shapes were the maximum size that could be inscribed in a half-inch diameter circle, and each shape was located on a three-quarter inch square background. In order to investigate the possibility that direction of contrast between shape and background influenced naming and confusability of the shapes, approximately half of the subjects (41 subjects) viewed black shapes on white backgrounds, while the remaining 42 subjects viewed white shapes on black backgrounds.

Figure 2. Examples of Different Directions of Contrast

Phase One

Phase one was designed to provide data about the number of names for each shape, concensus among subjects on each shape's name, and use of the same name for more than one shape. Each of five pages included six of the 30 shapes arrayed in two rows of three. The possibility of order effects in naming were partially controlled in this phase by systematically varying the order of the five pages across subjects. The subject's task was to provide one or more names for each shape. Instructions indicated that names could consist of more than one word, could be used for as many shapes as the subject felt appropriate, and should clearly communicate the shape being named. The first name given any shape was to be that which first came to mind or best described the shape. Subsequently, any other names which came to mind were to be listed. Subjects were told to work from one shape to the next (left to right and top to bottom on any page), providing a name or names for each shape until all 30 shapes had been named. Thirty seconds were allowed for naming each shape. Pacing was provided by the experimenter through use of a stop watch and voice command.

Phase Two

Phase two was designed to provide preliminary data about the perceptual confusability of the 30 shapes and to aid in the selection of shapes used in the second and third studies in this series. For this phase, all 30 shapes were arrayed in five rows of six on a single page. The possibility of order effects was combated by systematically interchanging rows of shapes (i.e., row one for some subjects was row two, three, four, or five for other subjects). Shapes were numbered from 1 to 30 beginning in the upper left corner and working from left to right and top to bottom. Under each shape were two response boxes, one marked "like" and one marked "unlike".

Procedure during phase two involved starting with the shape numbered one and writing in the appropriate box the number of shapes on the page judged most like and unlike that shape. A fifteen-second period was allowed to select like shapes followed by a fifteen-second interval to select unlike shapes for each shape. Instructions indicated that a shape could be judged like or unlike as many other shapes as the subject felt was appropriate. Pacing was again provided by the experimenter.

Phase Three

Phase three was designed to provide data about the confusability of shapes when subjects attempted to match shapes to remote verbal labels. All 30 shapes were again arrayed in five rows of six on a single page, and order effects were partially controlled by systematic rearrangement by rows. Shapes were unnumbered in this phase and only a single response box was provided under each shape.

Procedure during phase three involved the experimenter reading aloud a list of names each of which was paired with a number, in order, from one to thirty. Fifteen seconds were allowed after the reading of each name and number for the subject to scan the 30 shapes and assign that name's number to the most appropriate shape. Instructions stressed that each number was to be used only once, but, that any shape could be assigned as many numbers as desired.

The remote verbal labels used during this phase were derived from data acquired by administering the phase one task of this study to a group of 25 graduate students at The Pennsylvania State University. The name used second most frequently for each shape by this group was selected for use in phase three of this study. The use of the second most frequently occurring name was felt to provide a stronger test, in a retranslation sense, of the relative confusability of the shapes given only a name presented orally.

Results and Discussion

A total of 83 subjects participated in this study in groups ranging from 9 to 44 subjects. The 55 male and 28 female subjects ranged in age from 16 to 84 years, and averaged 26 years. Annual driving mileage ranged from less than 1,000 miles to more than 40,000 miles, and averaged between 7 to 8 thousand miles. Driving experience ranged from less than 1 year to 62 years, and averaged between 10 and 11 years. All but two subjects were American born and all had U.S. driving licenses.

Because the major effect of this study was to determine the relative nameability of 30 shapes, the findings of phases one and three are reported first. These are followed by the findings of phase two relating to the perceptual confusability of the shapes.

Phase One

Modal Shape Names. Phase one called for subjects to provide one or more names for each of the 30 shapes used in the study. The name given most frequently for each shape (i.e., the shape's modal name) is shown in Table 4, along with the shape and the number assigned to it for this study. In compiling these data, some grouping of very similar names for each shape was done (e.g., "square" and "squares"). This mainly involved singular and plural versions of the same name as indicated by the parenthetical S's following some names in Table 4. Shapes 22 and 24 presented a conflict in terms of their modal name ("Rectangle") and so were differentiated by the parenthetical information shown in Table 4.

Naming a Shape. For the most part, there appeared to be little difficulty in performing the naming task, but, some shapes were not given a name by all subjects. The number of subjects providing names for any shape varied from 75 to 83 with an average of 80 and 81 subjects providing a name for any particular shape.

The ability to rapidly produce a shape name was seen as most critical when a driver was receiving orally-presented information from an onboard navigator. All shapes in the study could be given at least one and usually several names. This was amply evidenced by the number of names given each shape comprising the sample set. Given this fact, and instruction to provide a name for each and every shape, it was somewhat surprising to find that there were shapes which did not receive names from all subjects. On the premise that inability to name a shape was an indication of a communication problem, the shapes were rank ordered with respect to the number of subjects who provided at least one name for them (see Table 5). Although shapes did not vary widely on this indicator, it was still seen as useful in pointing up the difficulty of naming the shapes at the bottom of the scale, i.e., "Halfmoon" [6], "Letter V" [27], "Bowtie" [1], "Clubs" [20], and "Rectangle (/)" [22].

Concensus on Shape Names. Following the ability to rapidly produce a name for a shape, the most important aspect of nameability was felt to

Table 4. Shapes, Shape Numbers, and Modal Name

Shape	Shape Number	Modal Name	Shape	Shape Number	Modal Name
	1	*Bowtie		16	*Barbell(s)
	2	*Quartermoon		17	Hat
	3	*Star		18	Backward Z
	4	Triangle		19	*Backward L
	5	Hourglass		20	*Club(s)
	6	*Halfmoon		21	Asterisk
	7	Spade(s)		22	Rectangle (/)
	8	Mushroom		23	*Boot(s)
	9	*Homeplate		24	Rectangle (-)
	10	*Heart		25	*Horseshoe(s)
	11	K		26	Diamond
	12	Cone		27	Letter V
	13	*M		28	*Circle
	14	*Square(s)		29	*Music(al) Note
	15	I		30	*Fish

*Indicates shape selected for studies two and three (applies to this and all other tables).

Table 5. Rank Order of Shapes with Respect to Number of Subjects Giving the Shape a Name

Rank	Shape Number	Modal Name	Number of Subjects Providing at Least One Name
2.5	8	Mushroom	83
2.5	10	*Heart	83
2.5	3	*Star	83
2.5	21	Asterisk	83
9.5	29	*Music(al) Note	82
9.5	2	*Quartermoon	82
9.5	25	*Horseshoe(s)	82
9.5	17	Hat	82
9.5	9	*Homeplate	82
9.5	28	*Circle	82
9.5	14	*Square(s)	82
9.5	12	Cone	82
9.5	4	Triangle	82
9.5	15	I	82
16.5	11	K	81
16.5	30	*Fish	81
16.5	16	*Barbell(s)	81
16.5	13	*M	81
20.0	23	*Boot(s)	80
20.0	5	Hourglass	80
20.0	19	*Backward L	80
23.0	26	Diamond	79
23.0	18	Backward Z	79
23.0	24	Rectangle (-)	79
25.0	7	Spade(s)	78
27.0	6	*Halfmoon	76
27.0	27	Letter V	76
27.0	1	*Bowtie	76
29.5	20	*Club(s)	75
29.5	22	Rectangle (/)	75

be agreement as to a shape's name. A high degree of consensus on the name for a shape was seen as increasing the likelihood it would be correctly communicated, i.e., that the driver would select the correct shape on the basis of the name provided by the navigator. The results indicated that the modal name for every shape was also the modal first name, i.e., the name given most frequently as a first response. Given the instructions to give the best, most descriptive name first, this appeared to be a highly likely but not absolutely necessary occurrence. This identity of the modal and modal first names permitted the use of the percentage of subjects giving the modal name as their first response to a shape as the primary measure of concensus. Becuase of the small amount of communication time available to a navigator, name concensus on first responses was felt to be particularly important. Individual shapes had values on this measure from 7 to 96 percent, and an average of 54-55 percent of the subjects gave the modal name as their first response for any shape (see Table 8).

Shapes for which a high percentage of subjects gave the modal name as their first response were felt to be the shapes which would most likely be correctly communicated. These shapes appeared to enjoy a high likelihood that the navigator and driver would agree as to the shape's name. The 30 shapes were rank ordered with respect to the percentage of subjects giving the modal name as their first response. As shown in Table 6, the twelve top ranked shapes ("Star" [3], "Diamond" [26], "Triangle" [4], "Fish" [30], "K" [11], "Square(s)" [14], "Circle" [28], "M" [13], "Boot(s)" [23], "Horseshoe(s)" [25], and "Spade(s) [7]) all had more than 75% of the subjects give the modal name as their first response. On the other hand, the four lowest ranked shapes ("Halfmoon" [6], "Homeplate" [9], "Rectangle (-)" [24], and "Rectangle (/)" [22] all had fewer than 25% of the subjects give the modal name as their first response.

Many subjects responded with more than one name for a shape. As a consequence, the name given as a first response by one subject might well be given as a second or later response by other subjects. This indicated that although some subjects did not agree that the modal name was the shape's most appropriate name, they did agree that it was an acceptable name for the shape. Regardless of response order, the number of subjects giving the same name to a shape could be taken as an indication of how well the shape could be verbally communicated. The percentage of subjects giving the modal name as either a first or subsequent response for a shape thus provided a secondary measure of how well a shape could be communicated orally. This measure ranged from 14 to 96 percent and averaged 63-64 percent. The rank order of the 30 shapes on this index is shown in Table 7. For the thirteen top ranked shapes ("Star" [3], "Triangle" [4], "Square(s)"]14], "Heart" [10], "Diamond" [26], "Fish" [30], "Circle" [28], "Horseshoe(s)" [25], "Spade(s)" [7], "K" [11], "M" [13], "Mushroom(s)" [8], "Boot(s)" [23]), more than 75% of the subjects gave the modal name. Meanwhile, 25% or less of the subjects gave the modal name for the last three shapes in the order ("Rectangle (-)" [24], "Homeplate" [9], and "Rectangle (/)" [22]).

Table 6. Rank Order of Shapes with Respect to the Percentage of Subjects Giving the Modal Name as Their First Response

Rank	Shape Number	Modal Name	Percentage of Subjects Whose First Response Was a Modal Name
1.0	3	*Star	96.4
2.0	10	*Heart	89.2
4.0	26	Diamond	86.7
4.0	4	Triangle	86.7
4.0	30	*Fish	86.7
6.5	11	K	81.9
6.5	14	*Square(s)	81.9
8.0	28	*Circle	79.5
9.5	13	*M	78.3
9.5	23	*Boot(s)	78.3
11.5	25	*Horseshoe(s)	77.1
11.5	7	Spade(s)	77.1
13.0	17	Hat	65.1
14.0	1	*Bowtie	59.0
15.0	29	*Music(al) Note	56.6
15.5	27	Letter V	54.2
16.5	5	Hourglass	54.2
16.5	8	Mushroom(s)	48.2
18.0	18	Backward Z	39.8
19.5	16	*Barbell(s)	39.8
19.5	20	*Club(s)	38.6
21.0	21	Asterisk	34.9
22.0	15	I	33.7
23.0	12	Cone	31.3
24.0	2	*Quartermoon	28.9
25.0	19	*Backward L	26.5
26.0	6	*Halfmoom	22.9
28.0	9	*Homeplate	19.3
29.0	24	Rectangle (-)	10.8
30.0	22	Rectangle (/)	7.2

Table 7. Rank Order of Shapes with Respect to the Percentage of Subjects Giving the Modal Name as a First or Subsequent Response

Rank	Shape Number	Modal Name	Percentage of Subjects Giving the Modal Name as a Response
1.0	3	*Star	96.4
2.5	4	Triangle	92.8
2.5	14	*Square(s)	92.8
4.0	10	*Heart	91.6
5.0	26	Diamond	89.2
6.0	30	*Fish	88.0
7.0	28	*Circle	86.7
8.5	25	*Horseshoe(s)	85.5
8.5	7	Spade(s)	85.5
10.0	11	K	84.3
11.0	13	*M	83.1
12.0	8	Mushroom(s)	80.7
13.0	23	*Boot(s)	79.5
14.5	1	*Bowtie	71.1
16.0	20	*Club(s)	69.9
17.0	17	Hat	68.7
18.0	29	*Music(al) Note	63.9
19.0	5	Hourglass	60.2
20.0	16	*Barbell(s)	54.2
21.0	21	Asterisk	51.8
22.0	15	I	47.0
23.5	6	*Halfmoon	44.6
23.5	18	Backward Z	44.6
25.0	12	Cone	43.4
26.0	19	*Backward L	33.7
27.0	2	*Quartermoon	32.5
28.0	24	Rectangle (-)	25.3
29.0	9	*Homeplate	19.3
30.0	22	Rectangle (/)	14.5

If the reason for low name agreement for some shapes in Table 6 had simply been ambiguity as to the most appropriate name for the shape, inclusion of names given subsequent to first should have produced much more name agreement for these shapes than was found in Table 7. Instead of ambiguity as to the most appropriate name, the problem for most low concensus shapes appeared to be that subjects drew in an idiosyncratic manner from large sets of possible names for the shape. Examination of the number of names given each shape supported this notion.

Number of Names Given a Shape. If subjects drew in an idiosyncratic manner from large sets of names for some shapes, the number of different names given these shapes in phase one would be expected to be large. This was found to be true. The number of different names given as first responses to shapes ranged from 4 to 46 and averaged 19-20 for individual shapes. The 30 shapes were ordered on this basis as shown in Table 8. At the top of the ranking several shapes ("Star" [3], "Diamond" [26], "Spade(s)" [7], "Hat" [17], "Heart" [10], and "Boot(s)" [23]) had fewer than 10 names given as first responses, which clearly differentiated them from shapes at the bottom, some of which had more than 30 names given as first responses ("Cone" [12], "Rectangle (-)" [24], "Homeplate" [9], and "Rectangle (/)" [22]).

Comparing the rank order in Table 8 with that in Table 6 showed that shapes with low concensus on the modal name also had a large number of different first names (rank order correlation 0.58). The design of phase one made this almost inevitable and so this could not be said to be strong evidence that subjects had drawn in an idiosyncratic manner from large sets of names for shapes with low name agreement. Examining the association strength of each of the different first responses to each shape did, however, add to the evidence that subjects had drawn idiosyncratically from large sets of names for some shapes.

The primary measure of association strength between a name and a shape used in this study was the percentage of subjects giving a shape that name as their first response. Table 9 shows the number of names given as first responses which fell in each of twenty strength categories (1-5 percent, ..., 95-100 percent of subjects giving a name as a first response) for each shape. Shapes in Table 9 were ordered with respect to the percentage of subjects using the modal name as the first name for a shape. Generally, as first response concensus for the modal name decreased, the number of different names given as a first response increased. The evidence for subjects having drawn idiosyncratically from large sets of names for some shapes was provided by the proliferation of very low associates (1-5 percent of subjects using a name) as the first response strength of the modal name decreased (see Table 9). This trend was also found in an increase in "singletons" (names given a shape by a single subject) with a decrease in first response concensus for the modal name. For each shape, singletons represented a sizeable percentage of the different names given as first responses. This percentage did not appear to vary greatly with the strength of the modal name.

Table 8. Rank Order of Shapes with Respect to the Number of Different Names Given as First Responses

Rank	Shape Number	Modal Name	Number of Different Names Given as First Responses
1.0	3	*Star	4
2.5	26	Diamond	8
2.5	7	Spade(s)	8
5.0	17	Hat	9
5.0	10	*Heart	9
5.0	23	*Boot(s)	9
7.5	4	Triangle	10
7.5	30	*Fish	10
9.0	28	*Circle	11
11.0	14	*Square(s)	12
11.0	11	K	12
11.0	8	Mushroom(s)	12
13.0	1	*Bowtie	15
14.0	20	*Club(s)	16
15.0	21	Asterisk	17
16.0	25	*Horseshoe(s)	18
18.5	2	*Quartermoon	19
18.5	13	*M	19
18.5	29	*Music(al) Note	19
18.5	16	*Barbell(s)	19
21.0	6	*Halfmoon	23
22.5	18	Backward Z	25
22.5	27	Letter V	25
24.5	19	*Backward L	26
24.5	5	Hourglass	26
26.0	15	I	29
27.0	12	Cone	36
28.0	24	Rectangle (-)	37
29.0	9	*Homeplate	43
30.0	22	Rectangle (/)	46

Table 9. Number of Different First Response Names Falling in Different Strength Categories for Each Shape

	Modal Name	Shape Number	Percentage of First Response 1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	51-55	56-60	61-65	66-70	71-75	76-80	81-85	86-90	91-95	96-100	Singletons	Total	% Singletons
1	*Star	3	3																		1		31	4	75
2	*Heart	10	8																	1			7	9	78
3	Diamond	26	7																1				7	8	88
4	Triangle	4	9																1				6	10	60
5	*Fish	30	9																1				9	10	90
6	K	11	11															1					11	12	92
7	*Square(s)	14	11															1					9	12	75
8	*Circle	28	9	1														1					9	11	82
9	*M	13	18															1					14	19	74
10	*Boot(s)	23	7	1														1					6	9	67
11	*Horseshoe(s)	25	17															1					16	18	89
12	Spade(s)	7	6	1														1					5	8	63
13	Hat	17	7			1									1								5	9	56
14	*Bowtie	1	12	2										1									9	15	60
15	Letter V	27	23	1									1										21	25	84
16	Hourglass	5	24	1									1										21	26	81
17	Mushroom(s)	8	10							1		1											10	12	83
18	*Music(al) Note	29	16	1	1							1											15	19	79
19	Backward Z	18	22	2						1													20	25	80
20	*Barbell(s)	16	17				1			1													12	19	65
21	*Club(s)	20	12	2			1			1													12	16	75
22	Asterisk	12	13	1		1	1		1														12	17	71
23	I	15	25	3					1														22	29	26
24	Cone	12	33	2					1														29	36	81
25	*Quartermoon	2	15	2				2															14	94	74
26	*Backward L	19	23	1	1			1															12	26	46
27	*Halfmoon	6	19		1	2	1																19	23	83
28	*Homeplate	9	39	3		1																	32	43	74
29	Rectangle(-)	24	31	4	2																		27	37	73
30	Rectangle(/)	22	43	3																			37	46	80

Through the first 16 shapes in Table 9, there was no evidence that reduced first response concensus on the modal name was due to one strong competing name. Rather, a single name was agreed upon by a large percentage of the subjects, and the remaining names had very low frequencies (including many singletons). This trend was also generally apparent for the final 14 shapes, but some indication of competitors nearly equal in strength to the modal first name was found. The sum of this evidence suggested that for some shapes most subjects had a readily producible (overlearned?) name. If, for some reason, a subject did not produce the overlearned name for such a shape, a name was drawn from among many possibilities. Post hoc, it appears that shapes with weaker modal names may have suffered from less "overlearning" of their names. The proliferation of very low-strength names for these shapes indicated that many more subjects, having no overlearned name, produced idiosyncratic names. In fact, for the shapes with lowest first response concensus on the modal name, it appeared that such agreement may have been largely fortuitous, and that upon repetition, other names might appear more popular.

Subjects were encouraged to give a shape as many names as they could with the proviso that the name given first be the one that best described the shape. As a consequence, there were many more names given the shapes than indicated by the first response data in Table 8. When all the different names for each shape were tabulated, shapes were found to have anywhere from 39 to 96 different names (average different names for a shape was 63-64). The rank order of shapes with respect to the total number of different names they were given is shown in Table 10. Several shapes at the top of the order ("Star" [3], "Diamond" [26], "Heart" [10], "Boot(s)" [23], "K" [11], and "Mushroom(s)" [8]) were given fewer than 50 different names while others, at the bottom of the order, were given more than 80 different names ("Letter V" [27], "Rectangle (-)" [24], "I" [15], "Cone" [12], and "Rectangle (/)" [22]). The rank order coefficient between the total number of different names given a shape as shown in Table 10, and the number of different names given as first responses as shown in Table 8 was 0.76, indicating fairly high agreement between the two indices. Both appeared to reflect the relative name ambiguity of the 30 shapes.

The data for the total number of different names per shape again reflected the high percentage of singletons and other low associations. Table 11 shows the number of names falling into different strength categories for each shape. Shapes are ordered by the percentage of subjects giving the modal name for a first or subsequent response. As previously mentioned, the <u>modal first name</u> was in every case the <u>modal name</u> when all names for a shape were examined. This meant that the name represented by the highest level of agreement in Table 11 was the same as the name represented by the highest level of agreement in Table 9 for every shape. As in Table 9, the shapes at the top of Table 11 had a single, well agreed upon name as well as a few names with very low agreement, while those at the bottom of the table had weaker modal names and a greater number of names. Again, the decreases in modal response strength was

Table 10. Rank Order of Shapes with Respect to the Number of Different Names Given as First and Subsequent Responses

Rank	Shape Number	Modal Name	Number of Different Names Given as First and Subsequent Responses
1.0	3	*Star	39
2.0	26	Diamond	40
3.0	10	*Heart	43
4.0	23	*Boot(s)	44
5.0	11	K	47
6.0	8	Mushroom(s)	48
7.5	17	Hat	50
7.5	14	*Square(s)	50
9.5	20	*Club(s)	51
9.5	7	Spade(s)	51
11.0	19	*Backward L	57
12.5	4	Triangle	60
12.5	18	Backward Z	60
14.5	6	*Halfmoon	62
14.5	21	Asterisk	62
16.0	16	*Barbell(s)	63
17.0	30	*Fish	64
18.0	13	*M	65
19.5	1	*Bowtie	66
19.5	5	Hourglass	66
21.5	29	*Music(al) Note	69
21.5	2	*Quartermoom	69
23.0	9	*Homeplate	75
24.5	25	*Horseshoe(s)	78
24.5	28	*Circle	78
26.0	27	Letter V	84
27.0	24	Rectangle (-)	85
28.0	15	I	88
29.0	12	Cone	94
30.0	22	Rectangle (/)	96

Table 11. Number of Total Different Names Falling in Different Strength Categories for Each Shape

	Modal Name	Shape No.	Percentage of First and Subsequent Responses																				Singletons	Total	% Singletons
			1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	51-55	56-60	61-65	66-70	71-75	76-80	81-85	86-90	91-95	96-100			
1	*Star	3	38													1							34	39	87
2	Triangle	4	58	1							1												42	60	70
3	*Square(s)	14	47		2						1												39	50	78
4	*Heart	10	40	2									1										35	43	81
5	Diamond	26	37	1									1										29	38	76
6	*Fish	30	63									1											54	64	84
7	*Circle	28	74	3				1															55	78	71
8	*Horseshoe(s)	25	77							1													66	78	85
9	Spade(s)	7	49			1				1													36	51	71
10	K	11	46											1									42	47	89
11	*M	13	64									1											54	65	83
12	Mushroom(s)	8	45	1				1	1														35	48	73
13	*Boot(s)	23	41	2								1											34	44	77
14	Letter V	27	82	1					1														66	84	79
15	*Bowtie	1	64	1				1															41	66	62
16	*Club(s)	20	49		1		1	1															40	52	77
17	Hat	17	48		1					1													39	50	78
18	*Music(al) Note	29	62	5			1																56	68	82
19	Hourglass	5	65						1														59	66	89
20	*Barbell(s)	16	65		1		1																49	67	73
21	Asterisk	21	58	1	1	1	1																49	62	79
22	I	15	83	4		1																	59	88	67
23	*Halfmoon	6	57	2	2	1																	47	62	76
24	Backward Z	18	56	3			1																42	60	70
25	Cone	12	91	2		1																	22	94	23
26	*Backward L	19	53	2	1	1																	37	57	65
27	*Quartermoon	2	65	1	2	1																	55	69	80
28	Rectangle(-)	24	81	2	2																		60	85	71
29	*Homeplate	9	71	4																			53	75	71
30	Rectangle(/)	22	95	1																			76	96	79

associated with an increase in singletons and other low associates with little evidence of strong competitors in the top half of the order. Shapes in the bottom half of Table 11 did show somewhat greater evidence of competition between stronger names, but the proliferation of names with very low association value for these shapes indicated that competition between nearly equal associates was only one factor related to the low agreement as to the modal first name.

Summarizing the evidence, it appeared that some shapes had highly overlearned names which were readily producible and preferred by most subjects. Other shapes did not have such strongly associated names, forcing subjects to dip idiosyncratically into a large pool of possible names for that shape. As a further note with respect to the number of names given shapes, the fact that the modal first name was also the modal name for each shape (and generally received little use subsequent to the first response) indicated that subjects for the most part followed the instruction to provide what they felt was a shape's most appropriate name first.

Use of Names for More Than One Shape. Another potential nameability problem is the use of the same name for different shapes. Such usage could produce error transmissions from navigators to drivers in the event the name given the shape by the navigator was one which might be used for other shapes in the system.

Some names were given to more than one shape. Any particular shape shared "as a first response" names given to from 0 to 10 other shapes. On the average, 4-5 shapes shared a name as a first response, though in only one case ("Rectangle" [22] [24]) did two shapes have the same modal name. Shapes were rank ordered with respect to the number of shapes with which they shared names given as first responses (see Table 12). Due to the small variation between shapes, this index was of low sensitivity, but it still appeared to provide some discrimination between better ("Mushroom(s)" [8], "Barbell(s)" [16], "Backward L" [19], "Hat" [17], and "Halfmoon" [6]) and worse ("M" [13], "Homeplate" [9], and "Square(s)" [10]) shapes with respect to the number of first response names shared.

When both first and subsequent names for shapes were examined for all shapes, a somewhat greater common use of names was evident. On the average, any shape shared names with 16-17 other shapes (range 3 to 26) when all responses were considered. Shapes were rank ordered with respect to this measure as shown in Table 13. This measure offered somewhat greater sensitivity than examination of the names given as first responses but it was still difficult to do more than discriminate between the better ("Star" [3], "K" [11], and "Halfmoon" [6]) and worse ("Circle" [28], "Diamond" [26], "Rectangle (/)" [22], "Triangle" [4]) shapes with this criteria.

In some cases shapes shared more than one name with another shape (or shapes). The number of different names a shape shared with each of

Table 12. Rank Order of Shapes with Respect to the Number of First Response Names Shared with Other Shapes

Rank	Shape Number	Modal Name	Number of Shapes with Share and First Associate
1.5	8	Mushroom(s)	0
1.5	16	*Barbell(s)	0
4.0	19	*Backward L	1
4.0	17	Hat	1
4.0	6	*Halfmoon	1
8.5	18	Backward Z	2
8.5	2	*Quartermoon	2
8.5	30	*Fish	2
8.5	10	*Heart	2
8.5	28	*Circle	2
8.5	3	*Star	2
12.5	1	*Bowtie	3
12.5	7	Spade(s)	3
15.0	21	Asterisk	4
15.0	26	Diamond	4
15.0	15	I	4
19.0	25	*Horseshoe(s)	5
19.0	24	Rectangle (-)	5
19.0	23	*Boot(s)	5
19.0	29	*Music(al) Note	5
19.0	20	*Club(s)	5
23.5	27	Letter V	6
23.5	11	K	6
23.5	4	Triangle	6
23.5	12	Cone	6
26.5	22	Rectangle (/)	7
28.0	13	*M	8
29.5	9	*Homeplate	10
29.5	14	*Square(s)	10

Table 13. Rank Order of Shapes with Respect to First and Subsequent Response Names Shared with Other Shapes

Rank	Shape Number	Modal Name	Number of Shapes Sharing First or Subsequent Response Names
1.0	3	*Star	6
2.5	11	K	10
2.5	6	*Halfmoon	10
4.0	16	*Barbell(s)	11
5.0	23	*Boot(s)	12
6.5	21	Asterisk	13
6.5	10	*Heart	13
9.0	1	*Bowtie	14
9.0	2	*Quartermoon	14
9.0	8	Mushroom(s)	14
11.5	18	Backward Z	15
11.5	17	Hat	15
13.0	30	*Fish	16
14.5	9	*Homeplate	17
14.5	7	Spade(s)	17
17.0	5	Hourglass	18
17.0	24	Rectangle (-)	18
17.0	19	*Backward L	18
19.5	12	Cone	19
19.5	25	*Horseshoe(s)	19
23.0	20	*Club(s)	20
23.0	13	*M	20
23.0	14	*Square(s)	20
23.0	29	*Music(al) Note	20
23.0	27	Letter V	20
26.5	28	*Circle	21
26.5	26	Diamond	21
28.0	22	Rectangle (/)	22
29.0	15	I	25
30.0	4	Triangle	26

the other shapes was tallied and is presented in Table 14. Because a single name might be shared by any number of shapes, summing down the columns or across the rows of Table 14 did not provide an accurate picture of the number of names any shape shared with the other shapes. The number was inflated by the number of shapes beyond the first that each name was shared with. This prevented an accurate rank ordering of the shapes with respect to the number of name associates it shared with other shapes. However, the data shown in Table 14 did allow a cluster analysis to identify groups of shapes which suffered most from the sharing of names. Anderberg's (1975) computerized cluster analysis program and the complete linkage option were used to perform this and all other cluster analyses in this study. The result of the name-sharing cluster analysis is shown in Figure 3.

The results of the cluster analysis are presented in binary tree form with strong linkages being represented by merges near the left side of the tree and weaker linkages being represented progressively across the tree to the right. All shapes were ultimately linked at the weakest level of a merger at the right side of the tree. Clusters could be identified by looking at mergers below (to the left of) any level. Looking at all except the final merge (at the right side of the tree), eight clusters of shapes could be found which shared names (see Figure 3). However, most of the mergers in these clusters occurred far to the right indicating weak relationships (i.e., sharing of names) between most of the shapes included in these clusters. Examining the strongest linkages revealed two clusters of two shapes each, and one cluster of three shapes which appeared to have extensive name sharing problems. The most strongly linked group was the cluster of shapes "I", "Rectangle (/)", and "Rectangle (-)" (numbers 15, 22, and 24 respectively). Somewhat weaker linkages were found between "Cone" and "Letter V" and between "Spade(s)" and "Club(s)" (shape numbers 12 and 27, and 7 and 20, respectively).

The cluster analysis of name sharing completed the analysis of phase one data. It was followed by analysis of phase three data which also contributed information about the nameability of the shapes. As both phase one and phase three contributed to the selection of shapes with good nameability characteristics, their results will be summarized together, following the report of phase three results.

<u>Phase Three</u>

Phase three called for subjects to assign an orally presented name to the one shape they felt most appropriate. The "correct" name for each shape was the name provided second most frequently for that shape by a normative group. This technique for selection of names was intended to provide a set of relatively rare names for the 30 shapes and to thus increase the difficulty of the phase three task.

Phase three provided data about: (1) the ambiguity of relatively rare shape names with respect to the 30 shapes, and (2) which of 30

Table 14. Matrix Showing Number of First and Subsequent Names Shared with Each Shape

Shape Number	Shape Name	Shapes With Same Name																													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	Bowtie		1	1	1	4	0	0	0	0	0	1	4	0	0	1	5	1	0	0	2	3	2	1	0	0	1	1	0	0	2
2	Quartermoon	1		0	1	0	3	1	4	0	0	0	1	0	0	1	0	1	0	1	0	1	0	2	0	3	0	1	2	0	0
3	Star	1	0		1	1	0	0	0	2	0	1	0	0	0	0	0	1	0	0	0	2	0	0	0	0	1	1	0	0	0
4	Triangle	1	1	1		3	0	4	1	6	0	1	10	2	3	2	0	2	1	1	3	1	1	1	3	1	6	4	3	2	2
5	Hourglass	4	0	1	3		0	0	0	1	0	1	3	1	2	3	1	0	1	0	0	1	0	0	0	2	5	1	1	1	1
6	Halfmoon	0	3	0	0	0		0	1	0	0	0	0	1	1	1	0	0	0	0	0	0	1	0	1	1	0	0	4	1	0
7	Spade(s)	0	1	0	4	0	0		1	2	5	0	4	1	0	1	0	1	0	1	10	4	0	0	0	0	5	5	2	2	2
8	Mushroom(s)	0	4	0	1	0	1	7		0	1	0	2	0	0	0	0	1	0	0	4	2	1	0	0	0	0	1	3	1	1
9	Homeplate	0	0	2	6	1	0	2	0		2	0	5	0	5	2	0	0	0	4	0	1	3	0	4	1	4	5	2	0	1
10	Heart	0	0	0	0	0	0	5	1	2		0	3	1	0	1	0	0	0	1	1	0	0	0	1	0	2	3	2	0	1
11	K	1	0	1	1	1	0	0	0	0	0		0	4	1	1	0	0	1	1	0	1	0	1	0	2	0	3	0	1	0
12	Cone	4	1	0	10	3	0	4	2	5	3	0		1	0	2	1	0	1	0	3	4	4	0	1	0	3	14	0	0	2
13	M	0	0	0	2	1	1	1	0	0	1	4	1		2	3	0	2	4	4	0	0	1	1	1	2	1	5	0	3	1
14	Square (s)	0	0	0	3	2	1	0	0	5	0	1	0	2		7	0	1	2	6	1	0	4	1	6	5	5	0	3	2	1
15	I	1	1	0	2	3	1	1	0	2	1	1	2	3	7		1	0	3	5	1	0	20	1	19	3	5	4	1	2	2
16	Barbell(s)	5	0	0	0	1	0	0	0	0	0	0	1	0	0	1		0	0	0	1	0	2	0	1	0	1	0	2	2	1
17	Hat	1	1	1	2	0	0	1	1	0	0	0	0	2	1	0	0		0	1	1	1	1	3	0	1	0	0	1	0	0
18	Backward Z	0	0	0	1	1	0	0	0	0	0	1	1	4	2	3	0	0		0	0	0	1	0	1	1	1	3	2	2	1
19	Backward L	0	1	0	1	0	0	1	0	4	1	1	0	4	6	5	0	1	0		2	0	3	5	4	3	1	0	0	2	1
20	Club(s)	2	0	0	3	0	0	10	4	0	1	0	3	0	1	1	1	1	0	2		5	1	0	2	0	2	1	1	3	2
21	Asterisk	3	1	2	1	1	0	4	2	1	0	1	4	0	0	0	0	1	0	0	5		1	0	0	0	0	2	1	0	0
22	Rectangle(/)	2	0	0	1	0	1	0	1	3	0	0	4	1	4	20	2	1	1	3	1	1		0	20	1	3	2	1	1	1
23	Boot(s)	1	2	0	1	0	0	0	0	0	0	1	0	1	1	1	0	3	0	5	0	0	0		1	1	0	0	0	2	0
24	Rectangle(-)	0	0	0	3	0	1	0	0	4	1	0	1	1	6	19	1	0	1	4	2	0	20	1		1	3	0	5	2	0
25	Horseshoe(s)	0	3	0	1	2	1	0	0	1	0	2	0	2	5	3	0	1	1	3	0	0	1	1	1		3	0	3	2	2
26	Diamond	1	0	1	6	5	0	5	0	4	2	0	3	1	5	5	1	0	1	1	2	0	3	0	3	3		1	2	1	2
27	Letter V	1	1	1	4	1	0	5	1	5	3	3	14	5	0	4	0	0	3	0	1	2	2	0	0	0	1		0	0	1
28	Circle	0	2	0	3	1	4	2	3	2	2	0	0	0	3	1	2	1	2	0	1	1	1	0	5	3	2	0		2	1
29	Music(al) Note	0	0	0	2	1	1	2	1	0	0	1	0	3	2	2	2	0	2	2	3	0	1	2	2	2	1	0	2		2
30	Fish	2	0	0	2	1	0	2	1	1	1	0	2	1	1	2	1	0	1	1	2	0	1	0	0	2	2	1	1	2	

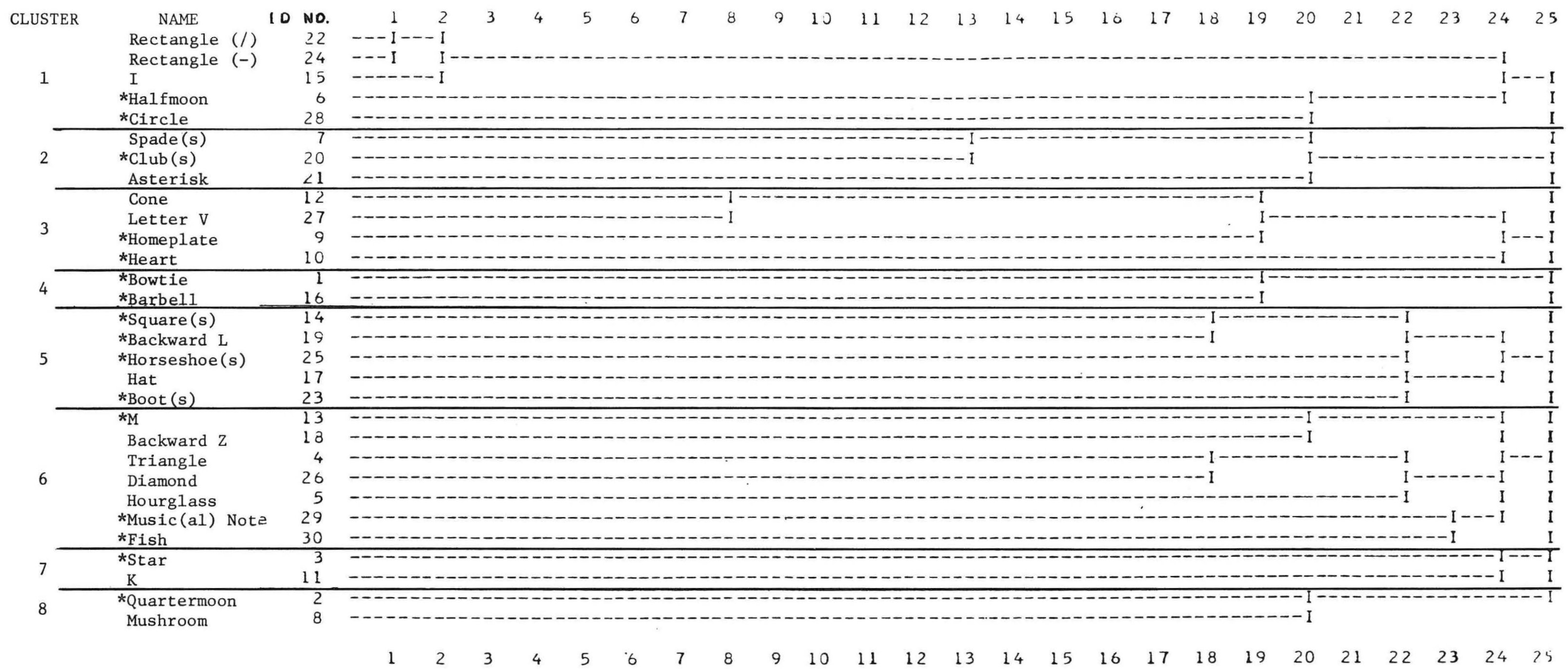


Figure 3. Cluster Analysis of Sharing of Name by Various Shapes

shapes were most often incorrectly assigned given the specific set of relatively rare names. Data as to name ambiguity, were available in several forms including: (1) number of name assignments to each shape, (2) number of names assigned to each shape, and (3) percentage of subjects agreeing on a name for each shape. Data as to the name confusion of the 30 shapes were provided by a cluster analysis.

Number of Name Assignments for each Shape. In an extreme case, every subject could have assigned all 30 names to a single shape. This would have resulted in 83 (subjects) x 30 (shapes) = 2490 separate assignments of a name to a single shape and no assignments of a name to any other shape. On the other hand in the ideal case every subject would have assigned the correct name to each shape resulting in 83 correct name assignments to every shape. The results of phase three were much closer to the ideal (in terms of name assignments per shape) than the extreme. Table 15 shows the rank order of shapes with respect to the total number of name assignments each had, and shows the number of correct name assignments each received. Comparing the two data items for each shape showed that the farther from the ideal of 83 name assignments any shape was (in either direction) the more likely it was to have a low number of subjects assigning the correct name.

In order to provide a specific index for name ambiguity, the shapes were rank ordered with respect to the absolute difference between the number of name assignments they received and the ideal of 83 name assignments (see Table 16). Shapes which deviated greatly from 83 name assignments were felt to suffer from one of two problems. Those shapes with very few name assignments (e.g., "Spade(s)" [7]) were apparently so weakly linked to any of the 30 names used that it was difficult for the subject to make either a correct or incorrect assignment. Those shapes with many name assignments (e.g., "Club(s)" [20]) were apparently ambiguous and could be easily linked to a number of names. In the present study, shapes which differed from 83 name assignments by $\pm$ 13 assignments or more tended to have a somewhat lower number of subjects make the correct name-shape assignment.

Number of Names Assigned Each Shape. The number of different names assigned to each shape in phase three was another indicator of the name ambiguity of the shapes. This number ranged from 3 to 13 names, with an average of 8-9 names assigned each shape. The rank order of shapes with respect to the number of names assigned in phase three is shown in Table 17. Due to the small range and even gradation, it was difficult to categorize any shape as good or bad based on this measure, but it was felt that those shapes with fewer names assigned were to be preferred if a choice was necessary (e.g., "Hat" [17] would be preferred to "Rectangle (/)" [22]).

Percent of Subjects Assigning Name Correctly. Subjects assigning the correct name to a shape ranged from 5 to 89 percent with an average 73-74 percent of the subjects assigning the correct name to any shape. Considering the lower limit of this range, the average was fairly high

Table 15. Number of Phase Three Assignments for Each Shape and Number of Correct Assignments

Rank	Shape Number	Modal Name	Number of Name Assignments	Number of Correct Name Assignments
1.0	7	Spade(s)	23	4
2.0	3	*Star	34	20
3.0	5	Hourglass	38	5
4.0	26	Diamond	49	34
5.0	25	*Horseshoe(s)	62	53
6.0	12	Cone	73	56
7.0	17	Hat	80	74
8.0	23	*Boot(s)	81	74
9.5	11	K	82	74
9.5	13	*M	82	73
11.0	30	*Fish	83	72
13.5	2	*Quartermoon	84	74
13.5	10	*Heart	84	74
13.5	29	*Music(al) Note	84	69
13.5	6	*Halfmoon	84	71
16.0	18	Backward Z	86	72
17.5	16	*Barbell(s)	87	74
17.5	4	Triangle	87	69
19.0	28	*Circle	88	72
20.5	8	Mushroom(s)	92	70
20.5	27	Letter V	92	74
22.0	9	*Homeplate	93	72
23.0	19	*Backward L	94	72
24.5	24	Rectangle (-)	96	53
24.5	22	Rectangle (/)	96	61
26.0	15	I	97	64
27.0	21	Asterisk	104	73
28.0	14	*Square(s)	112	68
29.0	1	*Bowtie	123	43
30.0	20	*Club(s)	139	57

Table 16. Rank Order of Shapes with Respect to the Difference Between Number of Name Assignments and 83

Rank	Shape Number	Modal Name	Absolute Difference of Name Assignments from 83	Number of Correct Phase Three Name Assignments
1.0	30	*Fish	0	72
4.5	13	*M	1	73
4.5	11	K	1	74
4.5	2	*Quartermoon	1	74
4.5	10	*Heart	1	74
4.5	29	*Note	1	69
4.5	6	*Halfmoon	1	71
8.0	23	*Boot(s)	2	74
9.5	17	Hat	3	74
9.5	18	Backward Z	3	72
11.5	16	*Barbell(s)	4	74
11.5	4	Triangle	4	69
13.0	28	*Circle	5	72
14.5	8	Mushroom(s)	9	70
14.5	27	Letter V	9	74
16.5	12	Cone	10	56
16.5	9	*Homeplate	10	72
18.0	19	*Backward L	11	73
19.5	24	Rectangle (-)	13	53
19.5	22	Rectangle (/)	13	61
21.0	15	I	14	64
22.5	25	*Horseshoe(s)	21	53
22.5	21	Asterisk	21	73
24.0	14	*Square(s)	29	68
25.0	26	Diamond	34	34
26.0	1	*Bowtie	40	43
27.0	5	Hourglass	45	5
28.0	3	*Star	49	20
29.0	20	*Club(s)	56	57
30.0	7	Spade(s)	60	4

Table 17. Rank Order of Shapes with Respect to the Number of Names Assigned to the Shape in Phase Three

Rank	Shape Number	Modal Name	Number of Names Assigned in Phase Three
1.0	17	Hat	3
2.5	23	*Boot(s)	4
2.5	11	K	4
5.5	30	*Fish	6
5.5	25	*Horseshoe(s)	6
5.5	13	*M	6
5.5	29	*Music(al) Note	6
10.5	16	*Barbell(s)	7
10.5	19	*Backward L	7
10.5	26	Diamond	7
10.5	10	*Heart	7
10.5	1	*Bowtie	7
10.5	2	*Quartermoon	7
17.0	14	*Square(s)	8
17.0	27	Letter V	8
17.0	8	Mushroom(s)	8
17.0	7	Spade(s)	8
17.0	28	*Circle	8
17.0	6	*Halfmoon	8
17.0	21	Asterisk	8
21.5	18	Backward Z	9
21.5	3	*Star	9
23.5	4	Triangle	10
23.5	12	Cone	10
26.0	24	Rectangle (-)	11
26.0	9	*Homeplate	11
26.0	15	I	11
28.5	20	*Club(s)	12
28.5	5	Hourglass	12
30.0	22	Rectangle (/)	13

and would have been higher had it not been for a few shapes with very low percentages of assignment of the correct name. The shapes were ordered with respect to the number of subjects assigning the correct name as shown in Table 18. Only the four or five lowest ranking shapes ("Bowtie" [1], "Diamond" [20], "Star" [3], "Hourglass" [5], and "Spade(s)" [7]) appeared to suffer real difficulties in terms of correct name assignments. Examining the phase one data for these five shapes indicated that the problem was perhaps not so much with the shape but with the name used for that shape in phase three. In each of these five cases the name used for the shape was one given to other shapes by a greater number of subjects than it was given for the correct shape.

Verbal Communication and Clusters of Easily Confused Shapes. A two dimensional matrix was constructed to show the number of times any name was assigned a shape in phase three (see Table 19). The majority of the data in this table fell along the main diagonal evidencing the high degree of correct assignment of names to shapes. The fact that all data did not lie along this diagonal allowed the use of a cluster analysis to aid in the identification of shapes verbally confused with others in the set of 30 (see Figure 4). Only one cluster of two shapes ("Bowtie" and "Hourglass" - shapes 1 and 5, respectively) appeared strong enough to warrant concern. All other clusters were weakly linked, probably as the result of the high percentage of correct assignments of name to shape.

Clusters were undoubtedly affected by the particular names used in phase three (e.g., the displayed linkage between shapes 22 - "Rectangle (-)" and 25 - "Horseshoe(s)" was probably due to the use of the name "Magnet" for shape 25 in phase three). Even the strong linkage between shapes 1 and 5 was probably at least partly due to the use of the modal name for shape 1 as the phase three name for shape 5. Phase three was designed to indicate the ability of subjects to correctly identify a shape given a relatively rare name for that shape. The cluster analysis based on data thus obtained was not originally intended, but was performed as an additional analysis. As noted above, the clustering of shapes was affected by the specific names selected for use in phase three. Discovery of this problem suggested a modification of phase three for future use which would involve using a number of names for each shape. These would be provided by a normative group, e.g., the phase one data of this study, and would include modal names as well as other names for all shapes.

Problems with Phase Three. The indication that phase three results for any particular shape might have been influenced by the name used for that shape led to a check for such occurrences. An estimate of the success of the technique used for selecting moderately rare associates for the shapes was obtained by tallying the number of times the name used in phase three for a shape occurred in the current study's phase one data for that same shape (see Table 20). For most shapes the name selected for use in phase three was in fact a relatively rare name when compared against this study's phase one data, but this was not the case for all shapes. Seven of the 30 names used in phase three to designate

Table 18. Rank Order of Shapes with Respect to the Percentage of Subjects Assigning the Correct Name

Rank	Shape Number	Modal Name	Percent of Subjects Assigning Correct Name
4.0	16	*Barbell(s)	89
4.0	2	*Quartermoon	89
4.0	17	Hat	89
4.0	10	*Heart	89
4.0	27	Letter V	89
4.0	23	*Boot(s)	89
4.0	11	K	89
9.0	21	Asterisk	88
9.0	13	*M	88
9.0	19	*Backward L	88
12.5	30	*Fish	87
12.5	18	Backward Z	89
12.5	28	*Circle	87
12.5	9	*Homeplate	87
15.0	6	*Halfmoon	86
16.0	8	Mushroom(s)	84
17.5	29	*Music(al) Note	83
17.5	4	Triangle	83
19.0	14	*Square(s)	82
20.0	15	I	77
21.0	22	Rectangle (/)	73
22.0	20	*Club(s)	69
23.0	12	Cone	67
24.5	25	*Horseshoe(s)	64
24.5	24	Rectangle (-)	64
26.0	1	*Bowtie	52
27.0	26	Diamond	44
28.0	3	*Star	24
29.0	5	Hourglass	6
30.0	7	Spade(s)	5

Table 19. Shape and Color Coding Experiment 1, Phase III--Retranslation of Second Modal Shape Names - All Subjects

NAME GIVEN		SHAPE SELECTED AS APPROPRIATE FOR NAME GIVEN																													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
PROPELLER	1	43	0	1	2	11	0	0	1	1	0	0	0	3	0	0	2	0	0	0	0	20	1	1	0	0	0	1	0	0	0
QUARTER MOON	2	0	74	0	0	0	1	0	3	0	0	0	0	0	3	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0
FLAG	3	1	1	20	1	0	0	1	4	6	0	0	1	0	15	1	2	0	2	10	0	1	0	0	2	0	1	0	0	0	0
PYRAMID	4	0	0	0	69	2	0	0	1	0	3	0	2	0	0	2	3	0	1	0	0	1	3	0	0	1	0	0	0	0	0
BOWTIE	5	69	0	0	0	5	0	3	0	0	0	0	0	2	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0
BOWL	6	0	1	0	0	0	71	0	0	0	0	0	3	0	0	1	0	0	3	0	0	0	0	0	3	0	0	0	1	0	0
TREE	7	0	3	0	0	0	0	4	10	0	0	0	0	0	1	0	0	0	0	0	64	0	0	0	0	0	2	0	0	0	0
PALM TREE	8	0	0	0	0	0	0	1	70	0	0	0	0	0	1	0	0	0	0	0	4	1	0	0	0	0	4	0	0	0	0
AN UPSIDE DOWN HOUSE	9	0	0	1	0	0	0	0	0	72	0	0	0	0	0	3	0	0	0	0	0	3	0	0	0	0	0	3	0	0	0
VALENTINE	10	0	0	0	0	0	0	1	0	0	74	0	0	0	0	0	3	0	0	0	1	0	2	0	0	0	0	0	3	0	0
K	11	0	0	0	0	0	0	0	0	0	0	74	0	0	0	0	0	3	0	0	0	0	0	3	0	0	0	0	0	3	0
WEDGE	12	0	0	1	2	3	1	0	0	1	0	0	56	0	0	0	1	0	2	2	0	0	3	0	1	0	0	7	0	1	3
M	13	3	0	0	0	0	0	0	0	0	0	0	0	73	0	0	0	0	0	3	1	0	0	0	0	3	0	0	0	0	0
BLOCK	14	0	2	0	0	0	0	0	0	0	0	0	0	0	68	0	0	0	0	0	4	0	1	0	4	0	4	0	1	0	0
I	15	0	0	3	0	0	0	0	0	1	1	0	0	0	0	64	0	0	0	0	0	3	3	0	2	0	0	2	4	0	1
DUMBELLS	16	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	74	0	0	0	0	0	3	0	0	1	0	0	3	0	0
COWBOY HAT	17	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	74	0	0	0	0	0	3	0	0	0	0	0	3	0
Z	18	0	0	0	1	0	3	0	0	0	0	0	0	0	0	0	0	0	72	0	0	0	0	0	3	0	0	1	0	0	3
BACKWARD L	19	3	0	0	0	0	0	3	0	0	0	0	0	1	0	0	0	0	0	73	0	0	0	0	0	3	0	0	0	0	0
CLUB	20	0	2	0	0	1	0	7	1	0	0	2	2	0	1	0	0	0	0	0	57	0	1	0	0	0	2	0	0	5	0
SNOWFLAKE	21	0	0	3	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	73	0	0	0	0	0	3	0	0	0
SLASH	22	0	0	0	3	1	2	0	0	1	1	0	0	0	0	5	0	0	0	0	0	0	61	0	7	0	0	1	3	0	0
COWBOY HAT	23	0	0	0	0	3	0	0	0	0	0	3	0	0	0	0	0	0	0	1	0	0	0	74	0	0	0	0	0	3	0
RECTANGLE	24	0	0	1	2	0	2	0	0	0	1	0	3	1	11	4	0	0	1	0	1	0	6	0	53	0	2	0	0	0	3
MAGNET	25	3	0	0	0	3	0	3	0	1	1	0	0	2	0	6	0	0	1	0	1	0	5	0	9	53	0	0	1	0	0
PARALLELOGRAM	26	0	1	1	0	1	1	0	2	3	0	0	2	0	12	7	0	0	1	1	1	0	6	0	10	0	34	0	0	0	1
V	27	0	0	3	1	1	0	0	0	3	0	0	1	0	0	3	0	0	0	0	1	0	0	0	0	0	0	74	0	0	0
HOLE	28	1	0	0	3	0	0	0	0	0	3	0	0	0	0	0	2	0	0	0	1	0	1	0	0	1	0	0	72	0	0
NOTE	29	0	0	0	0	4	0	0	0	1	0	3	1	0	0	0	0	3	0	0	0	2	0	0	0	0	0	0	0	69	0
FISH SUPPLIES	30	0	0	0	0	0	3	0	0	0	0	0	2	0	0	1	0	0	3	0	0	0	0	0	2	0	0	0	0	0	72

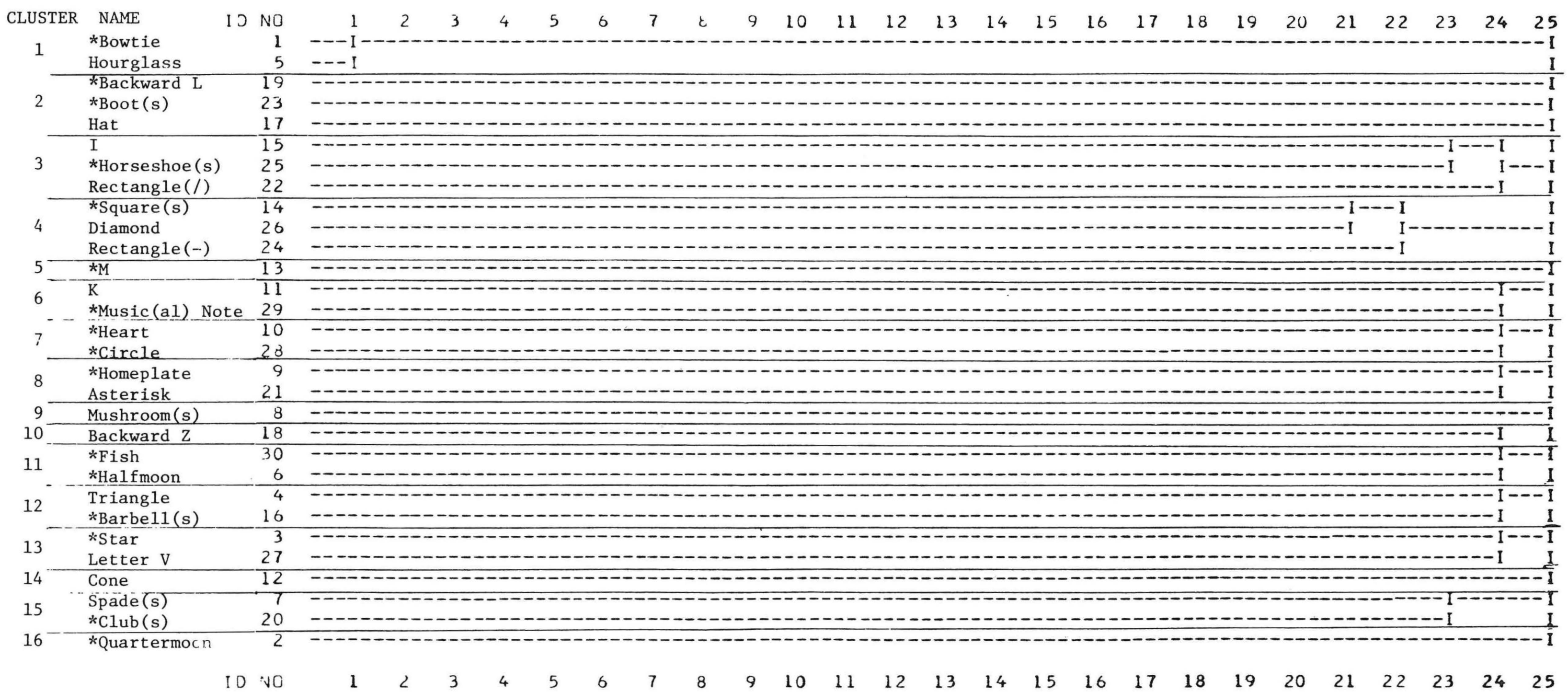


Figure 4. Cluster Analysis on Matrix of Name-Shape Assignments in Phase 3

Table 20. Phase Three Names with Respect to Phase One Data

Shape Number	Modal Name	Name Used In Phase Three	Number of Other Shapes Given Phase 3 Name in Phase 1	Subjects Giving Phase 3 Name as a Phase 1 Name in Phase 1	Subjects Giving Phase 3 Name as a Phase 1 Name for Another Study
1	*Bowtie	Propeller	16	0	0
2	*Quartermoon	Quartermoon (1)	27	0	0
3	*Star	Flag	1	0	0
4	Triangle	Pyramid	10	0	0
5	Hourglass	Bowtie	3	1	59
6	*Halfmoon	Bowl	31	0	0
7	Spade(s)	Tree	31	3	64
8	Mushroom(s)	Palm Tree	5	0	0
9	*Homeplate	Upside-down House	12	0	0
10	*Heart	Valentine	8	1	2
11	K	K (1)	70	0	0
12	Cone	Wedge	17	0	0
13	*M	M	70	0	0
14	*Square(s)	Block	20	3	6
15	I	I (1)	39	0	0
16	*Barbell(s)	Dumbbells	29	0	0
17	Hat	Cowboy Hat	20	0	0
18	Backward Z	Z	10	0	0
19	*Backward L	Backward L (1)	28	0	0
20	*Club(s)	Club (1)	0	1	5
21	Asterisk	Snowflake	38	0	0
22	Rectangle (/)	Slash	5	1	2
23	*Boot(s)	Cowboy boot	13	0	0
24	Rectangle (-)	Rectangle (1)	21	6	37
25	*Horseshoe(s)	Magnet	25	0	0
26	Diamond	Parallelogram	12	3	5
27	Letter V	V	67	1	1
28	*Circle	Hole	20	2	3
29	*Music(al) Note	Note (1)	16	0	0
30	*Fish	Fish supplies	0	0	0

(1) Same as modal first associate found in this study.

particular shapes were the modal names for the shapes as found in phase one of this study. These were "Quartermoon", "K", "I", "Backward L", "Club", and "Rectangle (-)" (Shape numbers 2, 11, 13, 14, 19, 20, and 24). This was expected to cause increased name-shape matches in phase three, and this may have occurred, but due to the generally high level of correct matches, it was not readily apparent in the data.

Another problem with the technique for selecting the names for use in phase three was that some of the selected names were found to be shared by several shapes in the current study. Checking the names used in phase three against phase one data showed that 10 of the 30 names were given for at least one shape other than the one for which it was intended to be paired. In 7 of these 10 cases this probably did not result in excessive ambiguity because the name of subjects in phase one giving that name for the correct phase three shape was much greater than the number giving it for other shapes. In the case of "Hourglass", "Spade(s)", and "Rectangle (-)" (shapes 5, 7, and 24), the number of subjects in phase one giving the name used in phase three for these shapes to another shape was equal to or greater than the number giving the name to the phase three shape. This was expected to lead to fewer correct name-shape matches in phase three, and this may have in fact occurred (see Table 20). Shapes 5 and 7 ("Hourglass" and "Spade(s)") had the fewest correct name matches of any shapes. Shape 23 (Rectangle (-)") had many more correct name-shape matches than did shapes 5 or 7, but was well behind many of the other shapes. Shape 24 may also have benefited from the fact that the name used for it in phase three ("Rectangle (-)") was the modal first name found in phase one of the current study. The difficulties encountered with shapes which had names in common with other shapes pointed up the importance of examining this aspect of nameability in the current study. Despite problems caused by the shape names selected for use in phase three the data did provide useful information as to the relative name ambiguity and confusability of the 30 shapes.

Summary of Nameability Data (Phases one and three)

Phases one and three of this study were concerned with the relative nameability of the 30 pre-selected shapes. Several aspects of nameability were examined. In phase one these aspects were: (1) ability to produce a name for the shape, (2) concensus on the name for a shape, (3) the number of names for the shape, and (4) usage of names for one shape by another. In phase three the lone aspect was: (5) recognition of the shape given a relatively rare verbal associate. Data analysis for phases one and three consisted of rank ordering the thirty shapes with respect to indices for each of the aspects of nameability. These indices are listed in Table 21.

From the outset, shape nameability was viewed as a multidimensional quality. Individual indices measured the relative strength of the shapes on various aspects of nameability but did not provide an overall picture. However, using the individual measures as a group did appear

Table 21. Nameability Indices Used in Phase One and Phase Three

Phase One		Aspect Measured
1-1	Number of subjects providing a name for a shape	(1)
1-2	Number of subjects giving modal name first response to shape	(2)
1-3	Number of subjects giving modal name as first or subsequent response to a shape	(2)
1-4	Number of different names given as first response	(3)
1-5	Number of different names given as first or subsequent response	(3)
1-6	Number of other shapes sharing a first response name (first response for both shapes)	(4)
1-7	Number of other shapes sharing a first or subsequent response name	(4)
Phase Three		
3-1	Number of phase three name assignments to a shape (in terms of number of subjects)	(5)
3-2	Number of phase three names assigned to a shape (in terms of number of names)	(5)
3-3	Percent correct phase three name assignment for a shape	(5)

Aspects

1	Ability to produce a name for the shape
2	Concensus on the name for a shape
3	The number of names for the shape, and
4	Usage of names for one shape by another
5	Recognition of the shape given a relatively rare verbal associate

to offer the possibility to derive composite measures of nameability. One approach involved summing the ranks of each shape on all measures and then ranking the shapes on the basis of these summed ranks. A second approach involved counting the number of indices on which a shape was ranked in the top third and then ranking the shapes on the basis of this count. It was realized that inclusion of the phase three indices in either of these measures might result in spuriously high or low ratings for some shapes. Artificially high scores might have occurred in those cases where the modal name for a given shape was used in phase three. Artificially low scores for some shapes might have occurred from the use of phase three names with extremely weak associations for the intended shape or from the name being associated with other shapes as well as that intended. Because of this problem, a check on which shapes were most affected by these factors was attempted.

Ranking and Basis of Sum or Rank Orders. The ranks of each shape on all the indices obtained from phases one and three were summed. The shapes were then rank ordered with respect to their individual sum of ranks score (see Table 22). This ranking showed clear differences among the shapes based on a composite of the criteria used in the study. Shapes at the top of the scale ("Heart" [10], "Hat" [17], "K" [11], "Boot(s)" [23], "Fish" [30], and "Star" [31]) would be preferred on the basis of nameability to those at the bottom ("Club(s)" [20], "Homeplate" [9], "I" [15], "Cone" [12], "Hourglass" [5], "Rectangle (-)" [24], and "Rectangle (/)" [22]) with some equivocation about those in the center.

As a check on the problems found in the phase three data, shapes were also ranked on the sum of phase one indices along (see Table 23). The rank order correlation between the ranks shown in Table 22 and those shown in Table 23 was 0.90, indicating that despite concern over the phase three data, it had no drastic effect on the overall ranking system.

In an attempt to identify those shapes most likely to have been affected by the problems in phase three, the difference in ranks for each shape on the sum of phase one ranks alone and the sum of phase one and phase three ranks combined was computed (see Table 24). The standard deviation of these different scores was 3.9 positions (around the expected mean of 0). Of the thirty shapes, ten had a difference in ranks which exceeded one standard deviation. Four of these were in a positive direction and six were in a negative direction going from phase one rank to the combined phase one and phase three rank. Of the four positive differences of more than one standard deviation, three ("Quartermoon" [2], "M" [15], and "Music(al) Note" [29]) involved use of part or all of the modal first name as the phase three name, and the fourth ("Barbell(s)" [16]) involved the use of a name very near in associative strength to the modal first name. Of the six negative differences of more than one standard deviation, three shapes had phase three names strongly associated with other shapes ("Hourglass" [5], "Spade(s)" [7], and "Square(s)" [14]) and two ("Star" [3] and

Table 22. Rank Order of Shapes with Respect to Sum of Phase One and Phase Three Indices

Rank	Shape Number	Modal Name	Sum of Phase 1 and Phase 3 Ranks
1.0	10	*Heart	51.5
2.0	17	Hat	83.0
3.0	11	K	86.0
4.0	23	*Boot(s)	90.0
5.0	30	*Fish	92.5
6.0	3	*Star	94.5
7.0	8	Mushroom(s)	108.5
8.0	16	*Barbell(s)	123.0
9.0	28	*Circle	135.5
10.0	2	*Quartermoon	139.0
11.0	26	Diamond	139.5
12.0	4	Triangle	141.0
13.0	13	*M	143.5
14.0	21	Asterisk	145.0
15.0	14	*Square(s)	149.5
16.0	29	*Music(al) Note	151.0
17.0	6	*Halfmoon	157.0
18.0	25	*Horseshoe(s)	160.0
19.0	7	Spade(s)	161.0
20.0	18	Backward Z	165.5
21.0	19	*Backward L	166.0
22.0	1	*Bowtie	172.5
23.0	27	Letter V	187.5
24.0	20	*Club(s)	210.5
25.0	9	*Homeplate	218.0
26.0	15	I	218.5
27.0	12	Cone	219.5
28.0	5	Hourglass	227.0
29.0	24	Rectangle (-)	240.0
30.0	22	Rectangle (/)	274.0

Table 23. Comparison of Rank of Shapes with Respect to Sum of Phase One Indices and Sum of Phase One and Phase Three Indices Combined

Rank Based on Phase 1	Rank Based On Phase 1 + Phase 3	Shape Number	Modal First Name
1.0	6.0	3	*Star
2.0	1.0	10	*Heart
3.0	7.0	8	Mushroom(s)
4.0	2.0	17	Hat
5.0	5.0	30	*Fish
6.0	3.0	11	K
7.0	4.0	23	*Boot(s)
8.0	11.0	26	Diamond
9.0	19.0	7	Spade(s)
10.0	12.0	4	Triangle
11.0	15.0	14	*Square(s)
12.0	9.0	28	*Circle
13.0	14.0	21	Asterisk
14.0	8.0	16	*Barbell(s)
15.0	18.0	25	*Horseshoe(s)
16.0	22.0	1	*Bowtie
17.0	10.0	2	*Quartermoon
18.0	17.0	6	*Halfmoon
19.0	20.0	18	Backward Z
20.0	16.0	29	*Music(al) Note
21.0	13.0	13	*M
22.0	21.0	19	*Backward L
23.0	24.0	]0	*Club(s)
24.0	28.0	5	Hourglass
25.0	26.0	15	I
26.0	23.0	27	Letter V
27.0	27.0	12	Cone
28.0	25.0	9	*Homeplate
29.0	29.0	24	Rectangle (-)
30.0	30.0	22	Rectangle (/)

Table 24. Difference Between Phase One and Phase One Plus Phase Three Ranks for Each Shape

Shape Number	Modal Name	Difference in Ranks
1	*Bowtie	-6.0
2	*Quartermoon	7.0
3	*Star	-5.0
4	Triangle	-2.0
5	Hourglass	-4.0
6	*Halfmoon	1.0
7	Spade(s)	-10.0
8	Mushroom(s)	-4.0
9	*Homeplate	3.0
10	*Heart	1.0
11	K	3.0
12	Cone	0.0
13	*M	8.0
14	*Square(s)	-4.0
15	I	-1.0
16	*Barbell(s)	6.0
17	Hat	2.0
18	Backward Z	-1.0
19	*Backward L	1.0
20	*Club(s)	-1.0
21	Asterisk	-1.0
22	Rectangle (/)	0.0
23	*Boot(s)	3.0
24	Rectangle (-)	0.0
25	*Horseshoe(s)	-3.0
26	Diamond	-3.0
27	Letter V	3.0
28	*Circle	3.0
29	*Music(al) Note	4.0
30	*Fish	0.0

"Mushroom(s)" [8]) had phase three names that were extremely weak associates. The sixth shape exceeding one standard deviation in the negative direction was Bowtie (shape number 1) which did not conform to either of the above conditions and thus stood as somewhat an anomaly.

Ranking on the Basis of Number of Individual Indices on Which Each Shape Ranked in the Top Third. The number of indices (see Table 21) on which each shape was ranked among the top third in rank order (including shapes which could be considered in the top third on the basis of a tie) was computed. This value ranged from 0 to 10 for the various shapes. Shapes were rank ordered with respect to this value as shown in Table 25. This ranking did little more than distinguish between best and worst shapes on the basis of a composite of criteria used in this study. Shapes at the top of the scale ("Heart" [10] and "K" [11]) were clearly better than those at the bottom ("Hourglass" [5], "Rectangle (/)" [22], and "Rectangle (-)" [24]). A large amount of equivocation remained about these shapes falling between.

A check on problems generated by the inclusion of phase three indices in this measure was performed in a manner similar to that used for the sum of phase one indices on which a shape was among the top third and then ranking the shapes with respect to that value. The shape's rank on the phase one and phase three combined count was then subtracted from its rank on the phase one count alone. Table 26 shows the ranking of each shape on both the phase one and on the phase on and phase three combined counts for each shape and the difference between these rankings. The standard deviation of the difference in ranks between the two counts was then computed (around the expected mean of 0) and was found to be 3.68 positions. Shapes exceeding one standard deviation in difference were assumed to be those most likely affected by problems generated in phase three. Eleven shapes met this specification; six in a positive direction and five in a negative direction. The six shapes ("Quartermoon" [2], "M" [13], "Hat" [17], "Backward L" [19], "Boot(s)" [23], and "Music(al) Note" [29]), having a difference of more than one standard deviation in the positive direction all involved the use of the modal name as part or all of the name used in phase three for that shape. Of the five shapes with a negative difference of more than one standard deviation, three had phase three names for other shapes ("Square(s)" [14], "Circle" [28], and "Spade(s)" [7]) and the other two had phase three names that were low to very low associates of the correct shape ("Mushroom(s)" [8] and "Triangle" [4]).

Comparison of the Two Summary Rank Orderings. The correlation between the rank ordering of shapes on the basis of sum of ranks on the individual indices and the rank ordering of shapes on the basis of number of top third rankings in was 0.97. Comparing the two rank orderings item by item (with ties in the number of top third ranking being positioned so as to minimize as much as possible the distance between the position of a shape in the two orderings), little or no position differences were found for the best and worst shapes (see Table 27). Shapes in the middle varied slightly more than those at the top and bottom of

Table 25. Number of Phase One and Three Indices on Which Each Shape Ranked in Top Third

Rank on Number of Phase 1 and 3 Indices in Top 1/3	Shape Number	Modal Name	Number of Phase 1 and 3 Indices in Top 1/3
1.0	10	*Heart	10
2.0	11	K	8
4.0	3	*Star	7
4.0	17	Hat	7
4.0	23	*Boot(s)	7
6.0	30	*Fish	6
8.5	2	*Quartermoon	5
8.5	8	Mushroom(s)	5
8.5	26	Diamond	5
8.5	28	*Circle	5
13.0	4	Triangle	4
13.0	7	Spade(s)	4
13.0	14	Square(s)	4
13.0	13	*M	4
13.0	16	*Barbell(s)	4
18.0	21	Asterisk	3
18.0	25	*Horseshoe(s)	3
18.0	29	*Music(al) Note	3
18.0	6	*Halfmoon	3
18.0	19	Backward L	3
21.5	1	*Bowtie	2
21.5	18	Backward Z	2
25.0	9	*Homeplate	1
25.0	12	Cone	1
25.0	15	I	1
25.0	20	*Club(s)	1
25.0	27	Letter V	1
29.0	5	Hourglass	0
29.0	22	Rectangle (/)	0
29.0	24	Rectangle (-)	0

Table 26. Differences in Rank of Shape on Number of Phase One Indices in the Top Third versus the Number of Phase One Plus Phase Three Indices in Top Third

Shape Number	Shape Name	Rank on Number of Top 1/3 Phase One Indices	Rank on Number of Top 1/3 Phase 1 & Phase 3 Indices	Differences
1	*Bowtie	22.0	21.5	0.5
2	*Quartermoon	15.0	8.5	6.5
3	*Star	1.5	4.0	-2.5
4	Triangle	9.0	13.0	-4.0
5	Hourglass	28.5	29.0	-0.5
6	*Halfmoon	15.0	18.0	-3.0
7	Spade(s)	9.0	13.0	-4.0
8	Mushroom(s)	4.0	8.5	-4.5
9	*Homeplate	22.0	25.0	-3.0
10	*Heart	1.5	1.0	0.5
11	K	4.0	2.0	2.0
12	Cone	22.0	25.0	-3.0
13	*M	22.0	13.0	9.0
14	*Square(s)	9.0	13.0	-4.0
15	I	22.0	25.0	-3.0
16	*Barbell(s)	15.0	13.0	2.0
17	Hat	9.0	4.0	5.0
18	Backward Z	22.0	21.5	0.5
19	*Backward L	22.0	18.0	-3.0
20	*Club(s)	22.0	25.0	-3.0
21	Asterisk	15.0	18.0	-3.0
22	Rectangle (/)	28.5	29.0	-0.5
23	*Boot(s)	9.0	4.0	5.0
24	Rectangle (-)	28.5	29.0	-0.5
25	*Horseshoe(s)	15.0	18.0	-3.0
26	Diamond	9.0	8.5	0.5
27	Letter V	28.5	25.0	3.5
28	*Circle	4.0	8.5	-4.5
29	*Music(al) Note	22.0	18.0	4.0
30	*Fish	9.0	6.0	3.0

Table 27. Comparison of Rank and Order of Shapes on the Two Summary Scales

Rank According to Sum of Ranks			Rank According to Number of Top Third Ranks		
Shape Number	Modal Name	Rank	Shape Number	Modal Name	Rank
10	*Heart	1.0	10	*Heart	1.0
17	Hat	2.0	11	K	2.0
11	K	3.0	17	Hat	4.0
23	*Boot(s)	4.0	23	*Boot(s)	4.0
30	*Fish	5.0	3	*Star	4.0
3	*Star	6.0	30	*Fish	6.0
8	Mushroom(s)	7.0	8	Mushroom(s)	8.5
16	*Barbell(s)	8.0	2	*Quartermoon	8.5
28	*Circle	9.0	28	*Circle	8.5
2	*Quartermoon	10.0	26	Diamond	8.5
26	Diamond	11.0	16	*Barbell(s)	13.0
4	Triangle	12.0	4	Triangle	13.0
13	*M	13.0	13	*M	13.0
21	Asterisk	14.0	7	Spade(s)	13.0
14	*Square(s)	15.0	14	*Square(s)	13.0
29	*Music(al) Note	16.0	29	*Music(al) Note	18.0
6	*Halfmoon	17.0	6	*Halfmoon	18.0
25	*Horseshoe(s)	18.0	25	*Horseshoe(s)	18.0
7	Spade(s)	19.0	21	Asterisk	18.0
18	Backward Z	20.0	19	*Backward L	18.0
19	*Backward L	21.0	18	Backward Z	21.5
1	*Bowtie	22.0	1	*Bowtie	21.5
27	Letter V	23.0	27	Letter V	25.0
20	*Club(s)	24.0	20	*Club(s)	25.0
9	*Homeplate	25.0	9	*Homeplate	25.0
15	I	26.0	15	I	25.0
12	Cone	27.0	12	Cone	25.0
5	Hourglass	28.0	5	Hourglass	29.0
24	Rectangle (-)	29.0	24	Rectangle (-)	29.0
22	Rectangle (/)	30.0	22	Rectangle (/)	29.0

the order indicating some question as to their proper order. It was perhaps more than a coincidence that the middle range on both rank orderings included most of the shapes about which there was some question due to biased treatment in phase three.

Clusters of Confusable Shapes. Both phase one and phase three offered the opportunity to determine if there were clusters of shapes that would be confused on the basis of name. A phase one cluster analysis was based on the number of names two or more shapes had in common. Several clusters were found to exist on this basis. The most strongly linked shapes were "I", "Rectangle (/)", and "Rectangle (-)" (shapes 15, 22, and 24). Clusters of less strongly linked shapes were "Cone" and "Letter V" (shapes 12 and 27) and "Spade(s)" and "Club(s)" (shapes 7 and 20). A cluster analysis of the phase three confusion matrix uncovered one other cluster of shapes linked by name. This involved "Bowtie" and "Propeller" (shapes 1 and 5).

Direction of Contrast and Nameability. A point of minor interest in this study was direction of contrast, i.e., whether a black on white (BONW) shape was labeled differently than a white on black (WONB) version of the same shape. Data on this question was provided by having approximately half (41) of the subjects respond to BONW shapes while the remainder (42) responded to WONB shapes. The BONW and WONB data were then compared on three phase one indices to determine whether direction of contrast had some effect on naming. These indices were: (1) the percentage of subjects giving the modal name as a first or subsequent response, (2) the number of different names given a shape on first and subsequent response, and (3) the percentage of subjects giving the shape a name.

The percentage of subjects giving the modal name to BONW shapes correlated 0.95 with the percentage of subjects giving the modal name to WONB shapes. This indicated that the strength of the modal names for the 30 shapes was not affected by direction of contrast.

The number of names given to BONW shapes correlated 0.84 with the number of names given WONB shapes. The list of BONW names was not identical to the WONB list for any shape but they were very similar in length. Name differences were due to singletons and other low associates and probably occurred by chance. The modal name was always found in both the BONW and WONB lists of names for a shape, and as shown above, was about equally shown in either list.

Finally, the percentage of subjects giving a name to BONW shapes correlated 0.62 with the percentage of subjects giving a name to WONB shapes. This was somewhat lower than the previously discussed correlations, but this was apparently due to the high percentages involved in both sets of data, i.e., the correlation was affected by a range restriction.

In summary, there was no evidence that direction of contrast affected the aspects of nameability discussed above. The possibility of other differences was not investigated, but such differences seemed highly unlikely given the total lack of evidence for such effects in the examined data. An added value to the analysis for direction of contrast effects was a check on the reliability of the indices examined. The high correlations obtained could be viewed as being between split-halves of the data and thus indicated high reliability.

Conclusions About Shape Nameability. This study provided a great deal of support for the concept of nameability by showing that there were clear differences on: (1) the number of subjects naming a shape, (2) the amount of name concensus for a shape, (3) the number of different names for a shape, and (4) the number of names a shape shared with other shapes. Furthermore, although the rank of any shape varied with the particular aspect being examined, some shapes could be said to be generally superior with respect to nameability. This was evidenced in the composite rankings where some shapes had high ranking on most aspects examined while others did not rank high on any aspect. In sum, the evidence appeared to support "Heart" [10], "Hat" [17], "K" [11], "Boot(s)" [23], "Fish" [30], and "Star" [3] as very nameable shapes compared to "I" [15], "Homeplate" [9], "Cone" [12], "Hourglass" [5], "Rectangle (-)" [24], and Rectangle (/)" [22]. Specific choices between shapes would seem to be reasonably based on the sum of ranks measure (Table 22), and, when particular nameability aspects are important, ranks on individual indices should be taken into account as well.

Phase Two

Phase two of this study called for subjects to select at least one "like" (most likely to be mistaken for) and one "unlike" (least likely to be mistaken for) shape for each of the 30 shapes. It was felt that this data would provide a basis for preliminary selection of shapes which were highly discriminable (in a perceptual sense). Instructions stressed that choices were to be made on the basis of "looked most like (unlike)". Information thus provided led to the selection of shapes for experiments two and three of this study as described below.

Two-dimensional matrices were contructed for both the like and unlike data (see Tables 28 and 29). These data in matrix form were subjected to separate cluster analyses. The like data matrix appeared nearly symmetrical, allowing the cluster analysis to be run, as is typical, on the lower triangle alone. The unlike data matrix appeared far from symmetrical and so the cluster analysis was run on data in lower triangular form but consisting of values from the lower and upper triangles added (i, jth value added to the j, ith value).

The results of the cluster analyses on the two matrices are shown in Figures 5 and 6. The branching structures of the analyses were divided horizontally into numbered segments (eleven segments in the like analysis and three in the unlike analysis). Shapes within each numbered

Table 28. Matrix Showing Number of Subjects Judging a Shape Like Another Shape

SHAPE JUDGED LIKE No.	Name	SHAPE PRESENTED 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	*Bowtie	0	1	3	2	30	1	0	0	0	0	0	5	2	0	1	22	7	0	0	0	7	0	7	2	1	2	1	1	2	32
2	*Quartermoon	0	0	3	1	0	38	0	45	0	2	0	5	0	1	0	1	3	0	1	0	1	2	0	0	21	0	1	14	0	3
3	*Star	0	3	0	7	8	0	2	1	1	2	0	2	0	0	0	0	1	0	0	3	58	0	1	0	1	5	4	0	0	0
4	Triangle	2	0	11	0	42	1	2	1	29	2	0	19	1	15	0	0	4	1	4	0	0	0	0	0	0	39	14	4	0	0
5	Hourglass	31	0	11	35	0	0	0	0	3	1	1	10	5	1	0	11	0	4	0	1	1	0	1	0	1	19	2	0	0	6
6	*Halfmoon	1	35	3	2	1	0	0	7	9	7	0	6	0	1	0	0	7	0	0	1	1	0	1	3	7	0	1	39	1	2
7	Spade(s)	0	0	1	5	2	1	0	16	1	49	0	1	0	0	0	0	10	1	0	60	1	0	0	1	2	9	1	5	1	7
8	Mushroom(s)	2	43	0	0	0	13	9	0	1	2	0	3	0	0	0	4	5	0	0	20	0	2	1	0	8	2	0	0	3	7
9	*Homeplate	0	1	3	20	6	12	2	1	0	4	0	11	4	49	2	0	5	0	9	0	0	0	2	0	0	12	2	2	0	0
10	*Heart	0	1	0	0	0	6	40	0	2	0	0	1	0	2	0	0	8	0	0	23	1	1	0	0	6	7	2	42	1	5
11	K	0	1	1	0	2	1	0	1	0	1	0	1	43	0	1	0	1	39	0	0	7	3	2	1	1	0	25	0	0	1
12	Cone	7	0	1	17	6	2	1	3	12	5	1	0	0	0	14	1	0	0	0	1	0	5	1	2	1	15	13	1	4	4
13	*M	0	0	1	1	2	1	0	1	1	1	51	1	0	1	1	1	4	58	2	0	4	1	1	0	10	0	40	0	0	0
14	*Square(s)	1	0	1	8	0	0	0	0	48	0	0	0	1	0	6	0	1	1	33	0	0	3	2	11	0	11	0	11	0	0
15	I	0	1	0	1	1	0	1	0	0	0	4	27	4	12	0	9	0	4	19	0	2	62	2	60	0	5	5	0	11	0
16	*Barbell(s)	30	0	1	1	6	1	2	0	0	0	2	0	0	1	3	0	0	2	0	2	8	10	0	6	1	0	0	5	36	8
17	Hat	1	1	1	1	1	2	2	2	2	5	1	0	0	0	1	2	0	0	0	6	1	0	27	0	14	0	0	3	0	2
18	Backward Z	1	2	0	0	1	0	0	1	0	0	47	0	47	0	1	1	1	0	1	0	1	3	1	3	5	0	25	0	2	1
19	*Backward L	1	0	0	0	0	0	1	0	3	0	0	0	1	18	7	0	0	0	0	1	0	4	36	7	1	1	1	0	19	0
20	*Club(s)	3	0	2	0	0	1	61	22	0	29	0	2	0	1	0	2	9	0	1	0	2	0	0	1	2	11	0	10	3	11
21	*Asterisk	10	1	60	0	1	0	3	0	0	2	4	1	3	0	1	3	0	2	0	4	0	0	1	0	0	0	0	4	1	0
22	Rectangle(/)	2	6	0	1	0	0	0	1	1	0	3	6	3	7	63	28	1	6	8	1	3	0	1	53	0	3	10	1	4	0
23	*Boot(s)	2	0	1	0	0	0	0	1	0	0	1	0	0	0	1	1	23	0	15	1	0	1	0	0	5	0	0	0	3	2
24	Rectangle(-)	12	0	0	0	0	1	0	0	0	0	0	3	0	15	51	3	0	3	19	0	0	54	1	0	0	1	0	0	1	9
25	*Horseshoe(s)	0	14	1	0	1	1	0	3	0	1	1	0	1	0	1	1	15	1	0	0	1	0	9	0	0	0	6	4	3	0
26	Diamond	3	0	5	38	23	0	11	1	19	8	0	14	0	13	2	1	0	0	2	10	0	0	1	1	0	0	13	2	0	0
27	Letter V	0	1	4	22	8	5	0	3	9	2	37	20	42	0	5	1	2	39	2	0	0	13	0	8	16	9	0	0	1	0
28	*Circle	2	27	5	6	0	49	4	2	2	23	1	0	0	13	0	1	2	0	1	5	9	0	0	0	10	4	1	0	13	5
29	*Music(al) Note	4	0	0	0	0	0	1	4	1	0	0	4	0	0	2	35	0	0	18	1	2	1	10	0	0	0	0	7	0	12
30	*Fish	22	0	2	0	5	2	4	3	1	0	0	5	0	0	0	1	1	0	0	6	1	1	4	4	2	0	0	4	13	0

Table 29. Matrix Showing Number of Subjects Judging a Shape Unlike Another Shape

SHAPE JUDGED LIKE		SHAPE PRESENTED																													
No.	Name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	*Bowtie	0	8	15	5	2	3	8	4	0	8	8	1	14	4	4	2	3	7	1	3	9	0	3	1	11	4	7	5	2	0
2	*Quartermoon	2	0	23	10	4	2	6	2	8	2	10	2	9	9	3	2	1	6	5	1	14	1	4	2	6	6	8	5	3	0
3	*Star	5	4	0	1	0	7	1	8	1	8	10	2	12	9	10	3	5	3	4	2	1	8	3	3	10	0	3	25	5	2
4	Triangle	4	9	0	0	0	13	4	6	0	8	9	0	9	4	3	6	5	3	5	2	9	5	9	4	7	1	2	20	7	8
5	Hourglass	1	6	1	0	0	16	6	8	2	11	12	2	5	3	1	4	7	4	0	3	3	1	3	0	8	4	1	23	6	9
6	*Halfmoon	1	2	8	6	4	0	0	3	2	2	22	11	17	7	3	5	1	21	4	3	10	3	8	5	3	1	7	1	4	2
7	Spade(s)	9	3	9	0	0	2	0	5	10	2	17	1	19	9	9	7	3	11	3	1	9	11	2	4	5	1	7	0	4	2
8	Mushroom(s)	7	1	11	3	3	2	1	0	10	7	14	2	9	9	4	5	1	10	7	4	7	2	3	3	4	4	13	6	3	2
9	*Homeplate	5	5	5	3	1	1	3	2	0	8	19	0	9	2	8	9	4	12	1	5	19	3	5	3	7	1	6	12	1	2
10	*Heart	3	2	11	1	7	1	1	2	0	0	31	4	18	2	7	10	5	14	3	1	7	8	5	4	6	3	9	2	3	2
11	K	4	5	6	5	1	8	4	2	3	15	0	4	5	10	4	2	10	4	3	10	2	1	4	2	5	2	0	31	1	4
12	Cone	4	5	8	2	0	4	6	8	0	2	10	0	8	6	2	8	9	12	2	3	11	4	9	8	7	1	0	13	7	5
13	*M	5	3	5	4	0	1	11	6	2	9	3	0	0	17	3	5	11	1	9	9	11	1	8	3	4	1	1	23	3	3
14	*Square(s)	4	6	7	3	0	4	3	4	0	2	11	2	14	0	2	15	6	15	2	1	18	1	5	0	11	1	7	21	1	2
15	I	2	8	7	2	2	0	7	10	3	12	6	1	2	3	0	3	23	2	2	8	16	1	6	5	10	1	2	19	1	1
16	*Barbell(s)	2	6	9	5	5	2	3	3	2	10	7	0	5	6	3	0	19	10	4	4	10	2	6	0	9	8	4	10	1	5
17	Hat	1	3	4	1	3	2	4	2	1	1	11	4	13	4	9	5	0	23	5	3	13	6	2	7	6	2	7	4	3	5
18	Backward Z	3	3	5	4	0	3	8	6	3	16	4	3	2	10	1	2	12	0	8	10	9	1	13	4	3	2	0	23	2	5
19	*Backward L	6	4	9	3	5	4	2	4	1	2	6	2	12	1	0	4	5	6	0	14	27	3	4	0	11	4	3	14	2	1
20	*Club(s)	4	3	3	1	2	2	0	4	4	1	10	2	10	4	8	6	1	9	4	0	14	14	10	9	9	8	11	0	2	7
21	Asterisk	2	3	1	3	2	4	4	5	6	4	4	3	3	16	6	2	8	3	5	3	0	11	10	11	9	8	2	9	3	1
22	Rectangle(/)	1	1	5	5	7	2	11	6	3	13	2	2	5	5	1	2	12	1	0	9	10	0	12	3	7	3	2	28	2	4
23	*Boot(s)	4	3	7	2	4	5	3	6	2	8	10	2	13	7	3	3	5	10	1	7	9	3	0	5	7	4	4	11	4	6
24	Rectangle(-)	2	6	6	2	6	6	7	7	3	9	7	2	5	2	3	1	9	3	1	3	4	2	3	0	12	4	5	32	3	9
25	*Horseshoe(s)	10	1	9	3	5	2	7	5	3	2	5	3	4	9	2	5	3	4	7	5	14	5	1	4	0	11	9	12	3	5
26	Diamond	6	9	7	1	5	3	5	8	1	5	6	0	7	1	1	7	3	6	2	8	16	4	3	4	4	0	5	22	9	7
27	Letter V	3	2	9	0	1	2	3	5	5	10	1	0	0	12	0	3	7	1	5	13	7	1	9	2	5	2	0	34	10	14
28	*Circle	6	3	6	6	2	1	0	0	5	0	11	1	10	18	11	2	2	12	5	1	8	13	6	13	5	6	12	0	4	3
29	*Music(al) Note	8	6	8	8	8	0	2	3	1	2	3	1	13	10	2	1	8	8	2	2	15	2	4	4	9	5	7	6	0	5
30	*Fish	4	4	15	5	5	3	1	3	4	2	7	3	14	8	9	2	2	11	4	0	15	6	10	4	7	2	5	3	1	0

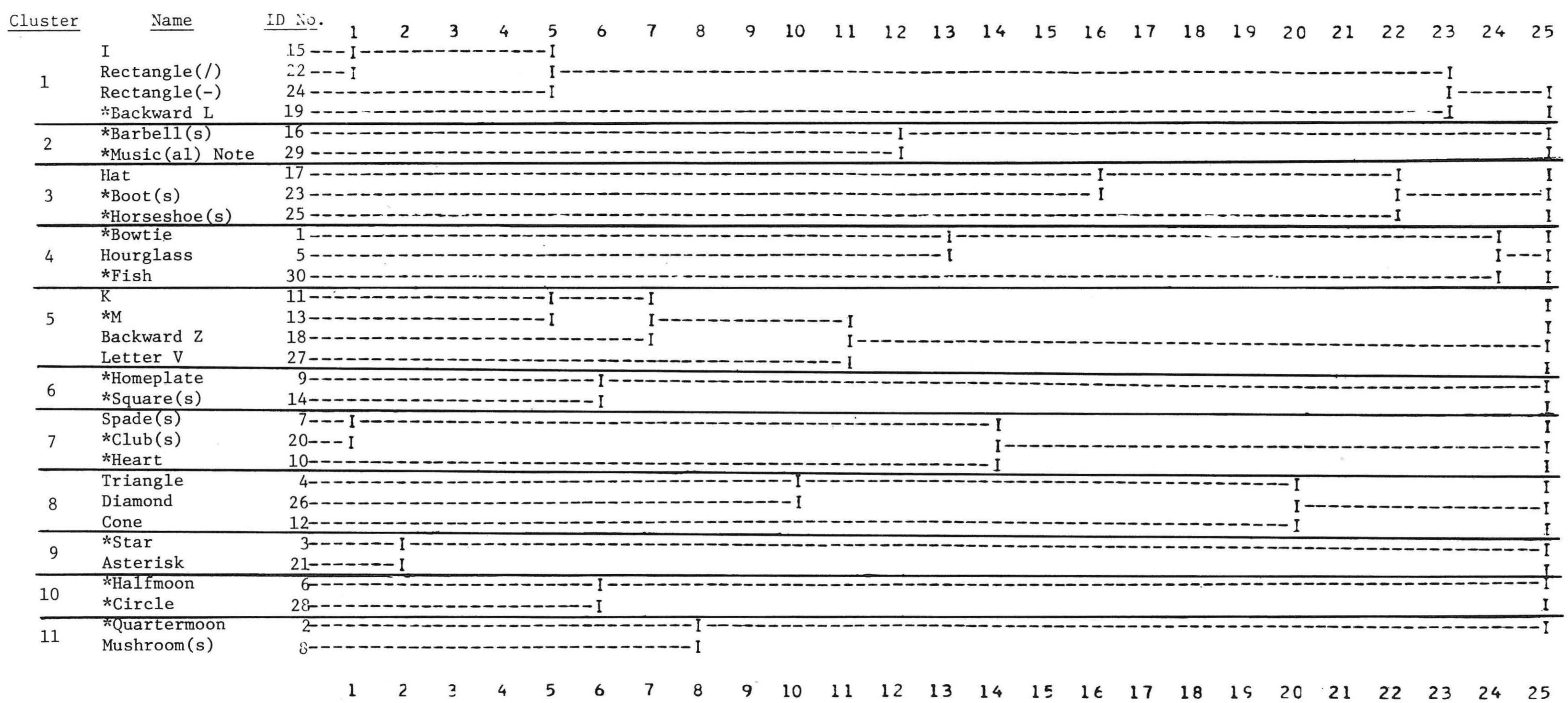


Figure 5. Cluster Analysis Performed on Like Data Matrix

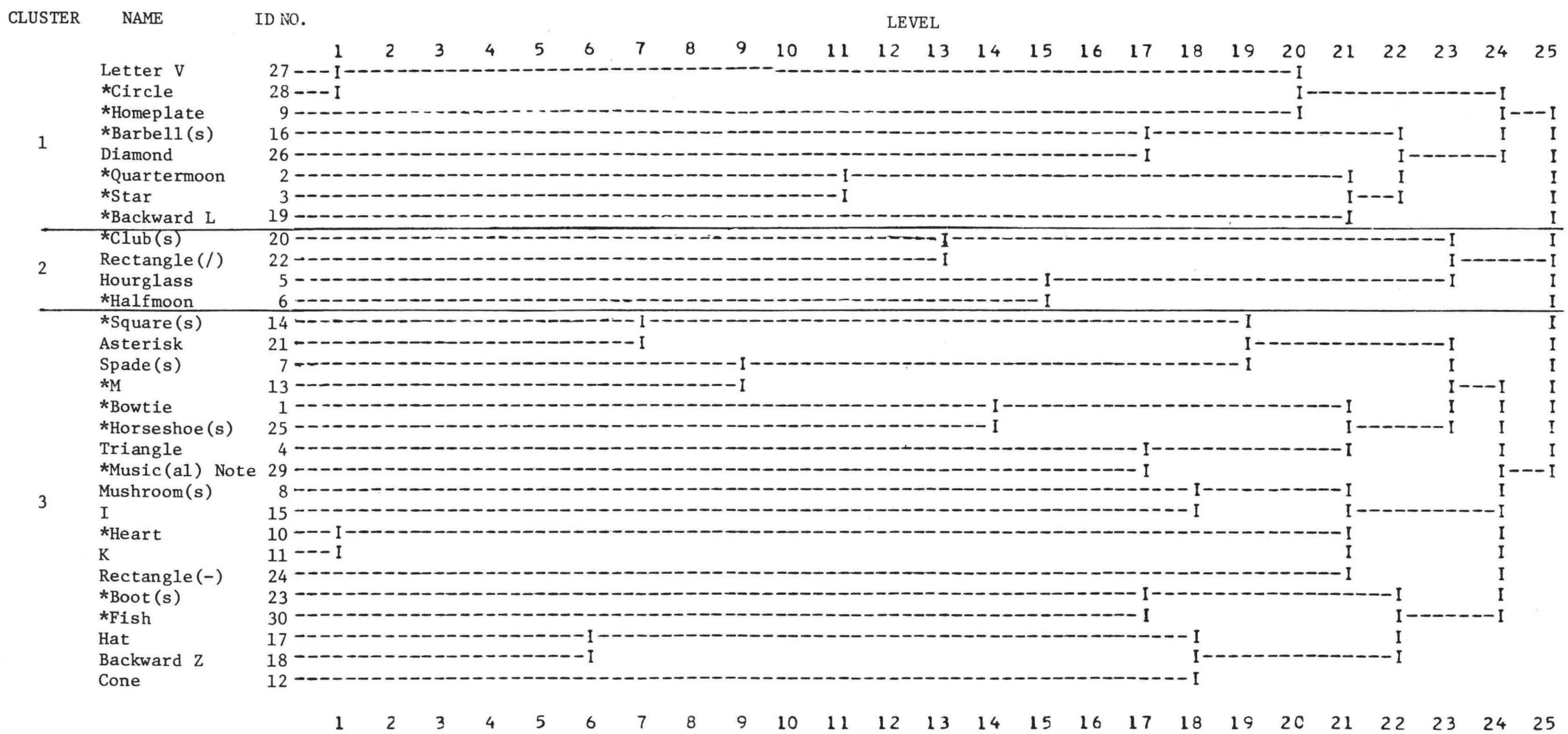


Figure 6. Cluster Analysis Performed on Unlike Data Matrix

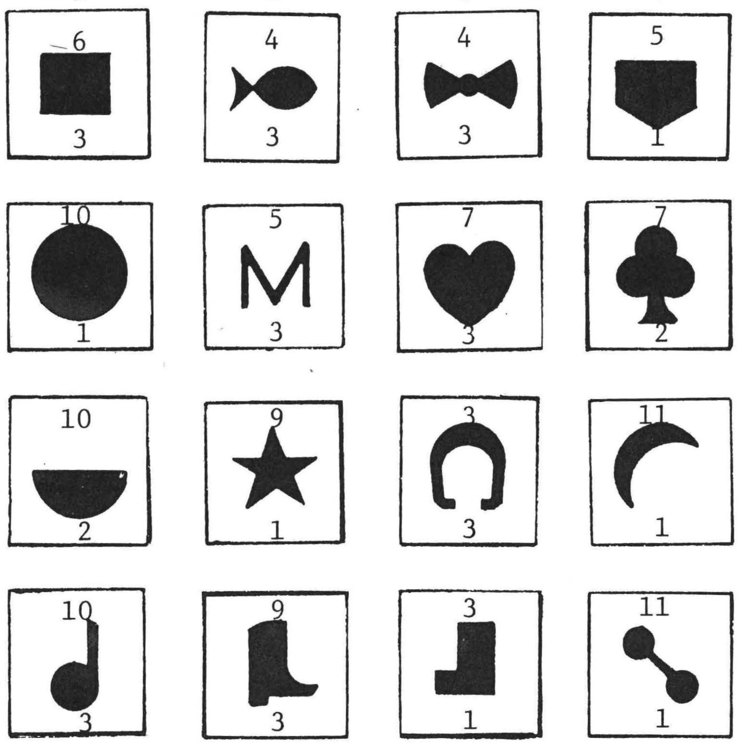
segment were judged more like (unlike) shapes in other segments.

The final stage of phase two involved development of a four by four matrix of shapes such that shapes in the same column were generally judged dissimilar (candidate sets) and shapes in the same row were generally similar (control sets). The matrix of 16 shapes was then used in experiments two and three in this series of studies.

The matrix developed in this phase is shown in Figure 7. The number at the top of each figure represents the segment of the like cluster analysis in which the shape fell. The number at the bottom of each figure represents the segment of the unlike cluster analysis in which the shape fell. The right and bottom marginals summarize this same information for each control (right marginal) and candidate (bottom marginal) set.

Ideally the shapes in a control set should all have been from the same segment of the like analysis and from different segments of the unlike analysis. Conversely, the shapes in a candidate set should all have been from different segments of the like analysis and the same segment of the unlike analysis. Unfortunately, this was not possible (particularly since the unlike analysis yielded only three groups of shapes). Despite departure from the ideal, the like and unlike segment numbers displayed in the marginals do demonstrate that shapes in control groups were judged generally more similar to one another than were shapes in candidate sets.

Candidate Sets (columns 1–4); Control Sets (rows 1–4)



Clusters for the control sets (rows):

Control Set	Like	Unlike
1	2 in 4 1 in 5 1 in 6	1 in 1 3 in 3
2	1 in 5 2 in 7 1 in 10	1 in 1 1 in 2 2 in 3
3	1 in 3 1 in 9 1 in 10 1 in 11	2 in 1 1 in 2 1 in 3
4	1 in 1 2 in 2 1 in 3	2 in 1 2 in 3

Clusters for the candidate sets (columns):

Clusters	1	2	3	4
Like	1 in 2 1 in 6 2 in 10	1 in 3 1 in 4 1 in 5 1 in 9	1 in 1 1 in 3 1 in 4 1 in 7	1 in 2 1 in 5 1 in 7 1 in 11
Unlike	1 in 1 1 in 2 2 in 3	1 in 1 3 in 3	1 in 1 3 in 3	3 in 1 1 in 2

Figure 7. Candidate and Control Sets for Use in Studies Two and Three of This Series

STUDY II. SPEED AND ACCURACY OF LOCATION OF TARGET SHAPES

Study I provided some basis for selecting shapes based on nameability and label confusability. Phase two of that study also provided a rationale for selecting groups of shapes which might be used together as sets in marking overlapping routes -- i.e., at the same interchange. This rationale was provided by the cluster analyses of the subjective judgments of which shapes were "like", i.e. likely to be confused with or mistaken for another, and those which were "unlike", i.e. least likely to be confused with or mistaken for one another. While the cluster analyses did not yield clusters as distinctive as one would have hoped for, they did permit the identification of four sets of four shapes wherein the members of each set were, essentially, from different "like" clusters and therefore subjectively not likely to be confused with one another. These four sets were identified as candidates for use in the color/shape route guidance systems; hence, they were labeled _candidate sets_.

Four additional sets of four shapes were identified from the cluster analyses as _control sets_. In contrast to the candidate sets, control sets were made up of shapes from the _same_ "like" clusters or "neighboring" like clusters, so that they were, subjectively, likely to be difficult to discriminate, i.e., more apt to be confused one with another.

The rationale of Study II was to attempt to validate the candidate sets of Study I in a controlled performance situation which simulated important dimensions of the automobile driver viewing situations. Just as in Study I where subjects were asked to judge where confusions would occur under "glance" viewing, Study II subjects were given a brief glimpse of the target shape in the context of either other candidate or control shapes. While indeed the highway driver may have more than a half second to locate, recognize, and read guidance information, the use of symbols requiring minimal processing time is desirable. Time not devoted to searching for, locating, recognizing, and reading route guidance information can be applied to attending to vehicle control and other traffic in the vicinity. Of course, it is equally important that the driver process the guidance information accurately. Hence, both response latency and accuracy measures were taken. To simulate the spatial uncertainty of route guidance information, shapes designated as "target" shapes occurred randomly in one of the four quadrants of the projected image. In addition, target (and non-target) shapes were located randomly at one of nine locations within each quadrant. While these features of the design do not simulate all aspects of the "real" situation, they do increase the likelihood that the laboratory results will be relevant to the subsequent field test situation.

In summary, then, it was predicted, on the basis of Study I results, that the sixteen shapes would be located and responded to more quickly and accurately when presented in the context of their candidate sets than in the context of the control sets. Stated another way, it was expected that trials involving the presentation of candidate sets would, on the average, result in faster and more accurate target location than trials involving control sets. In the event that this expectation was not borne out, the results of the present study would provide further and alternative criteria for selecting candidate shapes and, possibly, candidate sets of shapes. In the case of conflicting results, priority would have to be given to the perceptual performance data of the present study rather than to the judgmental data of Study I.

Method

Subjects

A total of 48 subjects, 30 males and 18 females, participated in the study. Sixteen subjects were classified in each of three age categories: 15 to 19; 20 to 24; and 24 to 60 years of age. Each subject was required to have far binocular visual acuity of 20/40 or better as measured by a Titmus Optical Tester.

Apparatus

The basic apparatus consisted of a Kodak Carousel slide projector and four Hunter Model 1521 digital clocks. The carousel was used to project the stimulus slides and the clocks were used to measure the latencies of the subjects' responses to pressing either of two response buttons. Slide presentation was controlled by an external shutter, the opening of which was synchronous with the starting of the four digital clocks. Each clock was wired to one of four subject stations such that the pressing of either of the two response buttons at that station stopped the appropriate clock. Stations were side by side at a long table facing the projection screen and separated by partial partitions to minimize inter-subject distractions.

Stimuli

The sixteen shapes selected for use in this study are shown in Figure 8. Each shape was presented together with the other shapes in its row and, alternatively, the other shapes in its column. Stated another way, the rows and column of Figure 8 designate the only combinations of four shapes presented together on the stimulus slides. Furthermore, the columns of Figure 8 represent the candidate sets, while the the rows represent the control sets, as defined earlier. Thus, each of the sixteen shapes were presented in the context of a candidate set and a control set.

Each slide included four shapes, one in each quadrant of the projection area. Each of the four control sets of four shapes occurred in different configurations on eight different slides for a total of 32 control slides. Configurations of sets were varied with respect to the assignment of shapes to quadrants and the location of shapes within a 3 x 3 matrix within each quadrant. Quadrant assignment was systematic

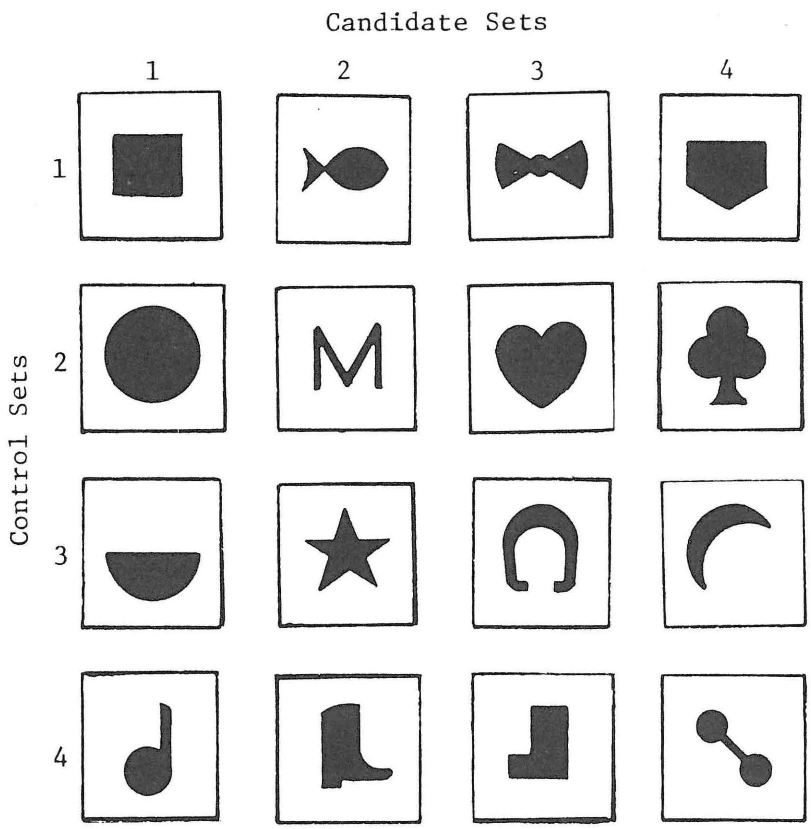


Figure 8. The sixteen shapes used in Study II

so that, for control sets, each target shape occurred twice in each quadrant. Location assignment within quadrants was randomized and designed to simulate spatial uncertainly of information in the highway environment (see Figure 9).

Candidate sets were each presented 16 times for a total of 64 trials. Sixteen of the candidate set trials were "catch trials"; that is, the subjects were given search targets which did not occur on the slide. These catch trials were introduced for two reasons: first, it was of interest to know how much time subjects required to determine that a target was not present; that is, that their "route marker" was not present in the displayed information. Secondly, without catch trials it would not be possible to obtain meaningful response latency data: with a target always present, subjects would simply respond as quickly as possible to the visual stimulus, than attempt to report where the target was located.

The slides were presented for 0.5 seconds duration at a viewing distance of 12 ft. Target shapes, as projected, were inscribed in a 1.2 inch circle and subtended a visual angle of 0.2 degrees. The total matrix of four shapes subtended a maximum of 2 degrees lateral by 2 degrees vertical field.

Procedures and Experimental Design

The 96 stimulus slides were presented in a fixed order for all subjects. This order was random with respect to control sets and candidate set slides. Each of the subjects who were tested at the same time had a different test booklet designating a different target for each slide. Thus, test form (booklet) was a between-subjects variable with 12 subjects per form. Each booklet contained 96 pages corresponding to the 96 trials (slides). Each page contained a replica of one of the 16 shapes which served as a search model for the subject on that trial, a set of coordinate lines, delineating four quadrants, and a response box to indicate "no target". (See Figure 10). As an example, slide X might contain symbols A, B, C, D. For this slide, the four test booklets might contain A, B, C, and D, respectively as search models, or A, B, C, N where N indicates a search model for which no target shape is presented on that slide. This would constitute a catch trial for the subject with that form.

The major experimental variables were the target shapes and the target sets, the latter grouped into control and candidate sets. Both of these variables were treated as repeated measures (within-subjects sources of variance) in the design. Each shape was designated as a target six times on each form, twice in its control set, three times in its candidate set, and once as a catch trial. Targets were located equally often in each quadrant and each shape occurred as a target equally often in each quadrant.

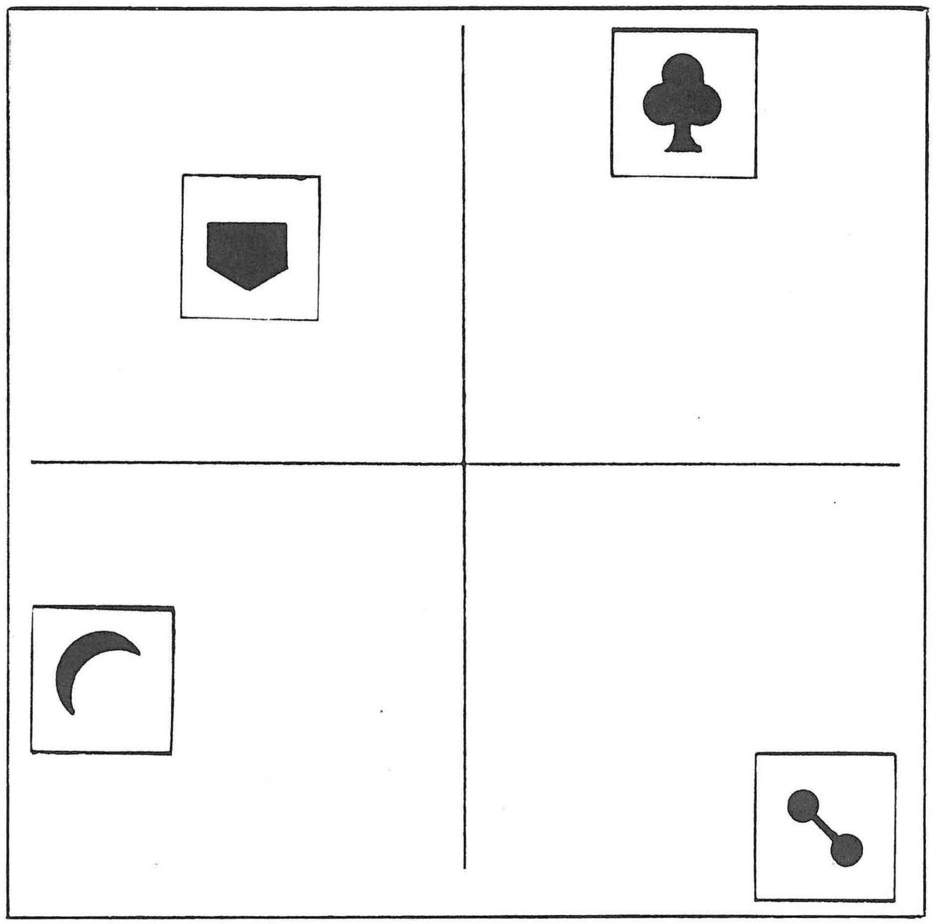


Figure 9. Schematic diagram of slide format

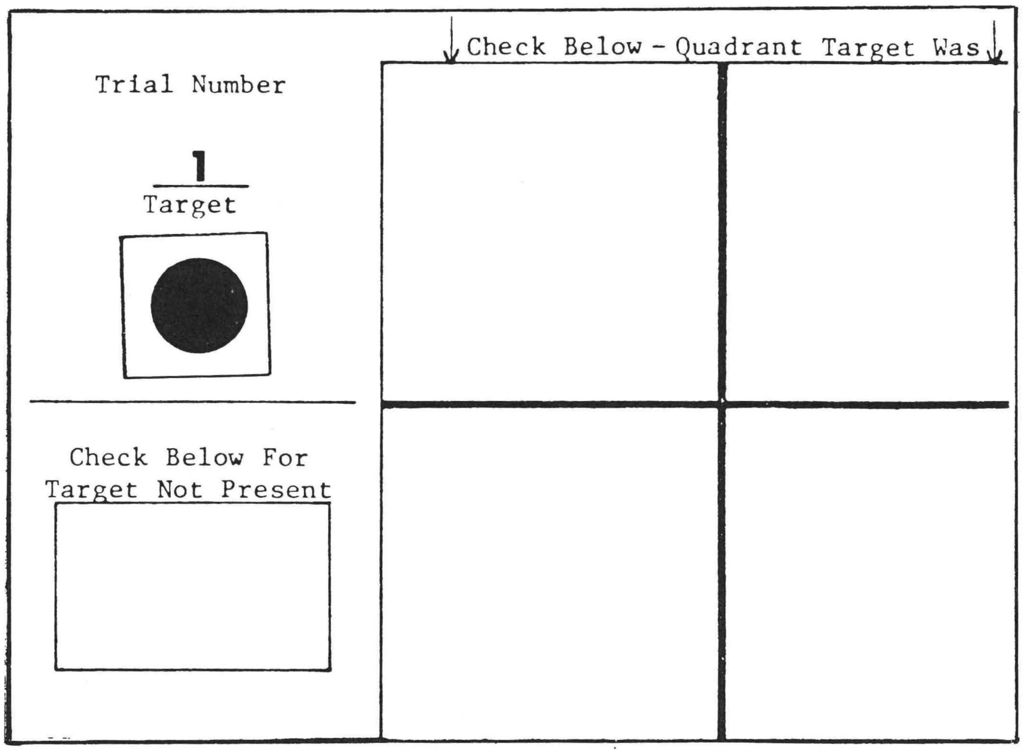


Figure 10. A sample page from the subjects' test booklet

All subjects signed "Informed Consent" forms and then were seated at the four stations with a booklet and two response buttons in front of each of them. The following instructions were read to each group of subjects:

> You will see a series of slides which will contain four symbols. In front of you, you have a series of cards with symbols on them and an answer sheet. You also have a control box with two buttons marked "yes" and "no". When we begin the experiment, you will be instructed to turn over the first card which is labeled "1" and to look at the symbol there. Do not turn the cards until the number is called in each case. After you have turned to a card, the slide projector will show four symbols for a brief period of time. During this time you are to look at the slide and try to locate the symbol which is on your card. As soon as you find the symbol, you press the "yes" button and indicate which location this symbol appeared, that is, 1, 2, 3, or 4, as in the slide now being shown. In some cases the symbol will not appear on the slide at all. Then you are to press the "no" button and to check the box "no" on your answer sheet. The experimenter will then ask you to turn to card number 2, a slide will be turned on, and you are to respond with "yes" when you see the symbol, or "no" if the symbol is not present and mark its location on the "no" answer for Item 2 on your answer sheet. This will continue through a series of slides. Please be careful to have the right card number exposed and to fill in the right number on the answer sheet for each one. Each of you involved in this experiment will have different tasks on each trial so that your performance will have no relationship to your neighbor's. Are there any questions?

Results

Analyses of variance were performed on both the latency and the error data, initially as a simple 1 x 8 analysis of the eight candidate and control sets. Subsequent comparisons were made between candidate and control sets using the Sheffe test.

Latencies. The analysis of the latency data for the eight sets yielded a significant F with $p < .001$. The mean latencies for the eight sets are shown in Table 30, and range from .89 sec. for control set 2 to 1.09 sec. for candidate set 4. The Sheffe test comparing control and candidate sets was not significant, but indicated, contrary to expectations, that response latencies to the targets in their control sets were slightly faster than responses to the same shapes presented in their candidate sets.

Table 30. Mean Response Latencies for the Eight Sets of Stimulus Shapes

SET	MEAN	SET	MEAN
Control 2	0.89 sec.	Candidate 1	0.97 sec.
Control 3	0.91	Candidate 3	1.04
Control 1	0.93	Candidate 2	1.06
Candidate 4	0.96	Control 4	1.09

Errors. The analysis of the error data for the eight sets also yielding a significant F with $p < .001$. The mean proportions of correct responses are presented in Table 31 for each of the eight sets. They range from 0.91 for candidate set 1 to 0.73 for control set 1. In contrast to the latency data, accuracy tended to be greater for the candidate sets than for the control sets ($p < 0.05$).

Table 31. Proportions of Correct Responses for the Eight Sets of Stimulus Shapes

SET	P	SET	P
Candidate 1	0.91	Candidate 4	0.81
Candidate 3	0.89	Candidate 2	0.77
Control 2	0.88	Control 4	0.73
Control 3	0.87	Control 1	0.73

Accuracy and Target Shape. The numbers of errors were tabulated for each of the individual target shapes under both candidate and control set conditions. The results are summarized in Table 32 in which the proportions of correct responses and the rank orders for accuracy are shown. The correlation between the two rank orders was rho = 0.60, indicating that the accuracy data for shapes is quite reliable across the two contexts in which each shape was presented.

The range of accuracy scores for the sixteen shapes is about 30 percent, from the circle (0.97) to the fish (0.65). This is convincing evidence that the specific shapes selected for shape and color coded route markers will make important differences in the accuracy with which shapes are recognized or confused. The top six shapes in Table 32 are highly consistent in rankings from candidate to control sets. The next three ("Halfmoon", "Horseshoe", and "Note") show the greatest variability as a function of candidate versus control set context. Meanwhile, the bottom five shapes are again rather consistently low in accuracy across the two contexts.

Table 32. Proportions of Correct Responses to Each Shape Under Candidate Set and Control Set Conditions

Shape	P Correct Candidate	Rank	P Correct Control	Rank	Overall Rank
Circle	0.96	1	0.98	1	1
M	0.93	4	0.94	2	2
Heart	0.93	4	0.91	4	3
Crescent	0.90	6.5	0.90	5	4
Barbell	0.90	6.5	0.88	6.5	5.6
Square	0.89	8	0.88	6.5	9
Halfmoon	0.83	11	0.93	3	8
Horseshoe	0.93	4	0.82	9	6.5
Note	0.94	2	0.79	10.5	5
Bowtie	0.88	9	0.79	10.5	10
Star	0.66	15	0.84	8	11
Boot	0.86	10	0.61	15	12
Clubs	0.75	14	0.79	12	13.5
Backward L	0.82	12	0.64	14	13.5
Fish	0.62	16	0.67	13	15.5
Homeplate	0.79	13	0.54	16	15.5

The expectation that target shapes would be located more accurately in the context of candidate sets than in control sets is not given any strong support by the data in Table 32. Of those shapes for which the proportion correct differs by more than 0.02 (i.e., the last 10 shapes in Table 32), three show higher accuracy in control than in candidate sets. Of those seven shapes showing substantially less accuracy in the context of control sets, three ("note", "boot", and "backwards L" were from the same control set (number 4). Thus, while the overall analysis showed that candidate sets were more accurately responded to than control sets, comparisons of individual shapes indicate that this is largely true for shapes with the lower overall accuracy scores. Furthermore, with the exception of a few shapes, the context effects of sets are relatively small.

Table 33 provides a detailed summary of the error data. The top row of matrices shows error data for the Candidate sets, the bottom row for the control sets. These data suggest specific combinations of shapes which probably should be avoided: in control set 4, shapes 42 and 43 ("boot" and "backwards L") are the prime example; in Candidate set 1, shapes 11 (square) and 31 (hemishpere) are confused, etc.

Table 33. Summary of Error Data

Candidate Sets (576 observations per set; 144 observations per shape)

Candidate Set 1

Shape	11	21	31	41	0*	T
11		4	1	5	4	14
21	2		2		1	5
31	7	2		1	11	21
41	1	1	1		6	9
0	6		4	6		16

Candidate Set 2

Shape	12	22	32	42	0	T
12		3	7		35	45
22	1			1	7	9
32	3			1	24	28
42	2	4			12	18
0	6	6	13	3		28

Candidate Set 3

Shape	13	23	33	43	0	T
13		1	1		15	17
23			4		5	9
33		2		2	6	10
43		1	4		16	21
0	28	2	5	6		41
T	28	6	14	8	42	98

Candidate Set 3

Shape	14	24	34	44	0	T
14		2	2		31	35
24	1		1	1	24	27
34		2			11	13
44		1	1		9	11
0	7	3	4	7		21
T	8	8	8	8	75	107

Control Sets (384 observations per set; 96 observations per shape)

Control Set 1

Shape	11	12	13	14	0	T
11			1	3	7	11
12	1		6	3	16	26
13	1	4		1	10	16
14	13		1		26	40
T	15	4	8	7	59	93

Control Set 2

Shape	21	22	23	24	0	T
21					1	1
22	2			1	4	7
23	2				5	7
24	1		2	1	19	23
T	5		2	2	29	38

Control Set 3

Shape	31	32	33	34	0	T
31		1			6	7
32			1	1	12	14
33		3		2	11	16
34	1	2	1		6	10
T	1	6	2	3	35	47

Control Set 4

Shape	41	42	43	44	0	T
41		1	2	1	14	18
42	2		17	2	12	33
43	6	12		4	12	34
44	2	1	3		4	10
T	10	14	22	7	42	95

*Column 0 indicates false negative errors; row 0 indicates false positive errors. All other entries are confusion errors; e.g., the circled 4 at the upper left indicates the number of observations in which stimulus 11 was presented as a search model, but the response indicated a confusion with shape 21 (see Figure 8).

<u>Latencies and target shapes</u>. The mean response latencies for each target shape are summarized in Table 34. Values are shown for each shape as it occurred in the context of its candidate and its control set as well as the overall mean latency. The shape names are ordered according to their latencies in the candidate sets from shortest to longest latencies. The overall mean latencies represent weighted means of the candidate and control set means shown, since the ratio of the number of candidate to control set observations was 3:2.

Table 34. Mean Latencies for Each Shape Under Candidate, Control, and Combined Data

	Mean Latencies (secs.)					
Shape	Candidate Set	Rank	Control Set	Rank*	Overall Mean**	Rank
Circle	0.783	(1)	0.831	(1)	0.802	(1)
Heart	0.871	(2)	0.928	(6)	0.878	(2)
Crescent	0.910	(3)	0.930	(7)	0.918	(4)
M	0.943	(4)	0.855	(2)	0.907	(3)
Square	0.948	(5)	0.948	(8)	0.948	(5)
Barbell	0.971	(6)	1.044	(10)	1.000	(6)
Note	1.008	(7)	1.095	(12)	1.043	(10)
Horseshoe	1.014	(8)	0.992	(9)	1.005	(7)
Clubs	1.072	(9)	1.188	(14)	1.118	(12)
Homeplate	1.076	(10)	1.258	(15)	1.149	(13)
Boot	1.093	(11)	1.288	(16)	1.171	(16)
Halfmoon	1.122	(12)	0.893	(4)	1.030	(8.5)
Star	1.130	(13)	0.879	(3)	1.030	(8.5)
Bowtie	1.138	(14)	0.905	(5)	1.045	(11)
Backward L	1.180	(15)	1.156	(13)	1.170	(15)
Fish	1.198	(16)	1.085	(11)	1.153	(14)

*rho = 0.35

**Overall mean based on 3 observations (candidate set) plus 2 observations (control sets).

Again, there is little support for the assumption that target shapes would be responded to more rapidly in the context of their candidate sets than their control sets. While it is true for eight of the target shapes, it is not true for seven, including the "M", "Horseshoe" and the last five shapes in the list. Thus, it tends to be true that those shapes with the shortest <u>overall</u> latencies are responded to more rapidly in the context of the candidate sets.

The range of latencies is from approximately 3/4 of a second ("Circle", 0.783) to 1 1/4 seconds ("Boot", 1.28), and the discrepencies between shape means in the two contexts are as high as 1.3 of a second (especially, "Star", "Bowtie", "Halfmoon"). The rank order correlation between the candidate set and control set values is 0.35. This value may be compared with the 0.60 obtained with the error data. The major discrepancies are that "Star", "Halfmoon" and "Bowtie", which had relatively long latencies in their candidate sets were ranked 3, 4, and 5 respectively, in the control set data, displacing the "Heart", "Crescent" and "Square" from the top five as they appeared in the candidate set data. These results suggest that context (as defined by the candidate and control sets) may well have a greater effect on the time required to respond to specific target shapes than on the number of errors made with the target.

The latency data provided a basis for selecting candidate shapes for a route guidance system. It is clear that the first five shapes at the top of Table 34 would be selected on the basis of this criterion. They are the top five both with respect to candidate and overall latencies and in the upper half with respect to control set latencies. Beyond the top five, the choice of candidate shapes becomes somewhat more difficult because of the discrepancies between candidate and control sets. This difficulty may be resolved, however, when both latency and accuracy data are considered.

Shape and accuracies and latencies. To this point, two criteria, speed and accuracy, have been considered separately as a basis for choosing candidate shapes. A comparison of the orders in Tables 32 and 34 strongly suggest that these criteria are not independent, nor is there any evidence of a trade off whereby shape responded to most quickly yield the greatest error rates, or vice versa. On the contrary, it appears that speed and accuracy are highly and positively correlated. This conclusion is supported in Table 35 which summarizes the rankings of the 16 shapes with respect to speed and accuracy. The rank order correlation is 0.88. The only major discrepancies occur for "Square", which ranks 5th on speed, but 9th on accuracy, "Note", which is essentially the reverse of "Square" and "Boot" which is low on both criteria, but fares better on accuracy (12th) than on speed (16th).

These results provide a reasonably unambiguous basis for selecting shapes which appear to be responded to both accurately and rapidly. With the possible exception of the "Square" for which the rankings are discrepant and the accuracy score relatively low, the top seven shapes in the "combined" order, Table 35, or any subset of these, would appear to be logical choices as candidate shapes. It is of some further interest to note that only one of these shapes -- "Horseshoe" -- falls (slightly) below the mean on the composite nameability data from Study I (see Table 22, page 92). At the same time, five of the seven shapes at the bottom of the combined ranking fall in the lower third of the shapes with respect to the nameability composite. Thus, there is fair agreement between the combined criteria of the present study and the nameability data: none of the shapes indicated by these criteria need be rejected because of poor nameability. Indeed, four of these same seven candidates would have been chosen on that basis alone.

Table 35. Speed, Accuracy, and Combined Rankings of the 16 Shapes

	Overall Ranks			
Shape	Speed	Accuracy	Combined	d*
Circle	1	1	1	0.0
Heart	2	3	2.5	1.0
M	3	2	2.5	1.0
Crescent	4	4	4	0.0
Square	5	9	7	4.0
Barbell	6	6.5	5	0.5
Horseshoe	7	6.5	6	0.5
Halfmoon	8.5	8	9	0.5
Star	8.5	11	10	2.5
Note	10	5	8	5.0
Bowtie	11	10	11	1.0
Clubs	12	13.5	12	1.5
Homeplate	13	15.5	14.5	2.5
Fish	14	15.5	16	1.5
Backward L	15	13.5	14.5	1.5
Boot	16	12	13	4.0

*d = discrepancy in the rank order between speed and accuracy data.
Rank order correlation between speed and accuracy = 0.88

STUDY III. THE ROLE OF BACKGROUND SHAPE AND DIRECTION OF CONTRAST AS CUES TO VISUAL TARGET LOCATION

The third experiment in this series was designed to evaluate the effects of two visually coded variables on the location and recognition of the shape coded signs. It was assumed that the route symbol signs would frequently be presented together -- that is, with two or more at the same location -- and that the effectiveness of the system would be enhanced by an additional design features which would reduce the time required to locate and recognize the relevant symbol. Of course, this is one of the benefits expected from the color coding of the symbols. However, it was expected that both direction of contrast and background shape could serve as additional coding dimensions. Thus, a specific route symbol might be unique, not only with respect to the figure shape, but also as the only shape appearing as a dark figure on a light circular background. Other code shapes used at the same interchange might appear as light on dark or on rectangular-shaped backgrounds. In any case, the information in these two variables would be redundant with the figure shape code, but nonetheless, either or both variables were expected to enhance speed and accuracy in locating and recognizing the target shapes.

Method

The apparatus and viewing conditions were identical with those in Study II.

Subjects

Twenty subjects participated in the study. Each subject was given a visual screening test and required far binocular acuity of 20/40 or better for participation in the experiment. A Titmus optical tester was used for the screening.

The 6 male and 14 female subjects ranged in age from 18 to 29 years. Driving experience ranged from 0 to 13 years with a median of 3 years. Seventeen of the subjects had U.S. drivers' licenses, and one had a Canadian license. Of the two remaining subjects, one male did not have a drivers' license and one male did not provide biographical data.

Procedures

The subjects viewed 80 slides in a fixed order. The slides were randomly ordered with respect to five combinations of the experimental variables, direction of contrast and background shape. In each instance a slide consisted of four shapes located one in each quadrant of the projection field. Shapes were located in one of nine positions within each quadrant, as in Study II.

The scheme with respect to slide types, or matrices, is shown in Figure 11. Matrix I slides were all black shapes on white rectangular backgrounds and were, therefore, identical to those used in Study II. They represent a control condition with respect to the variables under study, since the "target" could be discriminated from non-target symbols only on the basis of figure shape, i.e. direction of contrast and background shapes were constant in these slides. In Matrix II slides background shape (but not direction of contrast) was varied such that in each slide two of the four shapes were presented on square and two on circular backgrounds. Thus, the target -- for example, a star on a circular background -- represented a target shape unique to the slide and presented on a background shape shared by only one other symbol in the slide. For Matrix III, background shape was again constant (square), but direction of contrast was varied so that in any slide two of the four shapes appeared as black figures on white backgrounds and two as white figures on black backgrounds. Thus, the target shape was like only one other shape in the slide with respect to direction of contrast.

In Matrix IV slides both direction of contrast and background shape were varied in a redundant manner. That is, two of the four shapes appeared as black figures on white square backgrounds and the remaining two as white figures on black circular backgrounds. Thus, the target could be discriminated from two of the three non-targets either by direction of contrast or background shape (or both), but differed from the third non-target only with respect to the actual figure shape. Finally, in Matrix V direction of contrast and background shape were varied orthogonally. In this case, each of the four symbols presented in a stimulus slide was a unique combination of direction of contrast and background shape. The target, therefore, was unique with respect to the combination of these conditions, as well as a unique shape.

Figure 12 presents an example of a Matrix I type slide and a Matrix V type slide. In Matrix I the target can be discriminated from the non-targets only with respect to figure shape. In Matrix V the target is unique with respect to the combination of direction of contrast and background shape, as well as figure shape.

The sixteen slides of each matrix type were 16 combinations of four of the 16 shapes used in Study II. These combinations can be described with reference to Figure 13, which presents the 16 target shapes. The rows, columns, and principal diagonals provided 10 of the 16 combinations with the remaining six coming from combinations of the off-diagonal elements with each element used equally often. Thus, each of the sixteen target shapes appeared four times in each matrix type, each time in a unique combination of shapes. The sixteen shapes in each of the four configurations of direction of contrast and background shape are presented in Figure 14.

The 80 slides were presented in a fixed order for all subjects. However, each group of four subjects had a different target designated for each slide. Thus, for any slide consisting of shapes A, B, C and D,

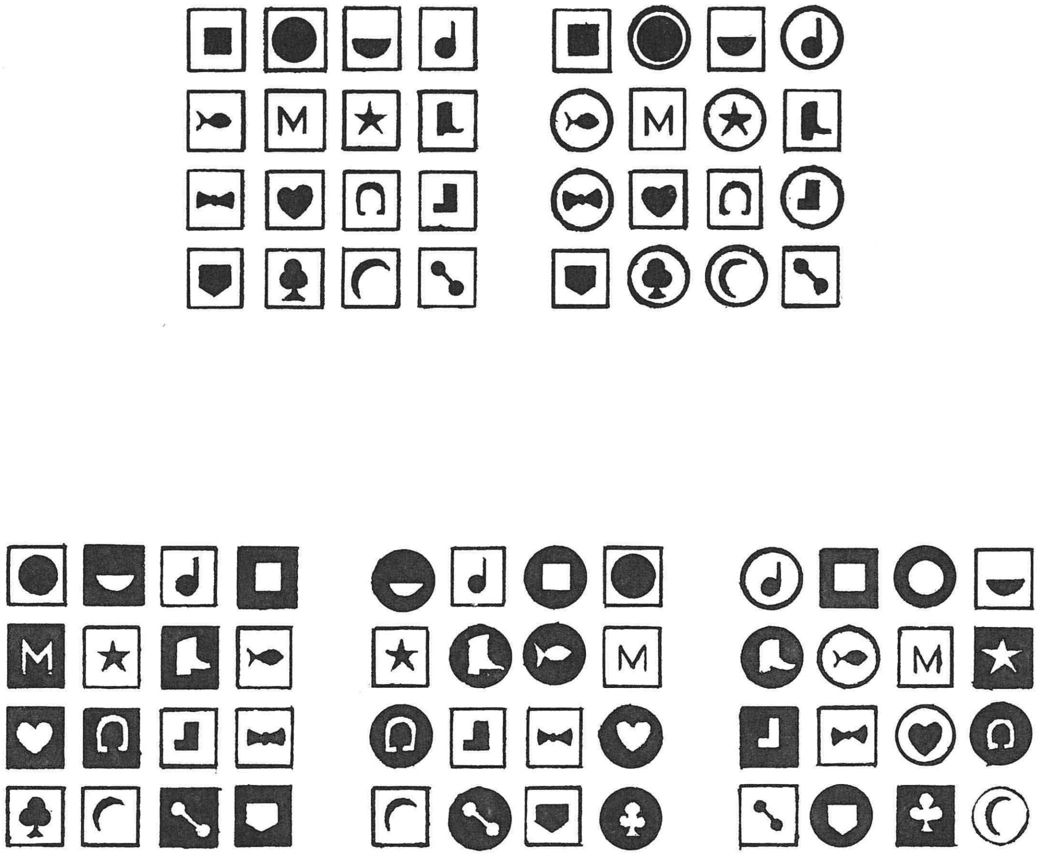


Figure 11. Scheme with Respect to Slide Types

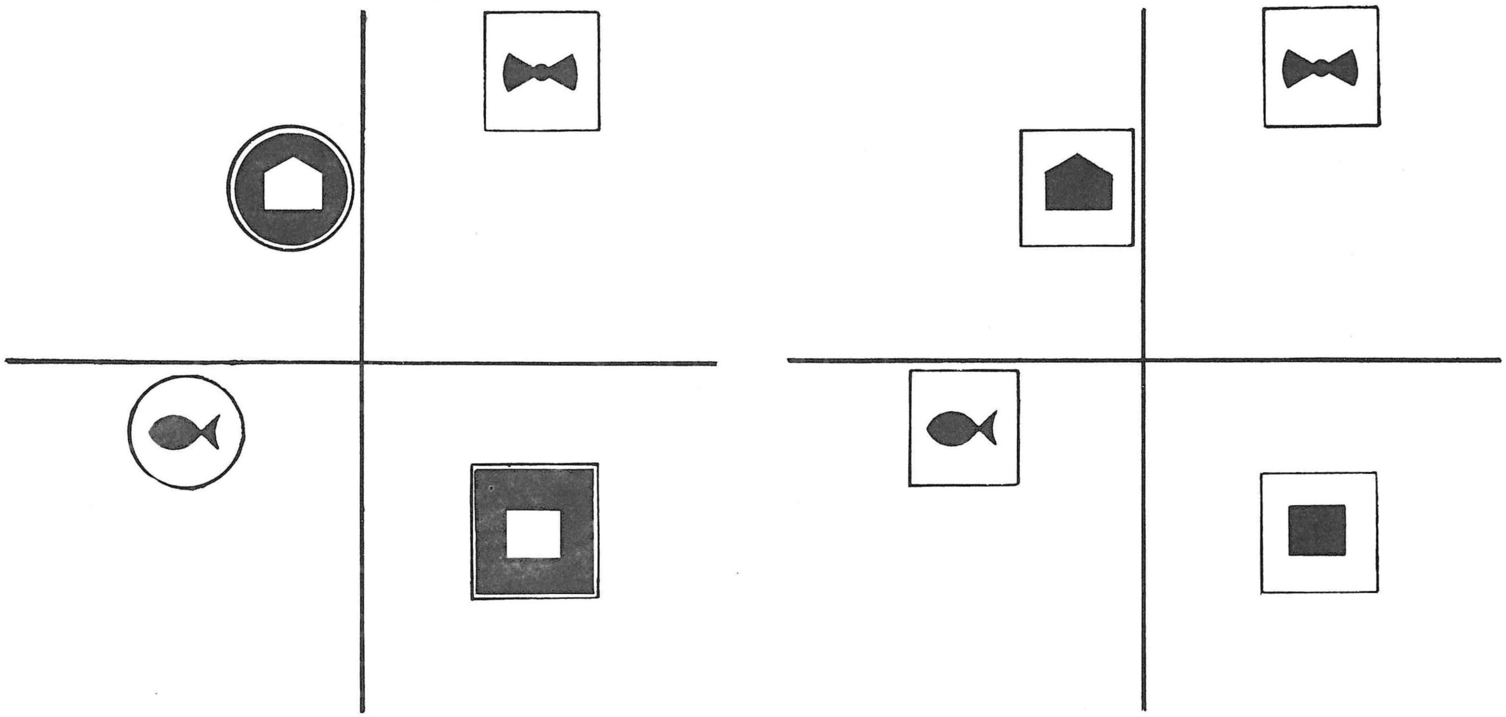


Figure 12. Examples of Matrix I and V Slides

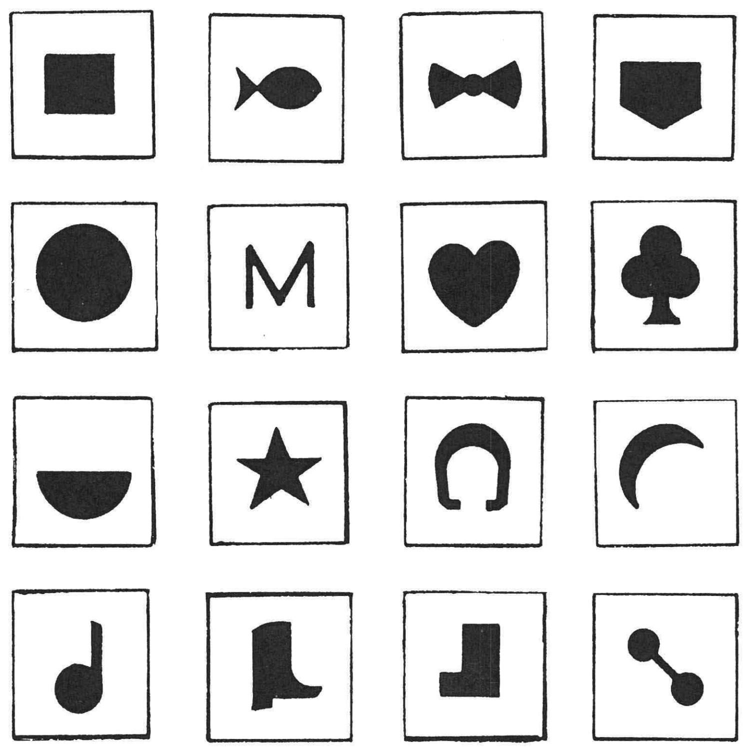


Figure 13. The Configuration of Target Shapes From Which the 16 Combinations Were Assembled

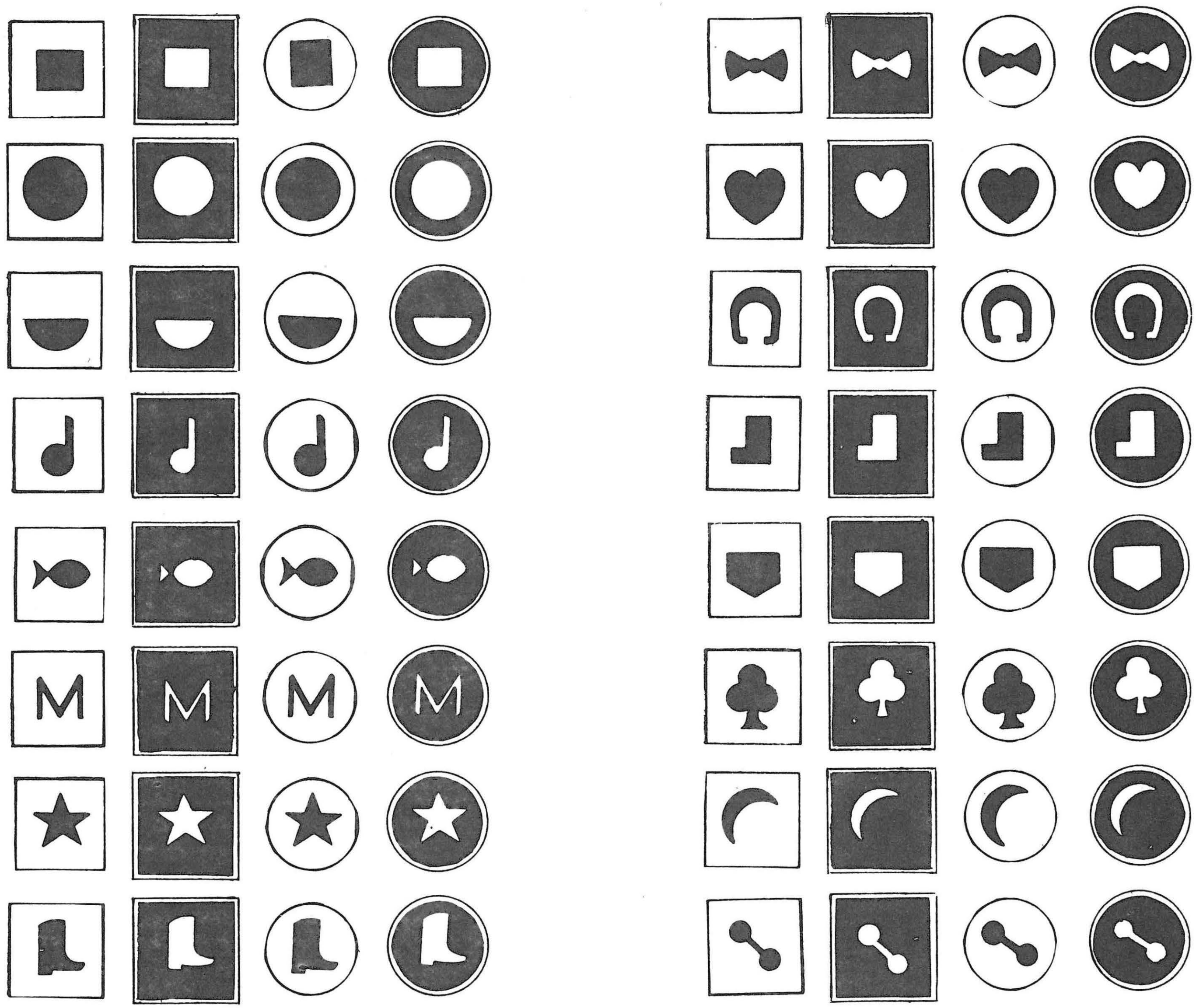


Figure 14. Each of the 16 Shapes in its 4 Possible Configurations

the five groups of subjects would have target search models A, B, C, D and X, where "X" represents a negative (no target) trial. Each of the five groups of four subjects had 64 positive and 16 negative trials. The same target shape occurred four times as a positive search target, for each group, but varied with respect to background shape and direction of contrast.

To avoid response biases, the targets occurred equally often in each quadrant. However, the assignment of specific target shapes to quadrants was randomized rather than systematically balanced.

Target search models were presented in five booklet forms, with a trial represented on each of eighty pages. As in Study II, a replica of the target model was presented. Each page was numbered and the experimenter announced the trial number before each trial to minimize errors. Search models conformed to targets with respect to background shape and direction of contrast, as well as target shape. A separate answer sheet provided a place to indicate in which quadrant the target was found ("5" was used to indicate "no target").

The subjects' task, as in Study II, was to search the slide for the target and to press one of two reaction time buttons as soon as the target was located or the other button in case no target was located. Following this choice reaction time task, the subject was to indicate on the answer sheet which quadrant contained the target.

Results

The major findings with respect to the speed and accuracy analysis indicate that the main effects of background shape and direction of contrast are clear-cut. The major concern, therefore, is with the differences among matrix types, which represent the effects of the variables' background shape and direction of contrast, singly and in combination.

Response latencies. An ANOVA assessed test booklet form (the between-subject variable) and matrix type, as a within-subject source of variance in the response latency data. Matrix type yielded a nonsignificant $F\ (4, 60) = 1.20$, indicating that the overall effects of the two experimental variables were nil with respect to the time required to locate the targets. The mean latencies ranged from 1.32 seconds for Matrix I to 1.40 seconds for Matrix V. While this difference is not reliable, it suggests that, contrary to expectations, the addition of background shape and direction of contrast as relevant and discriminable cues for target location actually served to increase, rather than decrease, search time. The between-subjects variable forms yielded a significant $F\ (4, 15) = 4.55$, $p < 0.05$. This unexpected finding was apparently the result of one form (or one subject group). Inspection of the data indicated that three of the four subjects on form A had the longest mean latencies in the entire sample. These subjects were consistently slow across stimulus types (matrices), target shapes, etc., suggesting that this form's effect was a case of sampling error.

Effects of target location. In a second ANOVA, each subject's mean latency (for correct responses) was included in an analysis of the effects of the quadrant in which the target was located. Negative (no target) trials were included as a "fifth quadrant" in this analysis. The results showed a significant effect of quadrant, F (4, 95) = 3.06, $p < 0.05$ and indicated an orderly progression of latencies from upper left (1.10 sec) through lower left (1.22), upper right (1.27) to lower right (1.40 sec) quadrant. The largest differences, however, were between those quadrant latencies for positive trials and those for the negative, "no target" trials (1.68 sec).

Effects of target shape. An F test of the 16 target shapes was performed using the individual trial observations. Therefore, any significant effects of shapes could be generalized across context (non-target shapes in the slides), matrices (target and non-target combinations of direction of contrast and background shape) and quadrant, as well as subject variability.

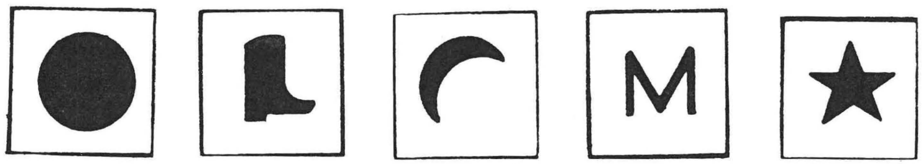
The results are convincingly significant, with F (15, 1271) = 80.4, $p < 0.001$. Figure 15 presents the major findings of this analysis. The top row shows the five shapes with the shortest mean latencies and the bottom row shows those with the longest latencies. These results agree rather well with those obtained in Study II, in which the shapes were tested in only two contexts ("candidate" and "control" sets) and where the selection of candidate shapes emphasized accuracy rather than response latency.

Accuracy

Errors by location. The datum for this accuracy analysis was the total number of errors by each subject in each quadrant. No-target trials were again included as a "fifth quadrant". The results indicated that quadrant differences were non-significant, F (4, 95) = 1.01. Inspection of the data failed to indicate any trends from upper left to lower right quadrants, or for negative versus positive trials.

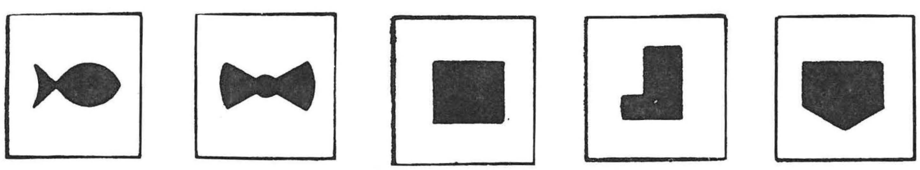
Errors by matrix type. An analysis was performed, similar to that for quadrant, to determine whether matrix type had any significant effect on error rate. The results were again convincingly negative: The F (4, 95) = 1.04, failed to approach statistical significance. Thus, despite the fact that the target would seem to be most discriminable (and least prone to errors) where it was unique with respect to the combination of background shape and direction of contrast, as well as figure shape, neither this condition (Matrix V) nor the intermediate conditions (II, III, IV) served to reduce the error rate.

Errors by target shape. Percentage of incorrect positive trials for every shape by subject were obtained and subjected to an ANOVA. Shapes were found to differ significantly F, (15,304) = 2.43 $p < 0.01$, with respect to accuracy of recognition. Figure 16 shows the sets of 5 shapes with most and least errors.



"Circle"	"Boot(s)"	"Quartermoon"	"M"	"Star"
1.15 sec.	1.21 sec.	1.23 sec.	1.23 sec.	1.23 sec.

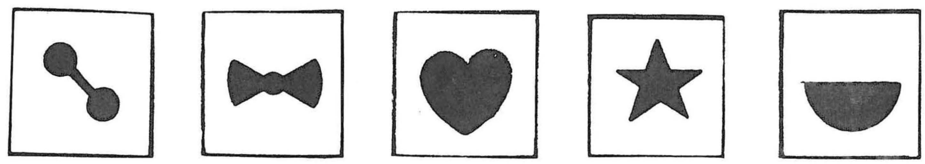
5 Short Latency Shapes



"Fish"	"Bowtie"	"Square(s)"	"Backward L"	"Homeplate"
1.34 sec.	1.38 sec.	1.39 sec.	1.46 sec.	1.62 sec.

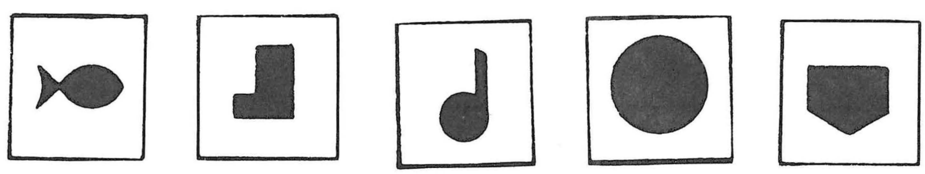
5 Long Latency Shapes

Figure 15. The Five Fastest and Five Slowest Shapes



"Barbell(s)" "Bowtie" "Heart" "Star" "Halfmoon"

5 Shapes With Fewest Errors



"Fish" "Backward L" "Music(al) Note" "Circle" "Homeplate"

5 Shapes With Most Errors

Figure 16. Five Shapes With Most and Least Accuracy

Discussion

The major results of this study were the null findings with respect to background shape and direction of contrast as additional discriminable cues in the location of target shapes. Under the conditions of the present experimental test, neither variable alone nor in combination improved either speed or accuracy of target location. It appears that the subjects could not or did not attend to the relevant information which these cues provided. While one would expect, for example, that when two of the four shapes in a slide were present as black figures on white backgrounds, searching for a white figure on a black background would be quicker, such was not the case.

One possible explanation which merits further investigation is that subjects attended only to the one critical cue, the target shape. Since the target shapes were never repeated within a slide, background shape and direction of contrast were not critical cues. Thus, rather than serving to guide and simplify the search process, these cues were apparently ignored. Subjects appear to have searched through the shapes in the matrix until the target shape was located, regardless of the matrix conditions.

This search process seems to have been systematic: Subjects may have "read" from left to right and/or from top to bottom at a rate of about 100 msec for each shape. "No target" decisions required an additional time of about 280 msec, suggesting they may have re-searched the slide to confirm the absence of a target before responding. The fact that errors were unrelated to target locations (quadrant) indicates that subjects did use time to search the entire matrix, either during the actual exposure time (500 msec) or in a sensory store, or both. Evidence for the time required for visual fixations and discriminations suggest that only two or three discriminations were made during the actual exposure, the remainder being based on information in sensory store. (Incidentally, this could be tested by varying the exposure duration and following each slide immediately with a noisy visual mask.)

Again, there is evidence that the target shapes vary with respect to the speed and accuracy with which they can be responded to when they are embedded in the context of other non-target shapes. These findings were pooled over matrix type, quadrant location and background shape-direction of contrast combination. The discrepancies from Study II results, where they occurred, may well reflect the fact that some shapes which did well in the context of the candidate and control sets, did less well in the larger sets of contexts provided in Study III.

STUDY IV. SIGN FORMAT EVALUATIONS

Since the results of Study III did not provide definitive information regarding direction of contrast, the decision regarding symbol vs. background (direction of contrast and reflectivity) had to be made on another basis. Further, it was necessary to make other sign format decisions including: the use of high intensity vs. engineering grade sheeting and the use or non-use of reflective borders on the background and on symbols. These format decisions were made on the basis of the pooled subjective judgments of seven staff members. A paired comparison technique was used, where each pair judged was varied on a single dimension. Symbol sign "component" plates were fabricated such that various combinations of reflective intensity could be quickly assembled. For example, symbol borders, background, and background border plates were fabricated with high intensity and engineering grade reflective sheeting and with a non-reflective material. These components could be sandwiched and temporarily clamped together to produce any combination desired. Each of the component sets was made in a bright color (yellow) and a dark color (blue) from 3-M reflective sheeting or a matching non-reflective paint in order to permit evaluation of symbol to background relationship of light on dark or dark on light.

The sign pairs were placed ten feet apart and the staff members serving as subjects made judgments first from 300 ft (91 m) and then from 200 ft (61 m). Since some earlier work with reflective materials showed that a "star" shape tended to result in fuzzy edge gradients under some conditions, it was chosen as the symbol, i.e. to represent a "worst case" condition. The subjects had no information regarding the components which were combined for any given trial and were simply asked to judge which symbol sign provided the best definition. The order of presentation was randomly assigned for the two sets of distance trials, as was the lateral position of the two signs.

The concensus of judgments resulted in the choice of a high intensity symbol on a dark non-reflective background, with a high intensity background border.

STUDY V. COLOR/SHAPE INTERACTIONS

The results of the first three studies identified eight shapes which are generally recognizable, nameable, and discriminable with a high degree of accuracy under short exposure viewing conditions. Further, four "unassigned" colors have been developed for use on reflective sheeting. These four "unassigned" colors and four of the "assigned" colors were used for this experiment. It should be noted that the terms "assigned" and "unassigned" refer to the Manual on Uniform Traffic Control Devices and the assignment of meaning to colors.

The purpose of this study was to explore the existence of interactions between shapes and colors. Specifically, this study was concerned with the possibility (suggested by the literature review) that some combination of colors and shapes might produce more discriminable targets than the same shapes with other colors or the same colors with other shapes. The goal of this study was to identify the best set of redundant color/shape symbols. Complete redundancy across the eight symbols cannot be achieved using only "unassigned" colors since only four "unassigned" colors are available for use with the eight shapes.

In order to obtain some evaluation of the discriminability of the four unassigned colors, four of the assigned colors were included as a control. The experiment design was therefore selected to evaluate the effect of color sets (assigned vs. unassigned) as well as the color/shape interaction within color sets.

Method

The eight shapes have been chosen to be discriminable from one another, and the four unassigned and four assigned colors were chosen as candidates from the applicable colors listed in the MUTCD. Since shape confusability is not an issue in this study, symbols were not paired. The experimental task was based upon the identificability of colors and shapes using a subject-target distance chosen to produce adequate color discrimination under night-headlight conditions and an exposure time chosen to produce an error rate sufficient to permit ranking of color/shape combinations. The subject-target distance and exposure duration for the symbol stimuli was established from pilot data.

Apparatus and Experimental Conditions. The apparatus was capable of controlling the exposure of one or two 12 in (30 cm) square stimuli at 0.25 s or greater. The apertures for stimuli were on 25 in (61 cm) centers located 5 ft (152 cm) above ground. The eight shapes, assigned and unassigned colors are listed in Figure 17. In order to control the effects of ambient illumination, target value, etc., the study site was located along an unopened section of highway through a relatively undeveloped non-commercial area.

COLORS		SHAPES	
Assigned	Unassigned	Assigned	Unassigned
Red	Coral	Circle	Horseshoe
Blue	Light Blue	Heart	Star
Orange	Yellow-Green	Crescent	Note (Musical)
Yellow	Purple	Barbell	Halfmoon

Figure 17. List of Assigned and Unassigned Colors and Shapes

The display apparatus utilized an air cylinder with a meter value to control the exposure shutter. The air cylinder was mechanically linked to the shutter release. Activating the air cylinder released two shutters consecutively as the piston rod retracted in the cylinder. Thus consistent shutter-opening times of 1.0 s in duration were possible over all sessions.

The site used for this study was an unopened section of divided highway. After the pilot study, a distance of 300 ft (91.4 m) was used as the target distance. All sessions were conducted one hour or more after sunset. All cars had the engine idling and low beams on. Each subject had a small shielded lamp bright enough to illuminate the answer sheets, but was not so bright as to cause glare to reduce the visibility of target stimuli.

<u>Subjects</u>

A total of 48 subjects were used in the experiment. Each subject was given a visual screening test with the requirement for far binocular acuity of 20/40 or better and no color vision deficiency. Each subject was paid a nominal fee at the end of the experimental session.

The ages of the subjects ranged from 16 to 68, with a median age of 22. The mean age was 25.7 with a standard deviation of 11 years. Of the group, 26 were males, and 22 females. The number of years of driving experience per subject ranged from zero to 52, with a median of six years experience. The mean experience was eight years, with a standard deviation of 8.8 years. The average miles driven by each subject, in their estimation, ranged from zero to 30,000 miles per year, with a median of 5,000 miles per year. The mean miles driven per year was 6,500 with a standard deviation of 7,200 miles per year.

<u>Procedures</u>

Subjects were randomly seated two to the front seat of each four passenger sedans spaced evenly across two lanes 300 ft (91.4 m) from the display device. The display aperture was 6 ft (1.8 m) right of the pavement edge and rotated 12° clockwise from perpendicular toward the line of sight of the observers to prevent specular glare. Since the angles of observation were important, the subejcts were rotated three times per session among the four vehicles such that each subject made observations from three known positions. This, when combined with the use of different order of presentation for different subject sessions, precluded any position bias which otherwise might be present.

Instructions and practice trials were provided using white-on-black shapes and colored square with 10-s exposures to insure that all shapes and colors were known and correctly named. Two 1-s exposures also were given to familiarize the subjects with the interval to be used. Once the colors and shapes had been displayed, the experiment with 96 trials, divided into three sessions of 32 trials each, was begun. A trial consisted of observing a presentation of a single symbol and writing both a color name and a shape name of that symbol on an answer sheet. No blanks were permitted. The intertrial interval was approximately 30 seconds. Instructions, color, and shape naming, and the three sessions with 5-minute breaks between them required about 110 minutes.

Experimental Design

The pairing of eight shapes with each of the eight colors results in 64 color/shape symbols, 32 with assigned colors and 32 with unassigned colors. To evaluate the effects of color, shape, and their interaction, a randomized, incomplete blocks design was used with repeated measures across all within block cells. Using subjects as their own control was essential to reduce between cell variance which otherwise would have been extremely large. Because of time constraints on subject availability, assigned and unassigned colors were separated into two blocks, treated as a between subject variable, and analyzed as separate experiments. The basic elements of this design are shown in Figure 18.

To minimize measurement error, three observations were made for each subject on each color/shape symbol. This required that 96 observations be made for each subject in Group 1 with assigned colors and another 96 observations for each subject in Group 2 with unassigned colors. The 96 observations were divided into 3 sets of 32 observations which were randomly assigned to the 32 treatment combinations within a color set. Each of the 3 sets of observations made by each subject were from a different vehicle (i.e., angle of view).

Results

Since the intent of the proposed color/shape coding system was to provide redundant information via two independent parameters to normal users under most conditions, it was imperative that the criterion for evaluating color/shape interactions reflect this redundancy. If an interaction existed, we wanted to pair colors with shapes in a manner which would facilitate proper identification of both. Responses were therefore scored on accuracy as either correct (color and shape both properly identified) or incorrect (either color and/or shape improperly identified).

	ASSIGNED				UNASSIGNED			
	B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8
C_1	n_1	n_2	n_3	n_1	n_2	n_2	n_2	n_2
C_2	n_1	n_1	n_1	n_1	n_2	n_2	n_2	n_2
C_3	n_1	n_1	n_1	n_1	n_2	n_2	n_2	n_2
C_4	n_1	n_1	n_1	n_1	n_2	n_2	n_2	n_2
C_5	n_1	n_1	n_1	n_1	n_2	n_2	n_2	n_2
C_6	n_1	n_1	n_1	n_1	n_2	n_2	n_2	n_2
C_7	n_1	n_1	n_1	n_1	n_2	n_2	n_2	n_2
C_8	n_1	n_1	n_1	n_1	n_2	n_2	n_2	n_2

Figure 18. Experimental Design for Analysis of Eight Colors (B_1 through B_8) Grouped Into Assigned and Unassigned Blocks and Eight Shapes (C_1 through C_8), $n_1 = n_2 = 24$

Separate analyses of variance were computed for assigned and unassigned groups using data rescaled by an arcsine transformation. The results of the AOV's for main effects (see Table 36) were highly significant. Even with the extremely conservative adjustment for degrees of freedom (Box, 1954) these F-ratios are significant. Colors and shapes are rank ordered in Table 37 with the proportion of correct responses associated with each. As is evident from this table, performance with any of the assigned colors was better than the unassigned colors although the difference between the poorest assigned color (blue = 0.71) and best unassigned color (green = 0.68) is small. Accuracy with assigned colors was 0.82 over all colors and shapes while accuracy of unassigned colors was 0.61. There was little difference in the rank order of shapes between assigned and unassigned colors. It is important to note that the star was poorest of all shapes by a large margin with either assigned or unassigned colors.

Table 36. Analysis of Variance Results

Factor	F	df	*p*
Assigned Color	6.79	3, 69	< 0.001
Assigned Shape	5.61	7, 161	< 0.001
Unassigned Color	10.74	3, 69	< 0.001
Unassigned Shape	4.91	7, 161	< 0.001

Table 37. Proportion of Correct Responses for Colors and Shapes for Symbols Viewed with Assigned and Unassigned Colors

ASSIGNED COLORS			
		Barbell	0.89
		Circle	0.89
Red	0.89	Note	0.87
Yellow	0.89	Quartermoon	0.86
Orange	0.80	Halfmoon	0.85
Blue	0.71	Horseshoe	0.83
		Heart	0.75
		Star	0.63
UNASSIGNED COLORS			
		Horseshoe	0.69
		Barbell	0.65
Yellow-Green	0.68	Circle	0.62
Coral	0.64	Halfmoon	0.61
Light Blue	0.64	Note	0.60
Purple	0.49	Quartermoon	0.60
		Heart	0.59
		Star	0.52

The results for the color/shape interaction were not so clear as the main effects. Although significant with normal degrees of freedom, the F-ratios for interactions were not significant with the conservative adjustment. This ambiguity, coupled with the fact that the response distributions showed significant departure from normality, provided a strong basis for questioning the appropriateness of analysis of variance, in spite of its robustness, for making inferences from these data. In view of this and the fact that our primary interest was with the interaction of color and shape, the data were analyzed using a non-parametric test: the Kendall Coefficient of Concordence.

Ranking the performance of the eight shapes independently for each of the four colors permits the coefficient of concordence (w) to reflect the degree to which the shapes are ranked similarly for each color. The significance of any observed value of w can be tested with H_o implying the presence of an interaction. The significance test is based upon a χ^2 statistic which is equivalent to a Friedman 2-way Analysis of Variance. The analysis of ranked shapes for both assigned and unassigned colors resulted in rejection of the null hypothesis (unassigned: $w = 0.52$, $\chi^2 = 14.50$, $df = 7$, $p = < 0.05$; and assigned: $w = 0.58$, $\chi^2 = 16.6$, $df = 7$, $p = < 0.05$) which suggests that the ranks orders of shapes for each of the four colors are related.

Discussion

Since the redundant color/shape coding system must be large enough to provide up to 6 unique symbols it is necessary to select two of the four assigned colors to be used with the unassigned colors whenever needed. Although the data suggest that red and yellow are the two best assigned colors, the decision was made to use yellow and orange because of the strong prohibitive associations which already exist for red.

The process of pairing shapes with colors for purposes of producing 6 unique symbols for field testing was based in large part upon the cell means in the two dimensional color/shape treatment matrix. Each color was assigned, in-so-far as possible*, the shape with which it performed best. Even through the interaction was not significant, there was no reason not to make assignments on the basis that it were. The cell means were the best estimate of the symbols performance and by using them we hede against the possibility of a type 1 error. The symbols chosen were:

Coral . . . . Heart
Yellow-Green . . . . Barbell
Light Blue . . . . . Horseshoe
Purple . . . . Halfmoon
Orange . . . . Quartermoon
Yellow . . . . Musical Note

*This procedure was limited by ties and the necessity to assign shapes to only one color, i.e., without replacement.

FEDERALLY COORDINATED PROGRAM OF HIGHWAY RESEARCH AND DEVELOPMENT (FCP)

The Offices of Research and Development of the Federal Highway Administration are responsible for a broad program of research with resources including its own staff, contract programs, and a Federal-Aid program which is conducted by or through the State highway departments and which also finances the National Cooperative Highway Research Program managed by the Transportation Research Board. The Federally Coordinated Program of Highway Research and Development (FCP) is a carefully selected group of projects aimed at urgent, national problems, which concentrates these resources on these problems to obtain timely solutions. Virtually all of the available funds and staff resources are a part of the FCP, together with as much of the Federal-aid research funds of the States and the NCHRP resources as the States agree to devote to these projects.*

FCP Category Descriptions

1. Improved Highway Design and Operation for Safety

Safety R&D addresses problems connected with the responsibilities of the Federal Highway Administration under the Highway Safety Act and includes investigation of appropriate design standards, roadside hardware, signing, and physical and scientific data for the formulation of improved safety regulations.

2. Reduction of Traffic Congestion and Improved Operational Efficiency

Traffic R&D is concerned with increasing the operational efficiency of existing highways by advancing technology, by improving designs for existing as well as new facilities, and by keeping the demand-capacity relationship in better balance through traffic management techniques such as bus and carpool preferential treatment, motorist information, and rerouting of traffic.

3. Environmental Considerations in Highway Design, Location, Construction, and Operation

Environmental R&D is directed toward identifying and evaluating highway elements which affect the quality of the human environment. The ultimate goals are reduction of adverse highway and traffic impacts, and protection and enhancement of the environment.

4. Improved Materials Utilization and Durability

Materials R&D is concerned with expanding the knowledge of materials properties and technology to fully utilize available naturally occurring materials, to develop extender or substitute materials for materials in short supply, and to devise procedures for converting industrial and other wastes into useful highway products. These activities are all directed toward the common goals of lowering the cost of highway construction and extending the period of maintenance-free operation.

5. Improved Design to Reduce Costs, Extend Life Expectancy, and Insure Structural Safety

Structural R&D is concerned with furthering the latest technological advances in structural designs, fabrication processes, and construction techniques, to provide safe, efficient highways at reasonable cost.

6. Prototype Development and Implementation of Research

This category is concerned with developing and transferring research and technology into practice, or, as it has been commonly identified, "technology transfer."

7. Improved Technology for Highway Maintenance

Maintenance R&D objectives include the development and application of new technology to improve management, to augment the utilization of resources, and to increase operational efficiency and safety in the maintenance of highway facilities.

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* The complete 7-volume official statement of the FCP is available from the National Technical Information Service (NTIS), Springfield, Virginia 22161 (Order No. PB 242057, price $45 postpaid). Single copies of the introductory volume are obtainable without charge from Program Analysis (HRD-2), Offices of Research and Development, Federal Highway Administration, Washington, D.C. 20590.

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