

**ABSOLUTE IDENTIFICATION OF COLOR FOR TARGETS
PRESENTED AGAINST WHITE AND
COLORED BACKGROUNDS**

*HAROLD P. BISHOP
MASON N. CROOK*

*INSTITUTE FOR APPLIED EXPERIMENTAL PSYCHOLOGY
TUFTS UNIVERSITY*

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FOREWORD

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ABSTRACT

The number of stimulus colors which can be absolutely identified by normal subjects when viewed against various colored backgrounds was investigated. Additive mixtures of light passed through narrow-band and Illuminant-C filters were projected onto a viewing screen by a device which permitted independent control of target and background characteristics. The stimulus parameters of hue, luminance, purity, target size, and target shape were varied, and the effects of such factors as training and the presence of a distracting task were studied. With target luminance above background luminance, about nine hues plus white, three luminance levels, and two purity levels, are estimated to be useful for operational coding, if no more than about 30 of the possible combinations are included in the set. Under optimal working conditions and with protracted training, the maximum size of an identifiable set is estimated to be about 60. Reduction of target luminance below the luminance of a colored background was found to make identification very difficult. No significant effect of target shape was found.

PUBLICATION REVIEW

Walter F. Grether

WALTER F. GREETHER
Technical Director,
Behavioral Sciences Laboratory
Aerospace Medical Laboratory

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ABSOLUTE IDENTIFICATION OF COLOR FOR TARGETS PRESENTED AGAINST WHITE AND COLORED BACKGROUNDS

INTRODUCTION

The importance of visual coding is enhanced by the current elaboration of visual displays, and by the increasing volume of information transmitted by such displays. Color is one dimension which can be used for coding, but its limits are imperfectly known. The determination of these limits is therefore a matter of practical concern.

In the study here reported, the number of colors which can be identified when presented singly was investigated. Such absolute identification is quite different from the comparative judgment called for when two colors are presented simultaneously in a classical discrimination experiment. By the latter procedure, about 150 colors can be discriminated in the spectrum to the conventional criterion of 50% accuracy. The number which can be identified to a high level of accuracy when presented singly is obviously much smaller.

Practical coding systems currently in use employ relatively few colors. For railway signal systems it is three or four. Whether or not more colors would be desirable in such a system, the outdoor environment imposes severe limitations through color changes produced by atmospheric haze interacting with distance. Electrical resistors are coded in 12 surface colors. For this type of application, limits are imposed, not only by the users' visual capacities, but also by distortions resulting from different types of illumination, accumulation of dirt, and aging. For such reasons these applications are not calculated to exploit the operators' full potentialities.

The classical literature records a certain amount of work on absolute judgments. Much of it is with non-visual stimulus materials, but it serves to highlight the process of establishing a subjective frame of reference in lack of an external standard, and to raise the question of the stability of the frame of reference under the impact of such factors as distraction and intervals of disuse.

A few recent studies are more directly concerned with the identification of colors. The most relevant are those by Halsey and Chapanis (1951), Conover (1959), Conover and Kraft (1958), and Hanes and Rhoades (1959). Halsey and Chapanis used spectral light and concluded that 10 to 12 hues can be discriminated to nearly 100% accuracy. Conover, and Conover and Kraft, used Munsell color patches and concluded that not more than eight maximally saturated surface colors can be identified by most subjects, a more realistic figure for operational conditions being five to seven. (Baker and Grether, 1954, on the basis of existing literature, concluded that nine is a practical number.) Hanes and Rhoades found that 50 Munsell colors, varying in hue, chroma, and value, could be identified after five months of practice.

The present study was designed to investigate the question on a broad basis, varying stimuli in hue, luminance, and purity, testing the effect of colored backgrounds, evaluating the effect of training, and comparing performance under optimal and non-optimal working conditions. Formal experimentation was preceded

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by an extensive exploratory period in which procedures were tried out, the apparatus was progressively improved, and limits of performance were tested. It was necessary to decide whether to distribute the available experimental time in a way to gather limited data on a large number of variables or fuller data on a small number. The decision favored the broader coverage. The results obtained in this way present a generally intelligible pattern, and conclusions are based as much on mutually reinforcing indications in the pattern as on evaluations of particular sets of scores.

APPARATUS

A. General Plan of the Optical System

The subject faced a rear-projection screen on which he viewed a target image centered in a circular background area about 5 in. in diameter. The target could be varied in size and shape. Luminance and chromatic characteristics of target and background could be independently controlled. The general arrangements were as follows. The target image was obtained by the projection of an aperture of the desired shape cut in a diaphragm and illuminated from behind. The diaphragm was a reflecting plate set in the target beam at an angle to allow projection of illumination from a separate source as background. The background system provided for the presentation of a light mixture made up of white and any one color component in any desired ratio. The target system was more flexible, providing for mixtures of white and three color components.

The detailed plan of the apparatus is shown schematically in Figure 1. The optical elements were arranged on two levels. The lower level (see top view in 1-A) incorporated the two component paths of the background system, originating with lamps L2 and Lb, and two components of the target system, the white path originating with lamp La and one color path originating with lamp Ll. The shaded areas in the figure indicate optical paths of the background system. Lamp Ll was on the main optical axis, in line with the target aperture T, projection lens PL, and viewing screen VS. Figure 1-B shows a side view of the main axis and the two remaining component paths of the target system, originating with lamps L3 and L4 on the upper level. In the physical construction the optical components from L3 to R4 inclusive were aligned at a horizontal angle of about 50° to the direction of the main axis.

All optical paths were provided with filter racks FR for narrow-band, Illuminant C, or neutral filters as required. In addition, each of the paths 1, 3, 4 and a (comprising the target system) included two filter wheels FW in which neutral filters of graduated densities were mounted. Rapid change of filters was accomplished by rotation of the wheels. All paths had neutral wedges W. Paths with 750-watt lamps were provided with water cells WC faced with heat-absorbing glass.

In operation, a blue target stimulus was produced by light from lamp Ll, which was converged by the double condenser DC, through the water cell WC, a blue filter in the rack FR, and a neutral filter when required in the wheel FW, to a narrow beam in the plane of the wedge W; from here the beam diverged through the partial reflectors R1 and R2 to the single condenser SC, which converged it again through the target aperture T to a narrow beam at the projection lens PL. The projection lens was positioned to produce an image of the target aperture on the viewing screen VS. Green light proceeded in a corresponding manner from lamp L3 to the wedge W; from here it was directed by the partial reflector R4 to the second double condenser DC, which converged it to a narrow beam at the partial reflector R1, where it entered the primary optical axis. Red light proceeded similarly by way of the reflector R5 to the partial reflector R1. Desaturation light from the lamp La, through an Illuminant C filter in the rack FR, could be added to any mixture of the color components by way of the partial reflector R2. A colored background

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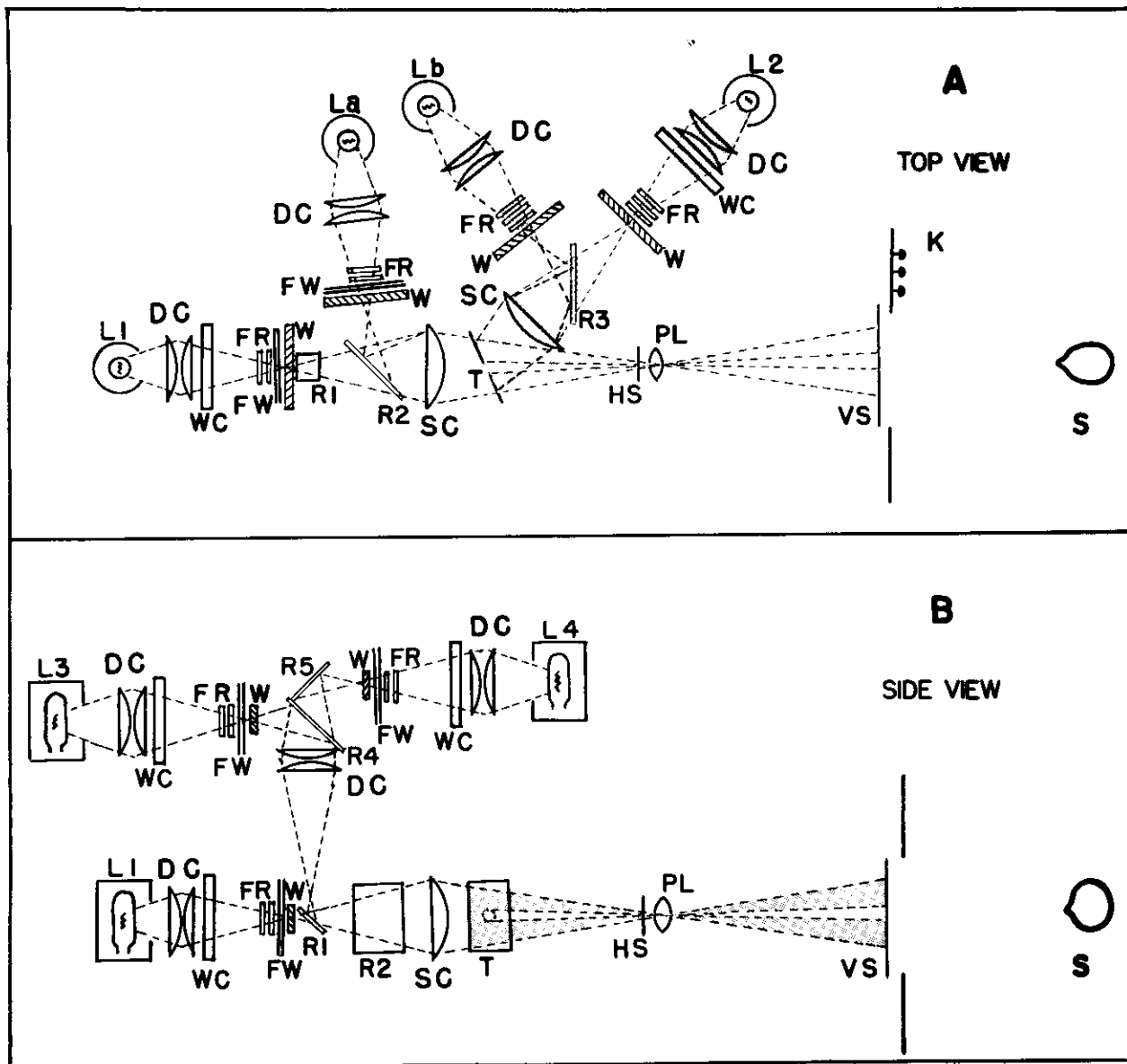


Figure 1. Apparatus. The optical elements are arranged on two levels. A top view of the lower level is shown in 1-A, with the main optical axis on the line from lamp L1 to the viewing screen VS. A side view of the main axis and additional components on the upper level is shown in 1-B. The subject S views the target-background configuration on the rear-projection viewing screen VS. The target is defined by an aperture in the reflecting plate at T, with an image of the aperture formed on the screen by the projection lens PL. Light reflected from the plate at T forms the background on the screen. Color components of the target light come from lamps L1, L3, and L4, through selective filters in the filter racks FR; the desaturation component comes from lamp La through an Illuminant C filter. The color component of the background light comes from lamp L2; the desaturation component comes from lamp Lb. The shaded areas indicate background light paths. Other optical elements are labeled as follows: DC = double condenser; WC = water cell; FW = filter wheel; W = wedge; R1, R2, R3, and R4 = partial reflectors; R5 = total reflector; SC = single condenser; HS = hand shutter. K labels knobs used for response signals. (For detailed description see text.)

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was produced by light from lamp L2 through a color filter in the rack FR; the converging beam from the single condenser SC was directed by the reflecting plate at T to the projection lens PL, which formed the background image on the screen. Desaturation light from lamp Lb could be mixed with the colored light at the partial reflector R3. The hand shutter HS provided exposure control. The knobs K were for subjects' responses.

B. Light Sources

The 750-watt projection lamps L1, L2, L3 and L4 were rated at 120 volts, but were operated at 115 volts from constant-voltage transformers. La and Lb were 300-watt, 120-volt, projection lamps operated at 96 volts through a constant-voltage transformer and a variac; this provided Illuminant A color temperature which was corrected to Illuminant C by appropriate filters mounted in the racks FR.

C. Cooling System

Lamps were mounted in specially designed housings and air cooled with blowers. Filters and wedges were protected both by the water cells WC in all 750-watt paths and by small blowers (not shown).

D. Filters and wedges

The color filters, all but one from the Corning and Wratten narrow-band series, are listed below. For blue it was necessary to choose a filter with a relatively broad transmission band (Corning No. 5-60 below) to obtain the maximum luminance desired. The dominant-wave-length specifications are for light transmitted in the system.

<u>Color</u>	<u>Catalog Designation</u>	<u>Dominant Wave-Length</u>	<u>Excitation Purity</u>
Red	Corning 2-78	630 mp	100%
Orange	Wratten 72B	606	100
Yellow	Corning 3-110	588	100
G-Yellow	Wratten 73	574	100
Y-Green 1	Corning 4-102	552	100
Y-Green 2	Wratten 74	538	96
Green	Corning 4-105	521	82
B-Green	Corning 4-104	500	92
G-Blue	Wratten 75	492	88
Blue	Corning 5-60	461	97

The "neutral" filters were partial reflectors of aluminum-coated glass. These were obtained in graduated steps of reflectance. Their wave-length selectivity, while not quite negligible in the higher densities, was very small. They had the added advantage of low breakage from heat absorption. To minimize multiple reflections in the system, the denser of the coated filters were mounted so that normals to their surfaces made a slight angle with the optical axis.

The "neutral" wedges were made from exposed photographic plates. Their density was considerably more dependent on wave-length than was the case with the reflecting filters, but less so than with gelatin wedges.

E. Fixed Reflectors

Partial reflectors R2 and R3 were uncoated glass plates to permit high transmission of the colored light. The low reflectance of these plates created no problem because ample light was available in the desaturation paths. Reflector R5 was a totally reflecting first-surface mirror. Partial reflectors R1 and R4 were specially prepared for a 50/50 reflectance/transmittance ratio, with a minimum of absorption loss. They consisted of line gratings on glass with alternate lines aluminum coated for full reflectance. There were approximately 50 coated lines per inch.

F. Targets

The target apertures were cut in pieces of hard transparent plastic, which were then aluminum coated for total reflectance. Though most of the apertures were elliptical, to produce round images on the screen, the plastic made it practical to cut other shapes, and this was done for one experiment. Edges of the apertures were beveled to knife-edge sharpness.

G. Viewing Screen and Visual Field

The rear-projection viewing screen VS was a fine-grained ground glass plate.

H. Head Position

Viewing was binocular, at 20 inches, with natural pupils. A plywood screen with an aperture for the nose and a rectangular eye slot restricted head position within narrow limits.

I. Response Indicators

The knobs K were the controls for operating dial indicators (not shown) visible to the experimenter, by which a subject could make a silent report. This device insured independent responses when subjects were serving in pairs.

J. Ambient Light

The subject sat in a booth which was flooded with faint bluish light from a bulb about 32 in. above and 6 in. forward of the eye position. This provided illuminance of 0.2 ft-c on a horizontal surface a little below the eye position, sufficient for reading large type or making notes. Interior walls of the booth were flat black except for an area of white cardboard surrounding the stimulus field. With the subject in his most relaxed position, the visual angle spanned by the cardboard was approximately 40° vertically and 100° horizontally. Luminance of this area varied from about 0.06 ft-L near the lateral edges to 0.1 ft-L at the top center where not blocked by the flat black positioning screen. The black screen spanned approximately 30° by 30° in the central region of the light area. With the subject in the viewing position (eyes close to the positioning screen), a dark rectangle 35° high by 23° wide was seen, flanked by sections of the light cardboard approximately the same height but extending laterally to approximately 55° on each side. The stimulus was presented within the dark rectangle. With this arrangement, the effective adaptation luminance of the surrounds was in the neighborhood of that of the stimulus background.

K. The Photocell

Initially all luminance calibrations were done by visual matching. Later a Weston Photronic cell (Type 3, Model 594RR) with a Viscor filter was used at the projection lens. The sensitivity curve of this combination, as represented in the catalogue, approximates the photopic curve of the eye, but shows minor deviations. As it was desired to use the cell with colored lights involving narrow wave-length regions, a sensitivity curve for the individual cell-filter combination was obtained from an electrical testing laboratory. It was then possible to make an appropriate correction in the calibration wherever the photocell curve deviated from that of the standard observer.

L. Calibration of Wedge and Filter Transmittance

On each wedge, a transmittance curve was determined for each of the selective filters used with it. In the background path (path 2) the filters were red, green and blue (see page 4); in path 1 they were all of those listed on page 4; in paths 3 and 4 they were the several filters used as primaries for mixtures; and in paths a and b they were the Illuminant C filters. In each case, the Macbeth illuminometer was used with a gelatin filter before the standard lamp to provide an approximately

homochromatic matching situation. With a given wedge, the curves for colors well separated in spectral locus differed somewhat, but for colors close together the differences were negligible. In practice, therefore, a small number of curves representing limited wave-length regions were used.

Step filters were calibrated from the wedges, using the Macbeth illuminometer as a null indicator. The illuminometer was pre-set, and wedge settings were obtained which gave matches with and without a step filter in the path. Where appropriate, transmittances were determined for different colors, again using gelatin filters before the standard to give homochromatic matches, but the wave-length selectivity of the neutral filters was very small so it was necessary to do only red, green and blue in this way. Filter density was found to vary slightly as a result of interaction with wedge density; therefore, use of the wedge for both calibration and experimental work was limited as much as possible to the mid-section of the wedge range.

M. Calibration of Luminance

The visual photometry used for luminance calibrations in the early part of the study was cumbersome and, in view of the necessity for frequent lamp replacement, inefficient in terms of experimental time. The photoelectric technique subsequently adopted was successful in minimizing this problem.

Output of the 750-watt lamps used in the color paths was found to increase for approximately two hours after installation, then gradually decline. Under conditions of use in the project the average life was over 40 hours, but premature failure of an occasional lamp made routine replacement at about 30 hours advisable. Calibration was done during the initial warm-up period, which gave a value somewhat greater than would have been obtained at the mid-point of the period of use. Judging from typical output curves, and check measurements made during use, luminance output remained constant within plus or minus 7% of the calibration value over the life of the lamp. When the initial calibration value for a new bulb differed by more than plus or minus 2% from that of the bulb it replaced, wedge settings used for luminance control were adjusted accordingly. In the regular routine, all of the lamps in the color paths were changed at the same time, so their fatigue curves were usually in phase, and errors in the mixture computations produced by decline in output were minimized.

Because the 300-watt lamps used in the desaturation paths were operated much below their rated voltage, they lasted several times as long as the lamps in the color paths, and their output changed very slowly. They were checked regularly and replaced at approximately 90-hour intervals. Their output values were within plus or minus 2% of calibration values.

1. Visual Calibration

Visual calibration data were used only with subject ZC, and all of the visual matches entering into the calibrations were done by this individual. The first step was to establish a wedge setting in the background path 2 which gave 2.5 ft-L of luminance on the screen when no color filter was used. This was done with the Macbeth illuminometer. The next step was to match the luminances of the target paths 1, 3, and 4, using blue, green and red color filters, respectively, to the luminance of path 2 by flicker photometry. This was done by means of a plastic sector disc, aluminum-coated to make it a first-surface mirror, which was rotated in the plane of the target aperture by a variable-speed motor. The viewing screen was masked to a 1/2-in. circular area, and the flicker-photometric judgments were made from the subject's viewing position 20 in. from the screen. The wedge settings determined for paths 1, 3, and 4 in this way were not the final calibration values, but were used in the next step. For the next step, the blue, green and red color filters were put in path 2 in turn and the luminances homochromatically

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matched against those of paths 1, 3, and 4 respectively. This gave path-2 wedge settings for each of the three colors. As a further step, the luminance of each target path was matched by flicker photometry with that of each of the non-corresponding colors in path 2. This gave several wedge settings for each of the paths 1, 3, and 4 (including the original setting against white), all corresponding to the reference luminance of 2.5 ft-L. The mean of the several settings for each path was taken as the calibration value. In all cases, the mean was within 9% of each of the empirical values on which it was based. Final calibration values for the colors in path 2 were then established by homochromatically matching the luminances in that path, with blue, green, and red filters in place, with those produced by the mean settings in paths 1, 3, and 4 respectively.

Path a, with an Illuminant C filter in place, was calibrated by matching its luminance by flicker photometry to that of path 2 with no color filter, and path b was then homochromatically matched with path a.

2. Photoelectric Calibration

The Photronic cell was used in connection with a microammeter, the scale of which had been calibrated for luminance with Illuminant-C light as measured by visual photometry. When colored light was measured with the cell, corrections for differences between the sensitivity curve of the cell and the curve of the standard observer were made as follows. For the bandwidth passed by the filter, the relative sensitivity of the cell was multiplied by the relative transmittance of the filter at 5 m μ intervals, and the products summated. A similar process was carried out using the curve for the standard observer instead of the photocell curve. The ratio of the two sums gave the correction factor which was applied to the measured value for the filter.

N. Calibration of Wave-Length

Dominant wave-lengths and excitation purities associated with the filters were computed from the spectral distribution curves of the lamps, the transmittance curve of the heat-absorbing glass, and the transmittance curves of the filters. The manufacturer's color-temperature specification for the 750-watt lamps operated at 115 volts was 3200°K. For the dominant-wave-length computation, 3243°K was used, as the best approximation in the available tables. Transmittance curves for the filters and the heat-absorbing glass were determined with a Beckman spectrophotometer. Trichromatic coefficients were computed by the weighted ordinate method, using 10 m μ intervals, and dominant wave-length and purity were obtained graphically from the ICI chromaticity diagram. For mixtures, the desired points were located on the diagram and the proportions of the components then computed by formula.

SUBJECTS

Subjects fell into the following three categories:

(1) One female research assistant (ZO). Most of the exploratory work was done with this subject and she continued to serve through the formal experiments.

(2) A "sophisticated" category consisting of two female staff members, three male graduate assistants, and one male undergraduate.

(3) A "naive" category consisting of five male undergraduates. Eight individuals started in this category but three dropped out before completing initial training.

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All subjects had normal color vision on the Ishihara and American Optical Co. tests, and normal near-vision acuity with or without correction.

GENERAL PROCEDURE AND DESIGN

A. Training and Review

All subjects were given extended training with the basic set of 28 stimuli, to be described below, presented on a 0.5-ft-L white background. Initially, a learning criterion of 100% correct identifications on successive days was held to. Practical considerations forced the acceptance of a lesser criterion in a few individual cases. For one of these (subject DL, Exp. 1) the final score was 91% correct over the last two days; in all others a final level of 98% was attained.

A refresher run, consisting of one presentation of the basic stimulus set, followed by a review of errors, was given in the first period of each week of experimentation, except as noted below, for Experiment 1.

B. Testing Routine

In the weekly routine (except for Experiment 1) a subject ordinarily had one to three experimental periods per day for four successive days. The three day week-end was left clear for calibration checks. In Experiment 1, subjects ordinarily had one experimental period per day for five successive days. An experimental period usually included one run, consisting of a single presentation of all the stimuli in a set. In the later experiments, one to three runs were given, depending upon conditions. Whenever schedules allowed, subjects were run in pairs. As each stimulus was presented the two individuals observed it in turn, and responded independently. Experimental periods lasted from approximately 40 to 70 minutes, the exact time varying as a function of such factors as number of subjects, number of stimuli in the series, and difficulty level of the testing conditions.

In most experiments, 0.5-in. circular targets were used, subtending $1^{\circ} 26'$ of visual angle. Subjects were asked to identify the stimulus with respect to each dimension in which it was varied. Hues were designated by code numbers, progressing in sequence through the spectrum, starting with red. Thus in a series including a range of hues and luminances (but one level of purity), a red stimulus at 10 ft-L was reported as "No. 1 at 10." This made unnecessary an extensive list of code numbers, with its attendant risk of memory errors.

At the beginning of a session, subjects were seated in the isolation booth and allowed to dark adapt for five or more minutes while the experimenter prepared the apparatus, data sheets, and stimulus guide cards. The guide cards carried the apparatus settings for the stimulus conditions, and these were shuffled before each run to provide a random order of presentation. With the shutter occluding the projection lens, the experimenter set up the first stimulus. He then gave the ready signal and opened the shutter. Immediately after the subject's response the experimenter closed the shutter, entered his record, and prepared the next stimulus. No time limit was imposed, but subjects were cautioned to avoid excessive delay. Response times varied widely, with an estimated modal value of approximately 10 seconds. Intervals between stimuli were 30-60 seconds.

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During training the standard procedure was to review errors at the end of each run. After criterion was achieved and the subjects were participating in an experiment they were not informed of errors except after refresher runs. The subjects did have internal feedback, however, and were aware that an experimental run included one presentation of each stimulus in a set. Therefore they were instructed to make an independent judgment on each item.

C. Design

In the designs for individual experiments, it was found impractical to include all combinations of variables or to provide for extended training under a single set of conditions. In most cases, experiments were planned to evaluate the effect of one variable under a sampling of secondary conditions; target size, for example, was tested at selected combinations of target purity and background purity.

In lack of substantial training under the specific conditions, some learning could occur in the course of an experiment. For this reason, conditions within an experiment were generally arranged to proceed from least to most difficult. Subject to this restriction, counterbalanced series were used when practical.

Experiment 1, the most complex and in some respects the most systematic of the experiments, was done with one presentation of the stimulus set for most subjects under most conditions, and conditions progressed from targets of maximum purity on a white background (easy) to targets of minimum purity on backgrounds of maximum purity (difficult).

In later experiments, which were liable to more disturbances such as irregularity of schedules, an attempt was made to include two presentations per condition, and greater use was made of counterbalanced designs.

Toward the end of the program, scheduling became an increasing problem and a round of more or less fragmentary testing was done on variables not previously covered.

THE DATA RECORDS

The main performance data are in terms of errors, but in Experiment 4 time scores were also recorded. The data are presented in tables and graphs, with the graphs showing selected features of the results. The curves in the graphs were fitted by inspection.

The unit for testing was the stimulus set, usually containing 28 items. The set was presented one or more times under each experimental condition, the number of presentations (or "runs") being indicated in the tables. The per cent errors are therefore based on the total number of test items for each condition, usually a multiple of 28. An occasional set, averaging not more than one per table, is incomplete; these cases are not identified unless the missing items in a set exceed two. Scores for combined individuals or combined experimental conditions (identified as "pooled" scores in the tables), designate the total errors in the combined distributions as a percentage of the total items.

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In most experiments the designs were incomplete, and the omissions are indicated by dashes in the tables. Certain sets of data, e.g., for trials in a learning sequence, are not reported in detail.

Total errors are used throughout except where otherwise specified. For a set of stimuli differing, for example, in hue and luminance, total errors can be broken down into those involving hue only, luminance only, and mixed. The breakdown is used in special cases, e.g., for the detailed analysis of hue; it should be noted that in this case the "hue" and "mixed" categories are combined to include all errors involving hue.

EXPERIMENTS

A. Preliminary

The main body of experimentation presented below was preceded by a long period of exploratory work with the subject ZC. During this period a number of sets of stimuli which differed with respect to the number of chromatic and luminance steps were tested with various combinations of target and background purities. The effects of such variables as stimulus size, ambient light, and stimulus/background luminance ratio were probed, and the effect of training was investigated.

A primary goal was the determination of a set of stimuli, varied in hue and luminance, which approached the maximum number absolutely identifiable within the dimensional limits adopted. For the background, a luminance of 0.5 ft-L was chosen, as a value in the range encountered in operational devices and one which made it possible for the apparatus to provide a considerable spread of stimulus luminances brighter than the ground. The latter ranged from one to 100 ft-L (i.e., from twice to 200 times the background luminance). Reducing target luminance to 0.75 ft-L was found to produce a definite increase in errors.

The problem of determining hue steps was approached by a method of successively splitting stimulus intervals. For example, starting with red, blue, and green primaries, a stimulus falling between red and green and one falling between green and blue were added. On the basis of test scores obtained, additional stimuli were interpolated and some intervals adjusted, and the set was tested again. This process was continued until adjacent stimuli were on the borderline of confusability throughout the set.

During this period it was found that purple stimuli posed special problems related to chromatic aberration, and also that stimulus purity was of limited usefulness as a criterion for identification. Furthermore, it was found that maximum performance could be attained only by a large investment of training time. For these reasons the qualified goal was adopted of establishing a set, including hues of high purity and white, varying primarily in hue and luminance, which would not be the maximum attainable, but which could be learned with reasonable rapidity to a fair level of stability. This would constitute the basic set for the investigation of other variables. The dimension of stimulus purity, and purple as a possible stimulus hue, were deferred to a later stage in the program.

The stimuli used during the greater part of the exploratory work consisted of mixtures of primaries. With these it was found that the maximum useful number was about 10 (including white). But the use of mixtures was cumbersome in the experimental routine, requiring a great deal of preparatory work and imposing an exacting

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task on the experimenter. In an attempt to increase efficiency, attention was directed toward the problem of approximating with single filters the distribution of hues previously arrived at. From this effort, the hues for the basic set used in the formal experimentation to be described were developed.

The "basic set" in its final form consisted of 10 colors at each of two luminance levels, plus eight of these at a third luminance level, for a total of 28. The colors were white and nine others determined by the single filters listed in Section II-D above (the Wratten 74 being omitted). For reporting and recording in the experimental routine, identification numbers were assigned in spectral order as follows: #1 = R, #2 = O, #3 = Y, #4 = GY, #5 = YG, #6 = G, #7 = BG, #8 = GB, #9 = B, #10 = W. The three luminance levels of 1, 10, and 100 ft-L were retained. Yellow-green was excessively confused with adjacent stimuli at 100 ft-L, presumably because of saturation loss, blue-green could not be obtained at this level; these two combinations were therefore not used.

Error distribution on the basic set obtained in this way by single filters was slightly less uniform than with the mixture colors, and it was also found to vary somewhat between subjects.

A "reduced set" of 18 stimuli, which consisted of the basic set with the 10-ft-L eliminated, was used in certain instances when the full complement was not required.

When the set was at maximum purity, each of the nine hues was at the maximum its filter would produce - five at 100%, and four ranging from 82 to 97% (see table in Section II-D). When at "90%" purity, G and GB were at their maxima, 82 and 88% respectively, while the others were desaturated to 90%. At lower purities, all hues were desaturated to the specified value.

B. Experiment 1 - Color Properties of Targets

1. Problem

The purpose of Experiment 1 was to determine the effect of variation in target purity, background color, and background purity, on the identification of a set of colored targets which had been learned under fixed conditions of these variables (maximum target purity, white background). Tests done on the three groups of subjects differed in detail, but were treated as parts of a single experiment because of their common goal.

2. Subjects

The three groups of subjects corresponded to the categories described in the general section above.

(1) Group 1 consisted of ZC only.

(2) Group 2 included the female staff member FG, two male graduate assistants DL and PL, and the male undergraduate GB, from the "sophisticated" category.

(3) Group 3 included the five male undergraduates ED, DG, LH, DM and RT.

3. Variables

Target purities were 10%, 20%, 30%, 50%, 70%, "90%", and maximum; background colors were red, green, blue, and white; background purities were 0% (white), 20%, 25%, 60%, 75%, and maximum.

4. Design

The three groups were tested under somewhat different circumstances.

For the subject ZC, the Experiment 1 runs were interspersed to some extent with other more exploratory tests. She received two runs on most conditions, the two being counterbalanced with respect to sequence of trials.

The subjects of Group 2 were assigned to scattered spots within the matrix of Experiment 1 conditions, with the goal of obtaining a broad coverage with a minimum expenditure of individual time. As a further economy, the reduced stimulus set, from which the middle luminance level had been eliminated, was used. Subjects who remained available after their original assignments had been completed were used to fill gaps and augment scanty data. In most instances one run per condition was given.

Group 3 was used to test several variables in a single more comprehensive design with the full stimulus set. In this design, two sub-groups were given alternate steps of target purity, except that all had maximum purity. Subjects had one run under most conditions. Sequence was from minimum to maximum difficulty.

5. Procedure

Subject ZC had received extensive previous practice. All others were trained to the standard criterion of 100% or nearly 100% correct on two successive days before formal experimentation started. The usual schedule for a subject consisted of one period per day, including one or two runs per condition, for five days a week instead of four days as in later experiments.

The refresher run was given to the subjects of Groups 1 and 2 occasionally, on request, and to the subjects of Group 3 regularly at the beginning of a week.

Other features of procedure were as outlined in the general section above.

6. Results

Results in terms of per cent errors for the three groups of subjects appear in Tables 1, 2, and 3 (in the Appendix). Each score is based on all of the runs pooled for the particular condition.

Figures 2, 3, and 4 show per cent errors as a function of target purity for each background purity level. Examination of the tables and individual plots indicated no systematic differences in general level associated with background hue. Therefore data for the background hues were pooled at each purity, and the scores derived in this way were plotted. Scores for separate background hues are shown as the scattering of individual points about each pooled data point.

For white backgrounds, the primary curves (solid lines) are based on data obtained in the regular runs as with other backgrounds. Additional data were available for targets of maximum purity on white backgrounds from the interpolated refresher runs. As these typically came after intervals of inactivity, errors on them were a little high. All scores for maximum target purities on white backgrounds were pooled, and the dotted branches of the curves were drawn to represent these values. It is possible that the dotted curves provide the more valid basis of comparison with scores on other backgrounds, because all backgrounds except white were unfamiliar when tested, and were therefore at a relative disadvantage as compared with white in its regular experimental run.

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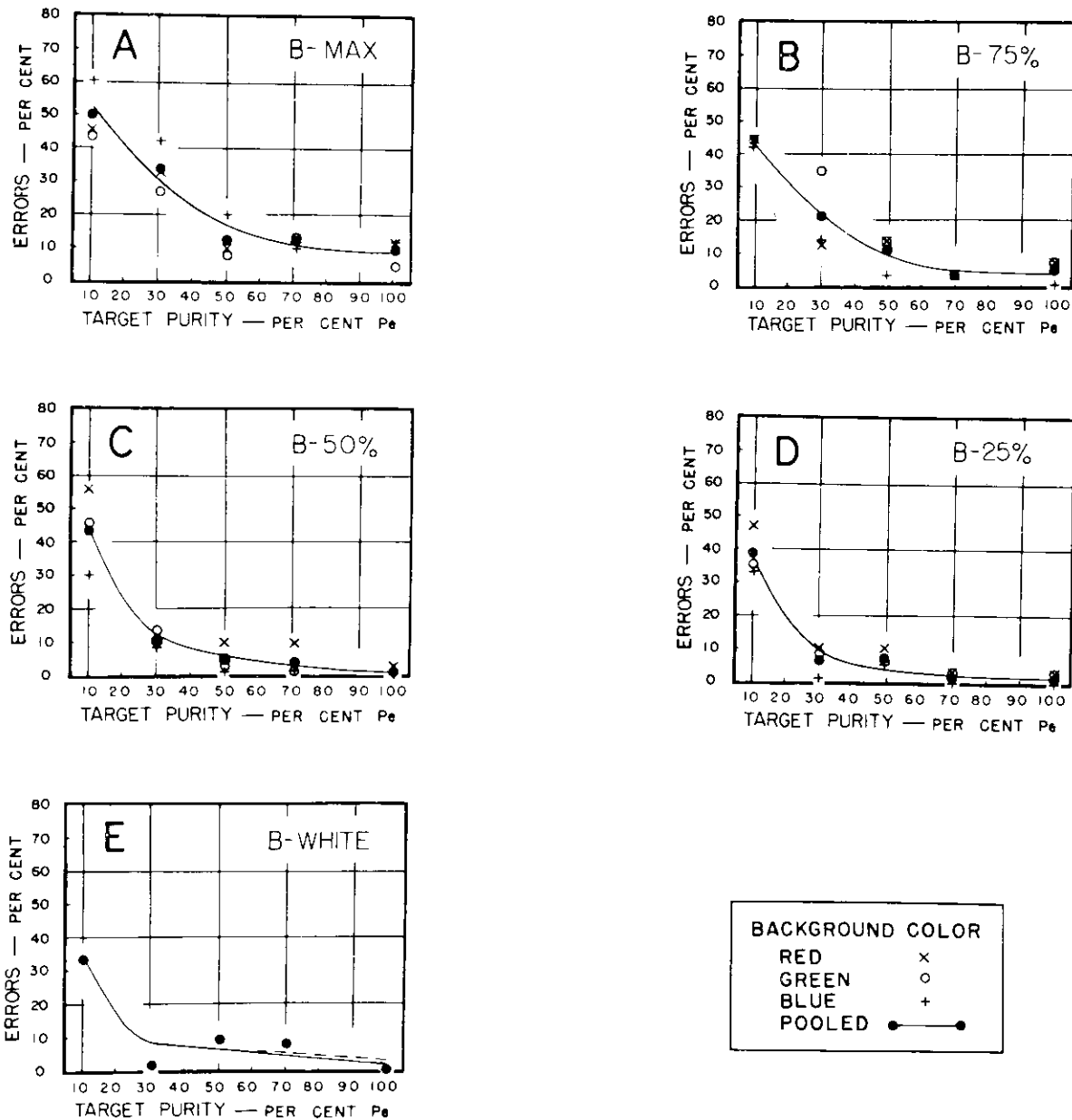


Figure 2. Per cent errors in color identification as a function of target purity for subject Group 1 (ZC). The basic stimulus set of 28 items was tested against red, green and blue backgrounds at 25%, 50%, 75% and maximum purity, and white. The dotted branch of the curve for white background is based on regular and refresher runs combined. Experiment 1.

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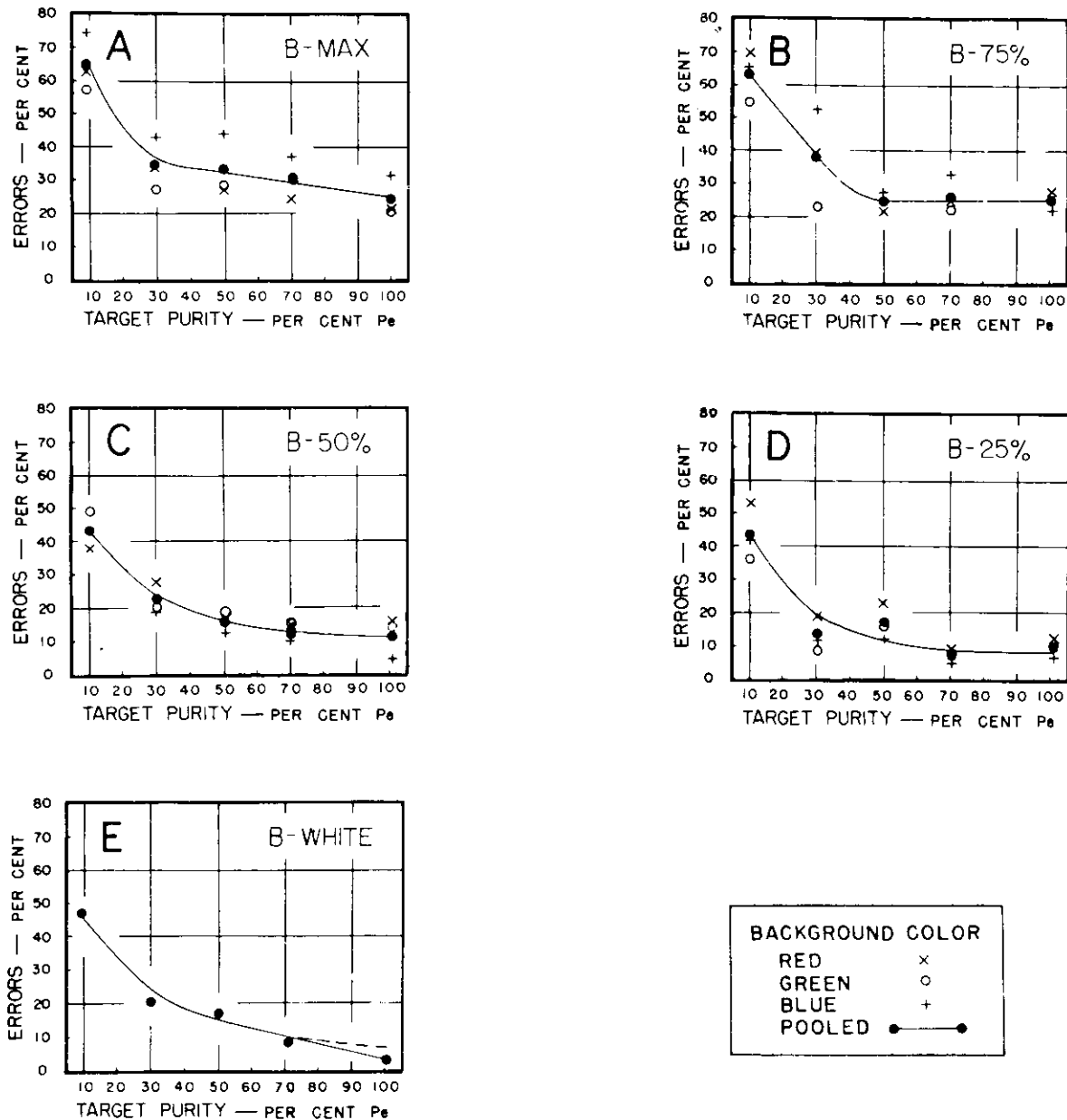


Figure 3. Per cent errors in color identification as a function of target purity for subject Group 2. The reduced stimulus set of 18 items was tested against red, green, and blue backgrounds at 25%, 50%, 75%, and maximum purity, and white. The dotted branch of the curve for white background is based on regular and refresher runs combined. Experiment 1.

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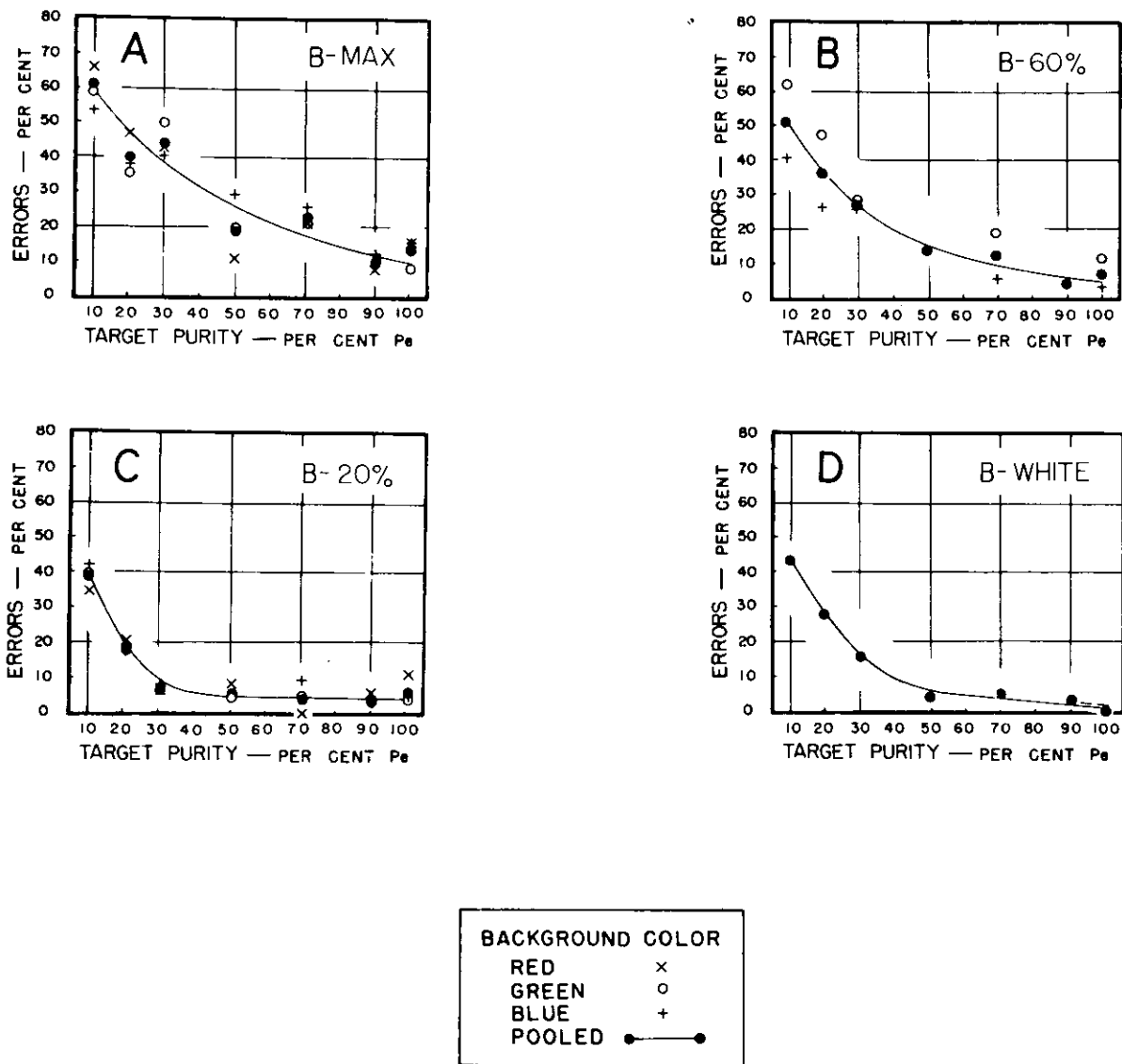


Figure 4. Per cent errors in color identification as a function of target purity for subject Group 3. The basic stimulus set of 28 items was tested against red, green, and blue backgrounds at 20%, 60%, and maximum purity, and white. The dotted branch of the curve for white background is based on regular and refresher runs combined. The data for 20%, 50%, and "90%" target purity are from subjects RT, LH, and DG, those for 10%, 30%, and 70% from subjects DM and ED, and those for maximum purity from all subjects combined. Experiment 1.

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The general pattern is quite similar for all groups. As target purity decreases (from right to left) errors increase in a positively accelerated manner. This trend obtains for all levels of background purity. There is some tendency for the groups of subjects to differ slightly in general level of errors, with Group 1 lowest and Group 2 highest.

General error level increases also as background purity increases. In this connection, it is necessary to take cognizance of the fact that targets ordinarily were presented first on a white background, then on colored backgrounds of increasing purity. The opportunity for additional learning as the series progressed may have introduced a slight bias, making errors on the white background appear relatively too high.

For white background, error scores rise slowly as target purity decreases from maximum to something less than 40% (right to left on the graphs), and then rise more rapidly. One effect of increased background purity is to initiate the more rapid rise of errors at higher target purities (farther toward the right in the graphs).

Though background color had little effect on mean scores for complete stimulus sets, some effects can be observed on individual stimuli. In Figure 5, per cent errors are shown by identification colors. These data are samples, for a variety of conditions, from results obtained with Group 3 subjects. All hue errors (both hue alone and hue and luminance mixed) are included in the counts, and data points represent pooled results for all subjects serving under the specified conditions. Two types of error patterns are shown; points joined by the broken line represent stimulus errors, i.e., stimuli incorrectly identified; points connected by solid lines indicate response errors, i.e., the incorrect responses given. Though colors on the abscissa do not constitute an interval scale, line graphs were plotted instead of column diagrams because they give a better picture of the relation between the error patterns. The data points for white targets were not joined to the curves because they do not fall on the spectral continuum.

Graph 5-C shows an exceptionally clear example of the effect of background hue, and may be used to clarify the two types of errors being considered. At its simplest, classical induction theory would predict that the effect of a green background is equivalent to the addition of a red (purple) component to the stimulus. The results in Graph 5-C suggest that this does occur. The stimuli in the YG to O region were difficult to identify correctly, while the red was always identified correctly. The response "red," however, was used incorrectly a great deal as were the responses through GY (solid line). The similarity of the two patterns, with the response error pattern shifted toward the red, suggests that perceptually the effect of the green background was to shift the apparent colors of the stimuli toward red.

In general, although the total error level is quite similar for all background hues, it may be seen that the different hues do result in different patterns of errors, and patterns tend to fall in line with classical induction theory. It can be judged from the data, moreover, (though the selected graphs of Fig. 5 do not happen to illustrate it) that the effects of background hue tend to be more clearly reflected in error patterns as target purity is decreased or as background purity is increased.

Errors by target luminance level were analyzed for Group 3. In general the lower luminances were judged less accurately. When examined in relation to purity of background, a systematic relation appeared; with backgrounds of 20% purity, the error difference between luminance levels was not significant by Friedman's χ^2_r test. With backgrounds of 60% purity it was significant at the 0.02 level, and with backgrounds of maximum purity it was significant at the 0.01 level. The 100-ft-L

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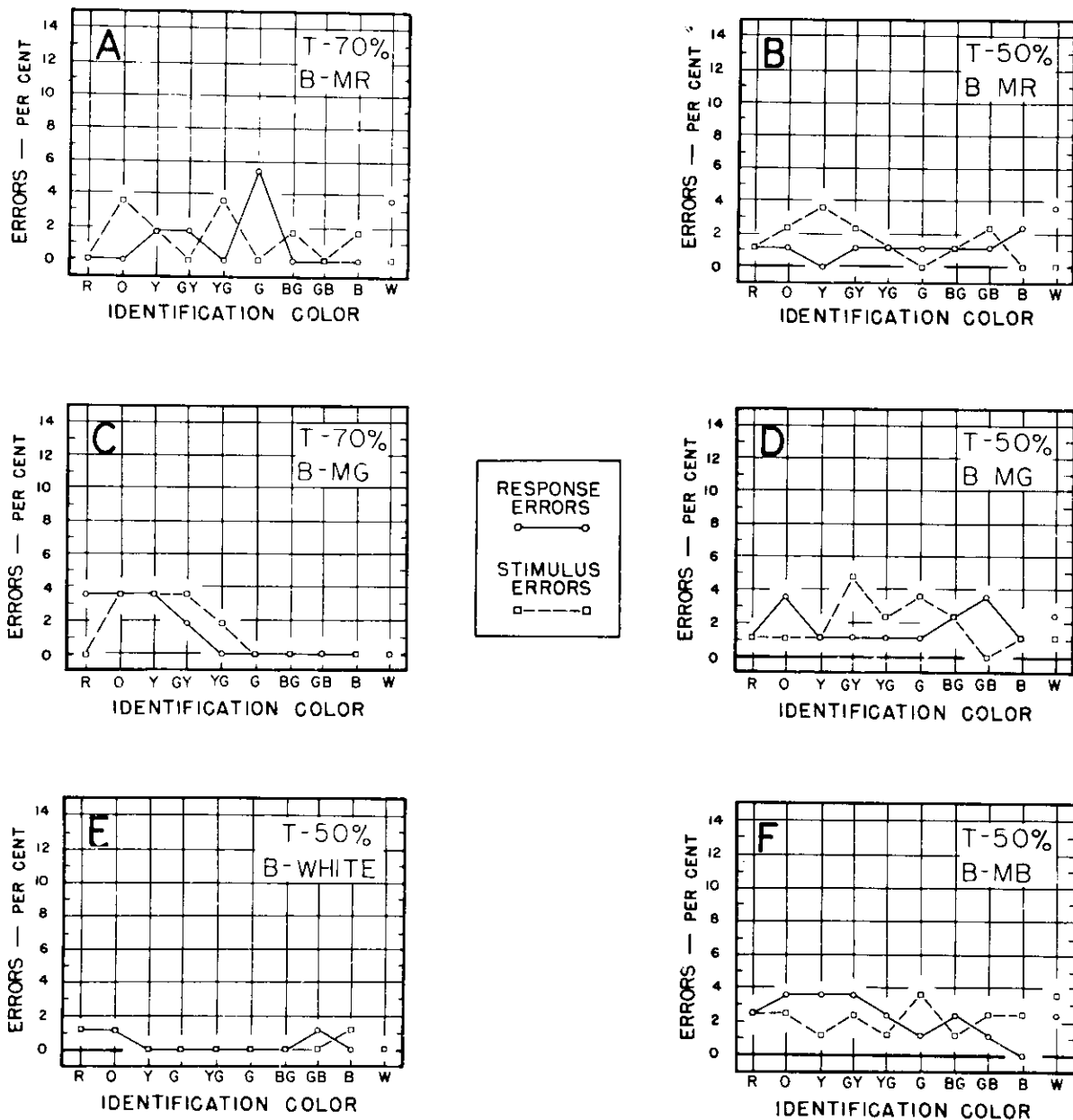


Figure 5. Per cent stimulus and response errors in color identification as a function of stimulus color. The basic stimulus set of 28 items at 50% and 70% purity was tested against red, green and blue backgrounds at maximum purity, and white. Scores are based on all hue errors, including "mixed". Subject group 3; Experiment 1.

level was at some advantage from the elimination of two hues, but this did not result in significantly fewer errors with the 20% backgrounds. It appears that the targets of low luminance suffered relatively more from induction when background purity was increased.

A further aspect of the results deserves comment. Examination of individual data records suggested the operation of some kind of order effect operating to reduce errors in the later part of a run. Accordingly the data obtained from Group 3 were selected for further study. The 29 trials were divided into serial quarters, and errors made in each quarter were computed. With all data pooled, the errors for successive quarters were found to be 21%, 16%, 14%, and 11%. The same pattern was found to obtain for the several subdivisions of the data. The reduction in errors could be attributed to simple elimination if (1) an external set of standard stimuli had been available for matching, and (2) the subjects had feedback on their performance. In the present situation, only an internal frame of reference and internal feedback were available. Subjective reports suggested that a process of reestablishing the frame of reference for the run was carried through during the early trials. It seems probable that this played a larger part in the regression of errors than did simple elimination.

C. Experiment 2 - Training

1. Problem

In the first experiment, conditions over a considerable range of difficulty had been tested, but with a small number of runs per condition, and with systematic training only on the relatively easy condition of targets of high purity on a white background. This resulted in relatively poor scores for the more difficult conditions. The primary goal of Experiment 2 was to obtain information about the effect of further training on additional conditions for which initial performance had been relatively poor. The investigation of training was not intended to be exhaustive. For practical reasons the more limited plan was adopted of obtaining evidence on the effect of a moderate degree of training, and probing the limits of difficulty for which training could compensate. A secondary goal was to evaluate the effect of a continuously visible reference standard consisting of Munsell chips.

2. Subjects

Four subjects from Category 2 participated. Of these, DL and PL had experience in Experiment 1; the others (a female staff member CD and the male graduate assistant JH) were given at least 35 practice runs with the basic stimulus set on a white background. This was well beyond the amount necessary to meet the criterion of 100% correct on two successive days.

3. Variables

Three target purity levels were used, 30%, 50%, and maximum; and three backgrounds, red at 50%, red at maximum, and white. The two new subjects worked with the reference standard of Munsell chips.

4. Design

All subjects were trained with targets of 50% and maximum purity on all three backgrounds. Subjects DL and PL were trained also with targets of 30% purity on all backgrounds.

5. Procedure

General training procedure, with a review of errors after each run, was standard, but a fixed criterion for termination of practice on a particular experimental condition was not held to. The decision to terminate was made for a given

subject in the context of problems at the moment and in light of the general trend of his scores under the condition in question. In most cases, however, the subjects passed through the primary learning phase and obtained perfect or near-perfect scores before termination.

6. Results

Figure 6 shows per cent errors as a function of number of practice runs. The curves represent about half the data, selected to show both individual differences and effect of experimental conditions.

All subjects had previously received practice well beyond the primary training criterion. The phase of initial learning was therefore well past, and the curves of Figure 6 reflect only supplementary learning as new conditions were introduced. With few exceptions, error scores for a new condition started relatively high and then declined. This was true even of the relatively difficult condition of desaturated targets on backgrounds of maximum purity. Problems of scheduling resulted in substantial interruptions of training in some instances. Delays in number of days for these cases are indicated on the graphs. It can be observed that such a delay was usually followed by a high error score. The curves for subject DL in Graphs 6-B and 6-C were plotted through 10 trials only, though training extended beyond that. With targets of 50% purity on backgrounds of maximum purity (6-B), DL was terminated on the twelfth run when he had attained a perfect score. With targets of maximum purity on backgrounds of 50% purity (6-C), he was continued through 20 runs, with a somewhat irregular but generally low error level on the last 10 runs, and a terminal score of approximately 2%.

Comparison of the curves of CD and JH who used the reference standard with those of DL and PL who did not suggests that the standard was of no help in stimulus identification. Reports from the subjects supported this interpretation.

D. Experiment 3 - Target Size

1. Problem

The problem in Experiment 3 was to determine the effect of target size upon identification of colors.

2. Subjects

The subjects were ZC (Category 1), with extensive previous practice, and CD (Category 2), with experience in Experiment 2.

3. Variables

Four target sizes were used, circles 0.06, 0.12, 0.50, and 2.0 in. in diameter. Viewed at 20 in., these subtended visual angles of approximately 10', 21', 1°26' and 5°44', respectively. These targets, at 50%, 70%, and maximum purity, were presented on red backgrounds of 20% and 60% purity and on white.

4. Design

An incomplete design counterbalanced for serial position was used. Data were obtained from both subjects with 0.06- and 2.0-in. targets; the other two sizes were split between the subjects. Both subjects had all combinations of target and background purity.

5. Procedure

Procedure was standard as previously outlined.

6. Results

Per cent errors are shown in Table 4 (see Appendix) and Figure 7. The plotted data points represent the several target purity levels, with subjects

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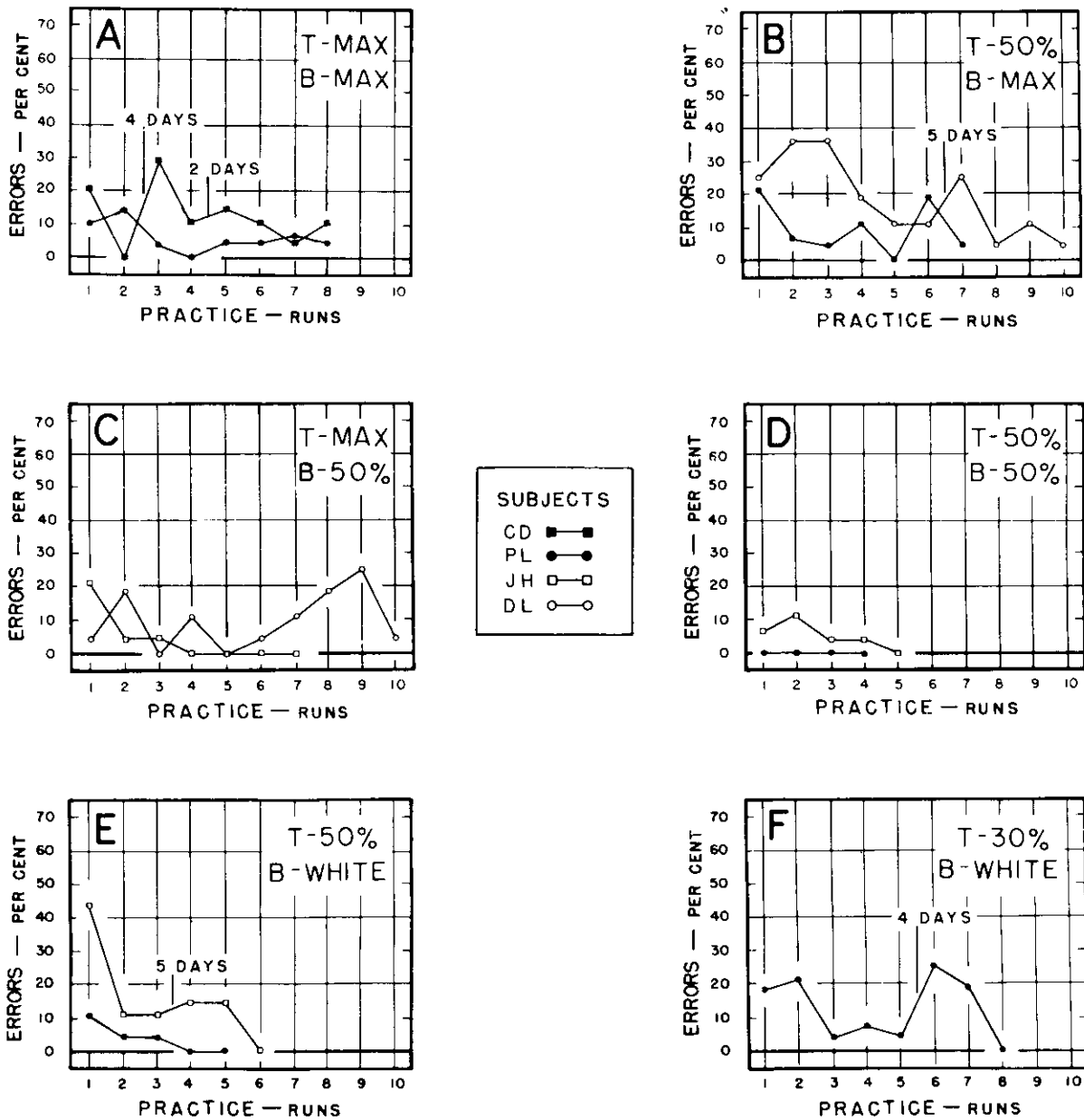
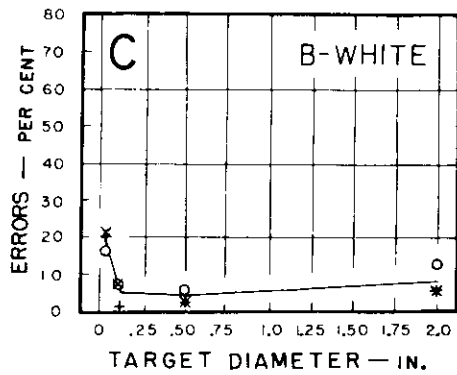
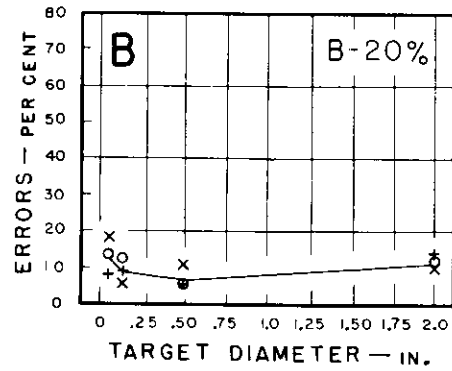
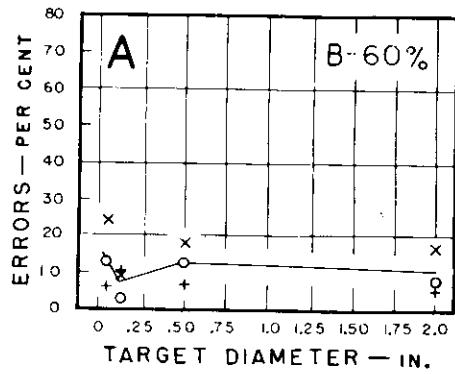


Figure 6. Per cent errors in color identification as a function of number of practice runs, for selected subjects and selected target and background combinations. The basic stimulus set of 28 items at 30% and 50% purity was tested against red backgrounds at 50% and maximum purity, and white. Unusual delays between runs are indicated in number of days in Graphs A, B, E and F. Experiment 2.

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TARGET PURITY	
MAX	+
70%	o
50%	x
POOLED	—

Figure 7. Per cent errors in color identification as a function of target size. The basic stimulus set of 28 items at 30%, 50% and maximum purity was tested against red backgrounds at 20% and 60% purity, and white. Data for 1/8-in. targets are from subject ZC, for 1/2-in. targets from subject CD, and for 1/16- and 2-in. targets from the two subjects combined. Experiment 3.

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pooled. The curves represent the general trend with both subjects and purity levels pooled. Probably because of the subjects' extensive experience, error levels were fairly similar for most conditions of target and background purity; the most deviant condition was targets of 50% purity on backgrounds of 60% purity, for which errors tended to be a little high. In relation to target size the two subjects showed somewhat different patterns, but so far as the three graphs of pooled data permit a generalization, errors were least in the range from 0.12 to somewhere above 0.50 in. The 0.06-in. targets (10') were of a size generally found to make color identification more difficult, and the 2.0-in. targets transcended the fovea and therefore presented a non-homogeneous appearance.

E. Experiment 4 - Distraction

1. Problem

The problem was to determine the effect of a moderately demanding distraction task upon the subjects' ability to carry out the primary task of color identification.

2. Subjects

Two experienced subjects from Category 2, DL and JH, participated.

3. Variables

Targets of 50% and maximum purity were presented on red backgrounds of 20% and 60% purity and on white. The distracting task was simple mental arithmetic; subjects were asked to perform continuous verbal multiplication of numbers from 10 to 20 by numbers from 2 to 9.

4. Design

Scores were obtained from both subjects with and without distraction at all combinations of target and background purity.

5. Procedure

Preliminary to the experiment, subjects were given several runs with targets of maximum purity on a white background to familiarize them with the task and operating procedure. Standard routine was used for presenting targets.

The procedure for distraction was as follows. Immediately prior to opening the shutter, the experimenter gave the subject a two-number multiplication problem as his starting point. The number was chosen at random from the ranges indicated above. The subject began to multiply aloud, the experimenter opened the shutter, and the subject continued his multiplication, taking numbers in serial order, until he identified the color and the experimenter closed the shutter. In addition to the subject's identification report, his response time to the nearest second was recorded.

6. Results

Per cent errors and response times appear in Table 5 (see Appendix). Figure 8 shows per cent errors as a function of background purity, for the two target purities separately, with distraction as the parameter. Response time is plotted similarly in Figure 9. The data points are based on individuals, the curves on the two subjects pooled. There were no statistically significant differences assignable to either target purity or background purity, which probably reflects, as in the preceding experiment, the extensive previous practice.

Distraction produced a significant impairment of both error and time scores (by Friedman's χ^2 test), the effect on the former being relatively small, on the latter, relatively large. Errors made in the multiplication task were not recorded. A few impressions, however, should be noted. The subjects were prone to multiplication errors of a type to suggest that the two tasks were mutually interfering.

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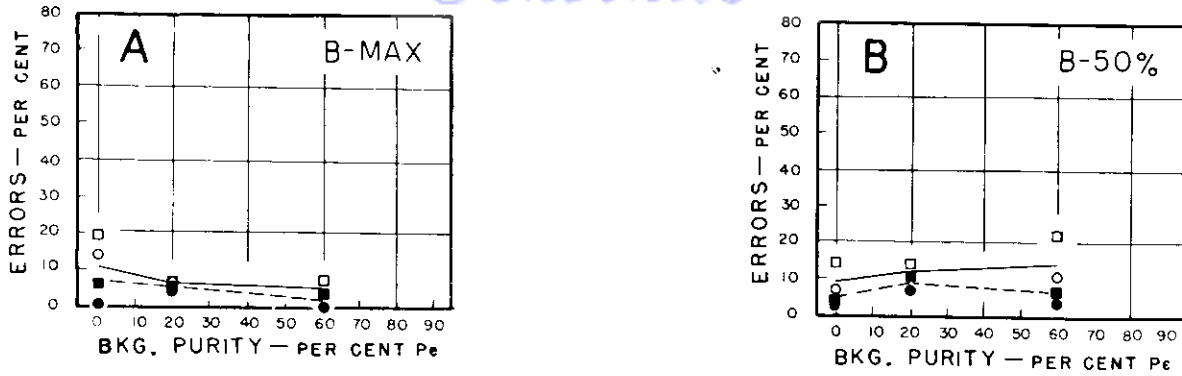


Figure 8. Per cent errors in color identification as a function of purity of a red background in the presence and absence of distraction. The basic stimulus set of 28 items at 50% and maximum purity was tested. Experiment 4.

DISTRACTION		NO DISTRACTION	
JH	■	JH	●
DL	□	DL	○
POOLED	—	POOLED	---

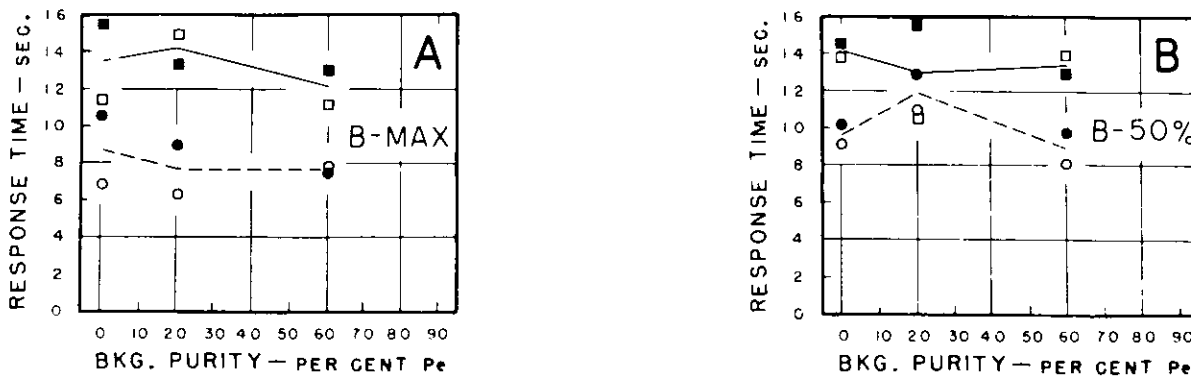


Figure 9. Response time per item for color identification as a function of purity of a red background in the presence and absence of distraction. The basic stimulus set of 28 items at 50% and maximum purity was tested. Experiment 4.

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The experimenter's impression from the response patterns, furthermore, was that the subjects alternated attention from task to task, with a tendency to automatize multiplication while attending to target identification. The small effect of distraction on identification errors, therefore, may have resulted from the tendency to assign priority to accuracy of identification at the expense of multiplication.

F. Experiment 5 - Target Shape

1. Problem

In Experiment 5 the problem was to compare color identification of circular and line targets of equal area.

2. Subjects

Two subjects, ZC from Category 1 and CD from Category 2, participated.

3. Variables

The targets were a circle 0.25 in. (43') in diameter and a 0.06- by 0.78-in. (10' by 2914') line equated to the circle in area. Target purities were 30%, 50%, and maximum. Backgrounds were red at 20% and 60% purities, and white.

4. Design

All 18 combinations of variables were used with both subjects in a counterbalanced design.

5. Procedure

Standard procedure for stimulus presentation was followed.

6. Results

Scores appear in Table 6 (see Appendix) and Figure 10. The latter shows per cent error as a function of target purity for each of the backgrounds. Data points represent individuals; the curves are based on the two subjects pooled, the broken line for circular targets, the solid line for line targets.

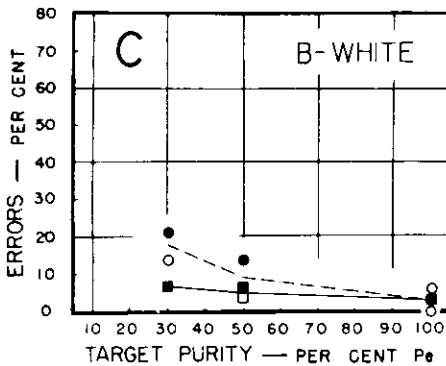
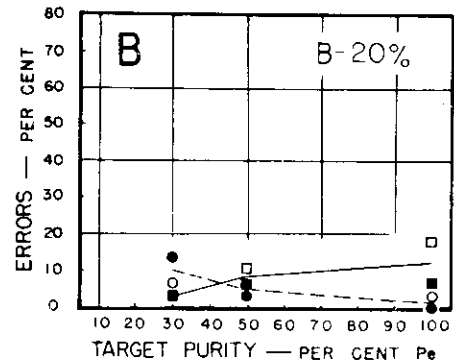
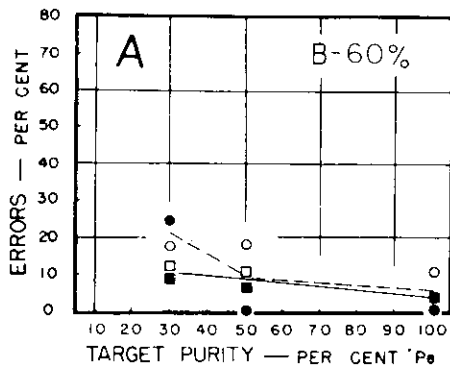
The only consistent effect of shape is the slightly lower errors for line targets than for circular targets at 30% purity. Induction from a colored background might be expected to affect the line target more than the circle, as all points on the former are relatively close to a boundary. This could be expected to increase errors, especially at low target saturation. Our data for 30% purity show the contrary effect. Though too limited to be conclusive, the data at least suggest that, with equal area, the narrow targets were at no disadvantage.

A comparison is possible between these results and those for the same subjects in Experiment 3 on target size. By appropriate interpolation, we can match 0.25-in. circular targets at the pooled purities of 50% and maximum in Experiment 3 with the same conditions in Experiment 5. For these conditions agreement is good, the estimated error level in Experiment 3 being 7.5% and in Experiment 5, 5.6%. We can therefore accept the comparisons within either experiment with more confidence. We can also infer that, relative to the 0.06-in. round target of Experiment 3, a 17-fold increase in area, at the higher purities, produces about the same improvement in errors regardless of shape.

SUPPLEMENTARY TESTS

In addition to the results of the more formal experiments above, limited data were gathered on a number of additional variables.

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TARGET		SHAPE	
LINE		CIRCLE	
ZC	■	ZC	●
CD	□	CD	○
POOLED	—	POOLED	---

Figure 10. Per cent errors in color identification as a function of target purity for circle and line targets equated in area. Circular targets were 0.25 in. in diameter, line targets 0.06 x 0.78 in. The basic stimulus set of 28 items was tested against red backgrounds of 20% and 60% purity, and white. Experiment 5.

A. A Third Stimulus Dimension

It was mentioned previously that, in the development of the basic set, target purity had been found to be of little help as a stimulus dimension and was therefore temporarily omitted. Later in the program the feasibility of increasing the number of stimuli in the set by the use of purity was again considered.

A trial and error attack was made on the problem. This required a considerable time investment and resulted in substantial clarification, but was not conducted on a sufficiently regular schedule to justify reporting the scores in detail. To approximate the range presumed to be attainable in the typical operational system, purities were limited to 70% and below.

The two female subjects, ZC and CD, were first given practice on an extended set which included the basic set, with white omitted, at 50% and 70% purities, for a total of 50 items. These were presented on a white background. For initial training the set was broken down by luminance levels into three separate sets, and the subjects were given four training runs on each. Sixteen stimuli were eliminated at this point on the basis of relative frequency of confusion. The remaining 34 stimuli were then combined into a single set and presented in seven practice runs. Learning took place slowly during this period, with a drop in errors from about 18% to 7%.

To widen the differences in the purity dimension a new set was constructed by replacing the 50% purities with their 30% equivalents. With this set, errors dropped in two practice runs from 5% to 2%. Three new 30% stimuli were then added to the set and two more practice runs given. Both subjects achieved 100% correct identifications on the last run. The final set of 37 included the 25 of the basic set (white omitted) at 70% purity, plus the following at 30% purity: R, Y, YG and BG at 1 ft-L; O, GY, BG and B at 10 ft-L; R, GY, G and GB at 100 ft-L.

In these tests, white was omitted to economize time, and because the two subjects ZC and CD had previously scored 100% on targets of 30% purity, with a white target included, on a white background. With less extensive practice, or with colored backgrounds, some confusion between the 30% purities and white could be expected.

In summary, the results indicate that, with well practiced subjects, purity can be used to a limited extent as a dimension for coding, at least with white backgrounds. The implication for colored backgrounds will be considered in the Discussion.

B. Size of Stimulus Set

During the exploratory phase of the study a question arose as to the relation between stimulus range (length of set) and size of intervals between absolutely identifiable stimuli. Fragmentary data suggested, for example, that more colors could be identified in the red to green part of the spectrum when the total range of colors was limited to this region.

To test this point, the 10 colors of the basic set were augmented by the addition of eight colors, and was then split into two sub-sets of nine items each, one ranging from R to YG and the other from G to B with white added.

Two subjects, JH and CD, were given seven or eight practice runs with each sub-set separately, at maximum target purity, at 10 ft-L, on a white background. The two sub-sets were then combined and two of the supplementary stimuli deleted, one because of high errors and the other because it came at the end of the first

sub-set, and, with the two combined, would have double its original confusion potential. The subjects were then given nine practice runs with the combined set.

At the end of initial training with the sub-sets, the error score was 10% for sub-sets and subjects pooled. On the first run with the combined set, errors jumped to 30%, though on a per item basis the task should have been easier because of the deletions. This tended to confirm the hypothesis that increasing size of the set increases difficulty in local regions. On the last run with the combined set, however, errors were reduced to 6%, indicating that the adverse effect of the enlarged set could be compensated for by additional training.

A further implication of these results is that, with extended training, the number of absolutely identifiable hues might be in the neighborhood of 15. This is in contrast to the nine hues (white excluded) of our basic set, but it will be recalled that the basic set was developed for use with a limited investment in training.

C. High Background Luminance

The three target luminances used in the main experiments, 1, 10, and 100 ft-L (providing target/background ratios of 2/1, 20/1, and 200/1 against the background luminance of 0.5 ft-L) had been established in the early exploratory work with ZC. At that time, data were gathered with a 0.75-ft-L target on a 0.5-ft-L background (ratio 1.5/1). When the background was white, reduction in target luminance from 1 to 0.75 ft-L had no effect on errors. With colored backgrounds, however, there was some increase in errors. It was desirable to explore the effect of further decreasing target/background ratio and thereby bringing luminance contrast more effectively into play along with color contrast.

For this purpose, a limited amount of data was gathered for a sampling of experimental conditions with three subjects, CD, JH and DL. Targets of 70% and maximum purity were used in combination with red backgrounds of maximum purity. Target luminance was set at 10 ft-L, and background luminance was increased to 10, 20, and 50 ft-L, producing target/background ratios of 1/1, 1/2 and 1/5.

Experimental conditions were split between two of the subjects; all were presented to the third subject. Two to nine runs were given per subject per condition, with standard target-presentation procedure.

Results were characterized by wide individual differences, with JH showing much lower error scores than the other two subjects. With targets of maximum purity, error levels for the group of subjects on the first two runs showed a central tendency of approximately 40% for all background luminances. The targets of 70% purity were used only with the 10- and 20-ft-L backgrounds, and produced initial error levels of 45% and 60% respectively.

Practice through nine runs produced little improvement for targets of maximum purity on the 50-ft-L background, the terminal error level being approximately 30%. Practice through four runs produced somewhat more improvement for targets of maximum purity on the 10-ft-L background, the terminal error level being approximately 20%.

For comparison, it can be noted that in experiment 2, with target/background luminance ratios of 2/1, the condition of maximum purity in both components produced initial and final error scores of approximately 20% and 8% respectively.

In summary, it appears that performance deteriorates as the target/background luminance ratio drops below 2/1. The deterioration becomes marked as the ratio

goes below 1/1, especially if color induction is present, and in this region practice becomes correspondingly less helpful.

D. Delay Intervals

The effect of short interruptions of the experimental routine was pointed out in Experiment 2. In a number of cases opportunity was provided for checking the effect of intervals ranging from approximately 2 to 21 weeks. Comparative scores for these cases for targets of maximum purity against a white background, are listed below. The pre-delay scores are those which the subject attained on his last run under the specified conditions before delay. The delay interval is counted from the date of that score, but the subject may have had up to five days of further practice under other conditions.

Subjects ED, DM, LH, DG and BT constituted the original Category 3. Each returned for a recall test after summer vacation. Subject ED returned twice, once after 52 days and the second time after an additional interval of 90 days. The 52-day test provided the pre-delay score for the 90-day interval; this pre-delay score was unique, however, because it was obtained from a single isolated test, whereas all other pre-delay scores were obtained toward the end of a substantial block of testing. Data for the 142-day interval, during which only this one review occurred, are therefore shown for subject ED in parentheses.

<u>Subject</u>	<u>Pre-Delay Score (% errors)</u>	<u>Interval (days)</u>	<u>Post-Delay Score (% errors)</u>
FG	7	12	14
PL	11	19	0
FG	4	21	18
ED	0	52	18
ED	18	90	12
PL	0	121	6
DM	0	134	7
LH	0	142	28
(ED)	(0)	(142)	(12)
DG	0	145	7
BT	0	145	25

The scores reflect a good deal of variability, but indicate better performance on the average after extended delays than might have been predicted from the disruption caused by short delays during training, and suggest that an occasional review might suffice to insure retention.

E. Ambient Light

Conceivably, in the operational situation there may be a demand for the interpreter to carry on tasks involving reading and writing. The use of "normal" room lighting, however, raises new problems. Careful arrangement and shielding of light sources may avoid those problems arising from illuminance on the screen. A primary consideration, then, is the effect of the subject's state of visual adaptation.

In the exploratory work with ZC, limited tests were run with ambient light at a low "normal" room level. These data suggested that the resulting state of adaptation was somewhat unfavorable. A solution for the problem would be to keep ambient light down to a level just sufficient to permit the carrying on of tasks demanding slightly more than minimal acuity.

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A small study of the problem was accomplished with one subject, FG. Error scores were obtained on 0.50- and 0.06-in. circular targets at several combinations of target and background purity. The subject acted as her own control and was tested with standard illuminance of 0.2 ft-c on a surface near the eye position, and also with 2 ft-c.

The results indicated no significant differences in error assignable to ambient light within the limits tests.

F. Purples

Non-spectral hues (purples) were found to be of limited usefulness in the basic plan of the study, because aberration produced chromatic rings which afforded additional cues. An effort to solve this problem with lenses was unsuccessful.

A small-scale test was run in which purples with dominant wave-lengths of 500 m μ and 565 m μ , at approximately 90% purity, were presented in a set with blue and red. Accuracy of identification was 100%. Subjects said they were judging by color, not by aberration rings, but this could not be objectively demonstrated. Aside from the question of cues, it seems possible that one or two purples in addition to those tested could be added with appropriate training.

G. Reference Standard

In Experiment 2 it was noted that the subjects CD and JH had available a reference standard made up of 9 Munsell hue chips. These had been selected on the basis of visual comparison with the 9 hues of the basic set at 10 ft-L and maximum purity. Exact matches were impossible; the chips, therefore, were chosen to provide a parallel, but not an identical, sequence of stimuli.

These subjects, who had not participated in Experiment 1, were given their training routine in preparation for Experiment 2. It required 10 to 14 runs for a subject to attain the criterion of approximately 100% accuracy on two successive days, but CD and JH were given additional training runs for a total of 35. During this process, as well as in the experiment proper, CD and JH used the reference standard. They were instructed that the standard was to be used as an aid to, rather than a means of avoiding, learning.

The resultant learning curves were not noticeably different from those of the Experiment 1 subjects. Conflicting impressions were reported by the individuals. One subject thought the standard may have helped a little in the early stages of learning, but not after that. The other regarded it as more of a hindrance than a help at any stage.

DISCUSSION

The absolute identification of a stimulus involves a process different from that used in a comparison judgment of two stimuli. In comparing the two halves of a photometric field, for example, the eye functions as a null indicator, and is capable of relatively high precision; as an absolute indicator, it is known to be much less efficient. In the present study, identification of colors was found to be of limited accuracy as expected.

Inefficiency might manifest itself not only in low accuracy, but also in poor stability. Evidence for poor stability could take the form of liability to

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disturbance from other activities, and poor retention over intervals of disuse. Various observations in the present study were consistent with this characterization. In the experimental routine, it was found advisable to include a refresher run from time to time, and the data of Experiment 2 show a rise in errors after short delay intervals. When a distracting task was imposed, time for identification judgments showed a marked increase.

Though the project as a whole did not constitute a unified training study, the sum total of training was extensive for subject ZC, and substantial for most of the others. It was possible to conclude from the records that learning is a major factor in absolute judgments. Among the relevant cues were (1) the importance of training when a maximum set of stimuli was being initially sought; (2) the fact that ZC, with the most experience under a variety of conditions, got the best scores in Experiment 1; (3) the finding that conditions which proved difficult when first presented to a practised subject could be mastered with training; and (4) the experimenter's impression that performance tended to improve in all respects, including stability, with extended practice.

Whatever the neurological basis for it may be, the internal standard of reference is a helpful construct. For a comparison judgment, the standard of reference is external and independent of what happens in the organism. For an absolute judgment it is internal, and sophisticated subjects can observe the process of reestablishing the standard during the early trials of an experimental period. When two small stimulus sets are combined into a larger set, as they were in one of our tests, the temporary loss in accuracy can be thought of as resulting from a disturbance of the existing standard, and recovery as resulting from the establishing of a new standard. It would seem to follow that vagaries of judgment should be reduced if an external standard is provided. This did not happen in Experiment 2, where an external standard proved to be of little help either in preliminary training or in the experiment proper. In that instance, however, the Munsell chips were not much more than an analogue for the set of stimulus colors, and the results hardly justify a prediction for a standard well matched to the test stimuli.

The basic stimulus set was developed as a compromise when it became apparent that an exhaustive search for the maximum set would be too time consuming. The basic set at maximum purity on a white background could be learned in 10 to 14 runs. At this level of learning, conditions which tended to attenuate the colors resulted in poor scores, but it was found that subjects could learn to identify targets of purities as low as 50%, presented on colored backgrounds of purities as high as 50%, with only a moderate amount of additional practice. Learning could be pushed to still more difficult conditions, but at the cost of more extensive practice. Analysis of stimulus and response errors (Figure 5) and subjects' comments and reports suggests that the process of adjusting to the induction produced by colored backgrounds consists, in effect, of learning to attach the same set of responses to slightly different sets of colors.

The basic stimulus set contained nine hues plus white. These are comparable in number to the nine colors conservatively estimated given by Conover and Kraft (1958) as available for coding and the 10 hues indicated by Halsey and Chapanis (1951). Neither of these studies included relative luminance nor stimulus purity as an independently controlled color dimension; furthermore, neither considered the effect of extended practice.

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In the present study the three luminances in the range of 1 to 100 ft-L were identified with satisfactory accuracy. An easily discriminable step above 100 would come to several hundred ft-L; this would be undesirable both because of the adverse effect of glare on discrimination of stimuli at lower levels, and because of the difficulty of attaining such a luminance in an operational system.

Turning to the lower end of the luminance range, a limiting condition is the ratio of target to background luminance. Our 1-ft-L targets were twice the background luminance. In the exploratory phase of the study a target/luminance ratio of 1.5/1 was found to be more difficult than 2/1 with colored backgrounds, and in the later supplementary tests with 10-ft-L targets and varying backgrounds, reducing the ratio below 1/1 produced a rapid rise in errors. Assuming the barrier of background luminance, then, the target-luminance range could not readily be extended at either end, and the approximately equal confusion at 10 ft-L with 1 and 100 ft-L indicated that the 10-ft-L level made a reasonable division of the total range.

In testing the purity dimension, 70% was the highest level included, as more likely than maximum purity to be approached by an operational system. Only two steps of purity were found to be definitely usable. (Inclusion of maximum purity would, at a minimum, have required considerable additional training.)

Assuming these limits for number of luminance and purity steps, we can estimate a maximum stimulus set for a thoroughly trained subject under optimum conditions. The basic set provides 28 stimuli. It was found that, with the basic set at 70% purity, against a white background, four colors could be added at 30% purity for each of the three luminances. This gave 12 new stimuli, increasing the set to 40. (At low purity levels fewer hues can be used because confusions increase. It should also be mentioned that 30% purity is on the verge of confusion with white, and 50% is not sufficiently distinguishable from 70%. Forty per cent, which had not been included in our experimental designs, would probably be better than either.) In the test for size of stimulus set, six new hues were interspersed among the original nine, for a total of 15. If we add three purples, going one beyond the two actually tested, the figure becomes 18, and white makes 19. This compares with the 10 items (nine hues plus white) on which the basic set was built. We saw above that expansion of the basic set in the purity dimension gave an estimated total of 40 items. One way to predict the size of the maximum set is to increase 40 in the ratio of 19/10, which gives 76. But this estimate makes no allowance for new confusions which are likely to occur when new colors are added, therefore it should be considered an upper limit not likely to be attained. We have for comparison the finding of Hanes and Rhoades (1959) that 50 Munsell colors could be identified after five months of training. If we take this as a lower limit, a "best guess" would give us a figure between 50 and 76, perhaps 60, for the number of items in the maximum set that could be identified against a white background by thoroughly trained subjects under optimum conditions, assuming no more than three luminance and two purity steps, and an upper target-purity limit of 70%.

There remains the question of colored backgrounds. Assuming a background of a particular color at not over 50% purity, the estimate would not be radically changed, for the following reasons. Results of Experiment 2 showed that, after training to criterion with a white background, additional training would produce as good or nearly as good performance with a colored background. For example, for targets of 50% purity on a background of 50% purity, errors dropped to zero quite rapidly (see Figure 6, Graph D). The stimuli look different with a colored background, and slightly different selections of stimulus colors might be optimal for different backgrounds, but the results here reported suggest that the task is

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not much more difficult with a background of intermediate purity than with white. It seems probable that, if initial training had been with a colored background, additional training would have been required to bring performance with a white background up to criterion. In light of these considerations, it seems reasonable to infer that the maximum number would be not much smaller for backgrounds of purities up to 50% than for white. For use against interchangeable backgrounds of any color, since the stimuli look different on different backgrounds, a given stimulus set would undoubtedly require still further training, and the maximum number would probably be still smaller.

For an operational set, the practical size would depend in part on how much training could be given in the particular situation. Our original set of 28, about half of the hypothetical maximum, might be reasonable for target purities at 70%, colored backgrounds at not more than 50%, fairly extensive training, no excessive work load on the operator, and a small allowance for variability in the display system. Identifiability could probably be maximized by setting alternate hues in the spectral sequence at purities of 70% and 40%; adjacent hues would then be differentiated in purity also, and the size of the set would remain unchanged. The safety margin could be increased by reducing the set, by elimination either of alternate hues or the intermediate luminance level. Moving in the other direction, if it should be desirable to increase the size of the set, two purples at the three luminances, for a total of six new items, might be the least confusing addition. As a further step, scattered intermediate hues, with purities staggered so that adjacent hues were always differentiated in two respects, could be added.

Two hypothetical examples of the application of color coding to a distance scale are given below. It is assumed that information about the distance of objects in the field is provided by some appropriate sensor (e.g., radar). It is assumed, furthermore, that a color code will be learned most readily and used with the least chance of error if the colors progress in their spectral order along the coded dimension. The first example is based on two primaries, and the five code colors, at maximum purity, are from the basic stimulus set used in this study. The numerical values for the primaries specify proportional parts of unit luminance.

TWO PRIMARIES

Red, $x = 0.7095$, $y = 0.2905$
(Corning 2-78)

Green, $x = 0.2203$, $y = 0.7481$
(Wratten 74)

<u>Color</u>	<u>Point on Distance Dimension</u>	<u>Primary</u>	
		<u>Red</u>	<u>Green</u>
R	1	.99	.01
O	2	.71	.29
Y	3	.49	.51
GY	4	.30	.70
YG	5	.01	.99

Luminance could be used as a multiplication key in conjunction with five colors such as the above to code a considerable range of distances. For example, the colors at 1 ft-L might be used to code one-mile intervals within the first five miles, at 10 ft-L, five-mile intervals up to 25 miles, and at 100 ft-L, 25 mile intervals up to 125 miles.

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As a second example, a more extensive code might be based on three primaries. The colors here again are from our basic set, but at two levels of reduced purity.

THREE PRIMARIES

Red, x - 0.7095, y - 0.2905
(Corning 2-78)

Green, x - 0.1268, y - 0.7313
(Corning 4-105)

Blue, x - 0.1482, y - 0.0404
(Corning 5-60)

Color Purity			Point on Distance			Primary			Color Purity			Point on Distance			Primary		
Hue	(%)	Dimension	R	G	B	Hue	(%)	Dimension	R	G	B	Hue	(%)	Dimension	R	G	B
R	70	1	.76	.22	.02	G	70	11	.02	.98	--	G	30	12	.11	.87	.02
R	30	2	.47	.49	.04	G	30	12	.11	.87	.02	BG	70	13	--	.98	.02
O	70	3	.61	.38	.01	BG	70	13	--	.98	.02	BG	30	14	.10	.86	.04
O	30	4	.42	.54	.04	BG	30	14	.10	.86	.04	GB	70	15	--	.94	.06
Y	70	5	.44	.55	.01	GB	70	15	--	.94	.06	GB	30	16	.14	.80	.06
Y	30	6	.36	.61	.03	GB	30	16	.14	.80	.06	B	70	17	.20	.50	.30
GY	70	7	.31	.68	.01	B	70	17	.20	.50	.30	B	30	18	.26	.64	.10
GY	30	8	.29	.68	.03	B	30	18	.26	.64	.10	P	70	19	.61	.34	.05
YG	70	9	.16	.84	--	P	70	19	.61	.34	.05	P	30	20	.33	.64	.03
YG	30	10	.21	.76	.03												

With this set also the luminance levels could be used as a multiplication key. An alternative, if large range is not a primary goal, would be to include the luminance level steps in the coding continuum. One progression, for example, might be as follows:

- 1 R 70% 1 ft-L
- 2 R 70% 10 ft-L
- 3 R 70% 100 ft-L
- 4 R 30% 1 ft-L
- 5 R 30% 10 ft-L
- 6 R 30% 100 ft-L
- 7 O 70% 1 ft-L
- - - - -
- - - - -

Other problems can be illustrated with color coding for infra-red. A conceptually simple conversion from near infra-red (800-1400 m μ) to visible (400-700 m μ) radiation would be one involving a straightforward point-to-point relation. The relative distribution of energy in the infra-red from a target complex being scanned would be reproduced as a relative distribution of energy in the visible range. This might be accomplished, for example, by means of three selective sensors with sensitivities in the low, middle, and high regions of the infra-red spectrum. Each of these would control phosphors with maximum radiation in the corresponding regions of the visible spectrum, i.e., the phosphors chosen for the visual primaries. Practically, this system would be quite demanding in technique. Dominant wave-length (hue) is a complex non-linear function of relative energies from the chosen primaries, and at best the point-to-point transformation indicated above would imply a complex conversion from infra-red output to phosphor output.

Further problems arise when visual display factors are considered. Displays would presumably appear as complex schematic or pictorial representations, with

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juxtaposed and perhaps overlapping images of target objects. Color discrimination in the more common sense of simultaneous comparison would be available to the operator for target separation, but the absolute identification of colors would be affected adversely by induction and afterimages as the display was scanned.

Assuming that the above type of wave-length transformation could be satisfactorily accomplished, the resultant visual effect would not necessarily be adequate. If, for example, two types of target object had similar (but not identical) distributions of radiant energy, the visual separation of the display color symbols might not be sufficient for identification. In view of these considerations, a more efficient approach might be to empirically code critical objects and materials by absolutely identifiable colors. Then colors which were visually well separated could be assigned to objects which showed only small differences in energy distribution, if that arrangement proved advantageous.

To minimize the effects of induction and afterimages, marked disparities in luminance level between different elements of the display should be avoided. This would limit the use of luminance as a coding dimension. In the absence of luminance variation, the purity dimension would be helpful in increasing the number of colors in a set. A practical set, for example, might be the nine original hues used in this study, plus purple and white, at the maximum available purity (presumably in the neighborhood of 70%), plus five hues in alternate positions around the spectrum at the reduced purity of 40%, for a total of 16. To compensate for reduced purity, the luminance of the 40% elements might be made noticeably higher than that of the 70% elements, the luminance increment being adjusted to provide some enhancement of the low-purity elements, but not to contribute appreciably to the adverse effect of afterimages or induction.

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CONCLUSIONS

There are probably 50 to 70 colors varying in hue, purity, and luminance in the range between 2 and 200 times the background luminance, which can be identified absolutely with extensive training under laboratory conditions.

There are approximately 30 colors usable in an operational system, assuming moderate training and reasonably favorable working conditions.

Identification of 28 colors at maximum purity, varying in hue, and in luminance in the above range, against a white background, can be learned in 10 to 14 practice runs through the set.

Such factors as colored backgrounds and reduced target purity increase the difficulty of identification.

After targets at maximum purity against a white background have been learned, targets at no less than 50% purity combined with colored backgrounds of no more than 50% purity can be learned with a moderate amount of additional practice. More severe conditions require extensive training.

About 10 hues (with white) are likely to be usable in an operational set, 3 luminances, and 2 purity levels (other than zero purity), though only about half of the possible combinations can be safely used without excessive training.

Background purity interacts with target luminance, high purity producing increased errors at the lower luminances.

Colored targets at luminances below that of a colored background cannot be identified with satisfactory accuracy.

Target size in the range from 0.12 in. (21' of visual angle) to somewhere above 0.5 in. (5° 4') is not a significant factor, but a decrease in diameter of round targets from 0.12 in. (21') to 0.06 in. (10') impairs identification.

Conditions which appear to interfere with the subjective reference standard, such as distracting tasks, lapse of time, and increase in the number of items tested in a set, tend to impair color identification.

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BIBLIOGRAPHICAL REFERENCES

1. Baker, C.A., and W.F. Grether, Visual Presentation of Information, WADC Technical Report 54-160, Wright Air Development Division, Wright-Patterson Air Force Base, Ohio, August 1954.
2. Conover, D.W., The Amount of Information in the Absolute Judgment of Munsell Hues, WADC Technical Note 58-262, Wright Air Development Division, Wright-Patterson Air Force Base, Ohio, June 1959.
3. Conover, D.W., and C.L. Kraft, The Use of Color in Coding Displays, WADC Technical Report 55-471, Wright Air Development Division, Wright-Patterson Air Force Base, Ohio, October 1958.
4. Eriksen, C.W., Multidimensional Stimulus Differences and Accuracy of Discrimination, WADC Technical Report 54-165, Wright Air Development Division, Wright-Patterson Air Force Base, Ohio, June 1954.
5. Halsey, Rita M., and A. Chapanis, "On the Number of Absolutely Identifiable Spectral Hues," Journal of the Optical Society of America, Vol 41, p 1057, 1951.
6. Hanes, R.M., and M.V. Rhoades, "Color Identification as a Function of Extended Practice," Journal of the Optical Society of America, Vol 49, p 1060, 1959.

APPENDIX

TABLE 1

PER CENT ERRORS IN COLOR IDENTIFICATION FOR SUBJECT GROUP 1 (ZC), EXPERIMENT 1,
WITH THE BASIC STIMULUS SET OF 28 ITEMS

BACK- GROUND COLOR	B		A		C		K		G		R		O		U		N		D		P		U		R		I		T		Y		Max																							
	10	20	30	50	70	90	Max	10	20	30	50	70	90	Max	10	20	30	50	70	90	Max	10	20	30	50	70	90	Max	10	20	30	50		70	90	Max																				
Red	48	--	11	11	4	--	4	57	--	11	11	11	--	4	45	--	12	14	4	--	7	46	--	(33)	(11)	14	--	12	36	--	2	7	46	--	(33)	(11)	14	--	12																	
Green	36	--	2	7	4	--	4	46	--	14	4	2	--	0	45	--	36	14	4	--	7	45	--	(27)	(8)	14	--	5	36	--	2	7	45	--	(27)	(8)	14	--	5																	
Blue	34	--	2	5	0	--	0	30	--	2	2	2	--	0	43	--	14	4	4	--	0	61	--	(43)	(20)	11	--	12	39	--	7	8	2	--	2	45	--	11	5	5	--	1	44	--	10	11	4	--	5	51	--	35	13	14	--	10
Pooled Scores	39	--	7	8	2	--	2	45	--	11	5	5	--	1	44	--	10	11	4	--	5	51	--	(43)	(20)	11	--	12	39	--	7	8	2	--	2	45	--	11	5	5	--	1	44	--	10	11	4	--	5	51	--	35	13	14	--	10

BACK- GROUND COLOR	BKG. PURITY (%)	TARGET PURITY (%)
White	34	2(10)(8)

^a Unless otherwise indicated, scores are based on one presentation of the set; underlined scores are based on two presentations, scores in parentheses on three.

^b Maximum purities were the maximum available with the filters used. "90%" included green and g-blue at their maxima, 82 and 88% respectively.

TABLE 2

PER CENT ERRORS IN COLOR IDENTIFICATION FOR SUBJECT GROUP 2, EXPERIMENT 1,
WITH THE REDUCED STIMULUS SET OF 18 ITEMS

BACK- GROUND SUB- COLOR	SUBJECT	P U R I T Y (%)																																					
		25				50				75				Max																									
		TARGET	TARGET	TARGET	TARGET	TARGET	TARGET	TARGET	TARGET	TARGET	TARGET	TARGET	TARGET	TARGET	TARGET	TARGET	TARGET	TARGET	TARGET																				
		10	20	30	50	70	90	Max	10	20	30	50	70	90	Max	10	20	30	50	70	90	Max	10	20	30	50	70	90	Max										
Red	DL	44	31	17	14	6	17	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	
	GB	56	17	39	6	17	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39		
	FG	61	14	17	17	22	22	11	6	39	61	39	33	14	33	50	56	44	17	28	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33		
	PL	11	11	0	0	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11		
Pooled	Scores	54	19	24	10	12	39	29	18	16	17	70	40	22	24	28	64	35	28	25	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22		
Green	DL	44	11	33	11	0	50	22	33	28	14	50	50	22	39	22	50	28	50	56	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	
	GB	33	6	6	0	17	17	44	6	6	17	67	6	25	11	28	67	33	33	22	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	
	FG	33	17	11	22	17	17	11	6	6	11	50	17	28	17	28	44	44	6	28	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	
	PL	6	6	0	0	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	
Pooled	Scores	37	10	17	8	11	50	21	19	11	14	56	24	25	22	25	58	28	30	32	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	
Blue	DL	33	17	33	11	0	44	33	(19)	22	6	44	67	28	39	39	94	56	67	33	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
	GB	50	22	0	3	17	17	22	0	6	0	83	50	28	17	6	56	44	28	39	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22
	FG	44	6	6	11	6	6	17	11	6	11	72	44	28	44	44	44	39	39	50	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44
	PL	6	6	0	0	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	
Pooled	Scores	43	12	13	6	7	44	19	13	11	56	67	54	28	33	22	75	44	44	38	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	
All Scores	Pooled	44	15	18	8	11	44	23	17	13	12	64	39	25	26	25	66	36	34	31	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	

^a The basic set of 28 stimuli was used instead of the reduced set with subject GB for maximum target purity on a white background, and with subject PL for target purities 30 and 70% on red, green and blue backgrounds and for target purity 30 on white; with subject PL for target purity 70 on white, each of the two sets was presented once. Unless otherwise indicated, scores are based on one presentation of a set; underlined scores are based on two presentations, scores in parentheses on three, those marked with asterisks on four.

^b Maximum purities were the maximum available with the filters used. "90%" included green and g-blue at their maxima, 82 and 88%, respectively.

TABLE 3
PER CENT ERRORS IN COLOR IDENTIFICATION FOR SUBJECT GROUP 3, EXPERIMENT 1,
WITH THE BASIC STIMULUS SET OF 28 ITEMS

BACK- GROUND COLOR	P U R I T Y (%)														
	20							60 ^c							
	SUB- JECT		TARGET PURITY (%)					SUB- JECT		TARGET PURITY (%)					
Red	RT	10	20	30	50	70	90	Max	10	20	30	50	70	90	Max
	LH	21	11	7	7	4	29	7	54	21	11	11	11	0	21
	DG	21	11	7	4	4	29	7	50	21	11	11	11	0	21
	DM	36	11	0	11	11	11	7	39	5	11	11	11	0	11
	ED	36	4	0	7	7	7	7	68	39	4	4	4	11	11
Pooled Scores	36	21	7	8	0	6	11	75	37	43	33	34	23	26	
Green	RT	25	4	4	7	7	7	4	64	14	14	14	14	4	4
	LH	18	7	7	7	7	7	4	50	14	14	14	14	4	4
	DG	14	4	0	0	0	0	4	29	14	14	14	14	4	4
	DM	50	14	7	7	7	7	4	57	39	18	18	25	25	11
	ED	32	0	4	4	4	4	4	68	18	21	21	18	18	7
Pooled Scores	41	19	7	5	5	4	4	62	48	29	14	20	5	11	
Blue	RT	21	7	7	7	7	7	4	25	11	11	11	11	7	0
	LH	21	7	7	7	7	7	4	25	11	11	11	11	7	0
	DG	14	4	4	4	4	4	4	29	29	29	29	29	4	0
	DM	46	11	11	11	11	11	7	32	21	21	21	21	4	0
	ED	39	7	7	7	7	7	7	50	32	32	32	32	7	7
Pooled Scores	43	19	9	6	9	2	4	41	26	27	14	5	5	3	
All Scores Pooled	40	20	8	6	5	4	6	60	37	33	21	20	11	13	

SUB- JECT	BKG. PURITY (%)		SUB- JECT	BKG. PURITY (%)	
	20	60		20	60
RT	10	30	RT	10	30
LH	32	4	LH	32	4
DG	32	11	DG	21	0
DM	50	11	DM	50	11
ED	39	21	ED	39	21
Pooled Scores	45	29	Pooled Scores	45	29

^a Unless otherwise indicated, scores are based on one presentation of a set; underlined scores are based on two presentations.

^b Maximum purities were the maximum available with the filters used; "90%" included green and g-blue at their maxima, 82 and 88%, respectively.

^c Data for 60% red background lost thru error.

TABLE 4

PER CENT ERRORS IN COLOR IDENTIFICATION FOR FOUR TARGET SIZES, WITH THE
BASIC STIMULUS SET OF 28 ITEMS, EXPERIMENT 3

TARGET PURITY (%)	SUBJECT	T A R G E T S I Z E (i n .)												
		.06		.12		.50		2.00						
		Red	White	Red	White	Red	White	Red	White					
Max ^b	Pooled Scores	5	7	25	18	11	9	7	5	4	11	20	9	6
		<u>9</u>	<u>9</u>	<u>18</u>	<u>18</u>	<u>11</u>	<u>9</u>	<u>7</u>	<u>5</u>	<u>4</u>	<u>11</u>	<u>20</u>	<u>9</u>	<u>6</u>
70	Pooled Scores	14	14	20	14	11	9	2	2	7	5	4	14	6
		<u>12</u>	<u>10</u>	<u>14</u>	<u>14</u>	<u>11</u>	<u>9</u>	<u>2</u>	<u>2</u>	<u>7</u>	<u>5</u>	<u>4</u>	<u>14</u>	<u>10</u>
50	Pooled Scores	21	14	17	17	11	12	7	7	12	5	6	8	13
		<u>27</u>	<u>23</u>	<u>16</u>	<u>16</u>	<u>11</u>	<u>12</u>	<u>7</u>	<u>7</u>	<u>12</u>	<u>5</u>	<u>6</u>	<u>8</u>	<u>13</u>
Target Purities Pooled by	Target Sizes	24	19	22	22	9	5	7	7	18	11	(4)	17	10
		<u>15</u>	<u>14</u>	<u>20</u>	<u>20</u>	<u>8</u>	<u>9</u>	<u>5</u>	<u>5</u>	<u>4</u>	<u>12</u>	<u>7</u>	<u>4</u>	<u>10</u>
		16				7				8			11	

^a Underlined scores are based on two presentations of the set, scores in parentheses on three.

^b Maximum purities were the maximum available with the filters used.

TABLE 5
 TIME PER ITEM AND PER CENT ERRORS IN COLOR IDENTIFICATION FOR CONDITIONS
 OF DISTRACTION AND NO DISTRACTION, WITH THE BASIC STIMULUS SET OF 28 ITEMS,
 EXPERIMENT 4

TARGET PURITY (%)	SUB- JECT	PER CENT ERRORS						MEAN TIME PER ITEM (sec.)					
		Red			White			Red			White		
		B A C K G R O U N D P U R I T Y (%)	60	20	B A C K G R O U N D P U R I T Y (%)	60	20	B A C K G R O U N D P U R I T Y (%)	60	20	B A C K G R O U N D P U R I T Y (%)	60	20
		Dstr.	No	Dstr.	No	Dstr.	No	Dstr.	No	Dstr.	No	Dstr.	No
		Dstr.	Dstr.	Dstr.	Dstr.	Dstr.	Dstr.	Dstr.	Dstr.	Dstr.	Dstr.	Dstr.	Dstr.
Max ^b	DL	7	4	7	7	19 ^a	14	11.2	7.7	14.9	6.3	11.3 ^a	6.8
	JH	4	0	5	4	6*	0	13.0	7.4	13.3	9.0	15.5*	10.6
	Pooled Scores	5	2	6	5	10	7	Mean 12.0	7.5	14.1	7.6	13.4	8.7
	DL	21	11	14	11	14	7	13.9	8.0	10.4	11.0	13.8	9.1
50	JH	7	4	11	7	4	4	12.8	9.7	15.5	12.9	14.6	10.3
	Pooled Scores	14	7	12	9	9	5	Mean 13.4	8.9	13.0	11.9	14.2	9.7
	All Scores Pooled	9	4	8	7	10	6	Mean 12.7	8.2	13.5	9.8	13.8	9.2

^a Unless otherwise indicated, scores are based on one presentation of a set; underlined scores are based on two presentations, those marked with asterisks on four. Subject DL, with maximum targets on a white ground under distraction, had three presentations plus an incomplete set of 15 items.

^b Maximum purities were the maximum available with the filters used.

TABLE 6
 PER CENT ERRORS IN COLOR IDENTIFICATION FOR TWO TARGET SHAPES,
 WITH THE BASIC STIMULUS SET OF 28 ITEMS, EXPERIMENT 5

		T A R G E T S H A P E							
		Circle			Line				
BACK- GROUND COLOR	BACK- GROUND PURITY (%)	SUB- JECT	TARGET PURITY (%)	TARGET PURITY (%)	30	50	Max		
	60	CD	18	18	11	12	11	4	
		ZC	25	0	0	<u>9</u>	7	4	
		Pooled Scores		21	9	5	11	9	4
Red	20	CD	7	7	4	4	11	18	
		ZC	14	4	0	4	7	7	
		Pooled Scores		11	5	2	4	9	12
White	0	CD	14	4	7	7	4	4	
		ZC	21	14	0	7	7	4	
		Pooled Scores		18	9	4	7	5	4
		All Scores Pooled		17	7	4	8	8	7

a Unless otherwise indicated, scores are based on one presentation of the set; underlined scores are based on two presentations.

b Maximum purities were the maximum available with the filters used.