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(U) CAMOUFLAGE PATTERNS– EFFECTS OF SIZE & COLOR

by

Alvin O. Ramsley

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In the past, camouflage patterns have been designed subjectively by application of artistic principles and experience. Recently, analytical approaches have been attempted, based primarily on image analysis and pattern recognition theory. The purpose of this study was to investigate the applicability of recently available psychophysical data on the visual process to the design of camouflage patterns for personnel. The analysis deals with an effort to maximize camouflage effectiveness, considering mainly the variables of pattern size and color.

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(U) PREFACE (U)

Most countries on both sides of the Iron Curtain consider camouflage patterns as part of their military doctrine. Examination of these patterns strongly suggests that most of them were designed on a subjective basis. The influence of the artist is clearly in evidence. The only known exceptions are limited recent studies in Germany and Australia that have led to patterns that are based on more analytical procedures.

This report summarizes some in-house studies based on the literature that have attempted to provide guide lines in the design of camouflage patterns. The analysis applies known properties of the unaided eye to pattern design, particularly to the colors and sizes of the elements in a pattern.

I would like to thank Mr. Charles R. Williams, Chief, Textile Research and Engineering Division, for his encouragement to do the work and his helpful comments in preparation of the manuscript.

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CAMOUFLAGE PATTERNS - SOME FACTORS IN DESIGN (U)

1. (U) INTRODUCTION. (U)

In the hope of avoiding enemy observation, the armies of many countries use camouflage patterns to conceal tactical vehicles, weapons, shelters and personnel. This practice is based on the expectation that patterns achieve camouflage objectives more effectively than selected monotone shades by presenting an appearance more like the variability of nature. Patterns may be used as over-lying screens or applied directly to an object for concealment, or they may be used as disguise to make an object appear to be something other than what it really is.

Military doctrine on the use of camouflage patterns varies from country to country and sometimes even within the military forces of a given country. This is evident as one compares patterns from various sources. Some patterns are detailed, others "crude"; some large, others small; some use many colors, others few; and the influence of the artist is evident in most.

Paradoxical as it seems, a pattern is effective only if it can be seen. If it is obscured, the pattern itself does not contribute to camouflage effectiveness. If a pattern is too small for an observer to resolve into its component parts but blends into a single average color, the design of that pattern contributes nothing to effective camouflage. The real purpose of a pattern, therefore, is to maintain its visibility but at the same time minimize its noticeability in the terrains for which it is intended. Each area of a pattern should resemble a major terrain element and yet be as different as possible from other areas within the camouflage pattern. The pattern will then be similar to and be as visible as the terrain itself; yet the object being camouflaged will be difficult to detect, identify, recognize, and acquire as a target.

What are the variables in a camouflage pattern with which an investigator can deal? Although there are secondary or detailed factors, the most obvious are size, color, and shape. In all of these variables, it appears that most designs represent efforts to resemble the terrains in which they are to be used. In some patterns a second objective seems to be an effort to disrupt the outline and other regular features of the object to be camouflaged, as perceived by an observer. To accomplish these ends effectively, all three variables must be considered in the design of a pattern.

Apart from size, the shapes of pattern elements differ mostly in the degree of fidelity used in reproducing terrain elements. Most recent patterns, however, are impressionist representations of what an observer sees at some significant distance rather than faithful reproductions of terrain

Figure 1. Photograph of several camouflage patterns.

a. Upper left: Current standard US Army 1948 Camouflage Pattern, often referred to as the four-color or verdant pattern.
b. Upper center: British pattern being evaluated.
c. Upper right: Early US Marine Corps pattern, first used in a helmet cover, now obsolete.
d. Lower left: Experimental German pattern, not fully evaluated.
e. Lower center: Standard US Army Desert Pattern, being considered for adoption.
f. Lower right: Vietnam Tiger pattern, French design, used by some ARVN forces.

elements—more like a Renoir than a Rockwell. In Figure 1 we see illustrated one pattern (upper right) so detailed that rib structures show in what are surely intended to be oak leaves. Several impressionist designs are also illustrated; one characterized by long, narrow figures, high contrast and fine detail; and others by sweeping, convoluted shapes with less detail. The pattern in the lower left of Figure 1 is suggestive of a computer-generated design.

One effort has been made in Australia to synthesize optimum pattern designs by analytical, objective methods;[1] this study included consideration of size and color as well as shape. The result, as intended,

1. D. R. Skinner, A pseudo-random pattern generator for camouflage research, Report No. 599, Australian Defence Scientific Service, Materials Research Laboratories, Maribyrnong, Victoria, Australia, Nov 1974.

was a computer-generated pattern found to be effective at short observation ranges in a specific, heavily foliated terrain. The procedure was based essentially on texture analysis of photographic imagery of the specific terrain considered. Validation of the Australian pattern was made through a field test by comparisons of models of soldiers covered with monotone fabrics and a number of camouflage patterns that included the 1948 US Army four-color pattern. It is of interest to note that in the heavily foliated terrains in which the test was conducted and at ranges up to the maximum of 50 meters, the current version of the four-color pattern was more effective than all the others, except the specially designed Australian pattern. The pattern in the lower left of Figure 1 is one designed on analytical principles by the Federal Republic of Germany.[2] This is basically produced by printing circular spots, with some overlap, over a lighter ground shade. In all, five colors are used in this pattern. The detail is progressively lost as observation distances increases. At 75 to 100 meters one sees three areas; dark, medium, and light. At longer ranges the pattern begins to blend into a solid color, somewhat more brown than the US pattern and many others.

Recently, a concept of camouflage pattern design has been developed at the US Military Academy. Based on the psychological research, the concept has been developed into camouflage patterns that have come to be called "Dual-Tex" patterns.[3] Following a limited demonstration of the concept, a small-scale field trial was conducted with armored vehicles. Comparison of one Dual-Tex pattern was made with the Standard US Army Pattern in a variety of situations. Although the scale of the test was small, the performance of the specific Dual-Tex pattern at that test site was impressive.[4]

Possibly of more importance than the specific shape is the size of a pattern's various elements, because the size of pattern elements largely determines the distance beyond which an observer can no longer resolve the elements. It is obvious that the larger an object is (for a given contrast), the further it can be seen. So it is with a camouflage pattern. Thus, one can expect a small pattern to be effective only at short observation ranges and larger patterns to be more effective at longer ranges. It also follows that at short ranges a large pattern may be too conspicuous and less effective than a properly designed small pattern. Military establishments in some countries emphasize effectiveness at short observation ranges; others favor long range effectiveness, even to the extent of using monotone coloration. Current US military doctrine appears to favor as wide a range of effectiveness as possible for camouflage of personnel.

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2. Ermittlung der Tarnwirksamkeit von Kamfanzugen mit verbesserten Fleckenmustern, Bundesamt fur Wehrtechnik and Beschaffung, 23 Sep 1975.

3. T. R. O'Neill, Dual-Tex 2: Field Evaluation of Dual-Tex Gradient Pattern, USMA, West Point, N.Y., July 1977.

4. U.S. Army Combat Developments Experimentation Command and BDM Scientific Support Laboratory, Dual-Textured Gradient Camouflage Paint Pattern, Report No. CDEC FR-78-002, Nov 1978.

The third factor, color, is closely related to the size of the elements. In most camouflage patterns we recognize colors that are similar to those seen in natural terrains for which the designs are intended. The intent in choosing individual colors for camouflage patterns is to minimize overall contrast with a variable terrain background. Within that constraint, however, colors within the pattern should be as different as possible from each other in order for the pattern to be visible at as long a range as possible. The purpose of this report is to discuss two of several factors in visual observation that have an influence on the design of camouflage patterns. These factors are the size and color of the areas in a camouflage pattern and how induced monochromacy caused by small fields limits the effectiveness of a pattern and influences its design.

Some of the other factors that are not considered here are vibration (such as would result from an observer riding in a vehicle), the atmospheric effects of scattering and absorption, and fixation time while scanning a visual field. All of these factors will degrade an observer's performance. To illustrate the factor of fixation time, consider an observer viewing a sector, looking for enemy intrusion. His eyes move rapidly in discrete jumps (saccades) and pause briefly (perhaps one second) before moving on. As one would expect, it has been determined experimentally that for high efficiency, the eye needs a certain time to react to a stimulus. Analysis of some of Blackwell's data lead to the conclusion that to be detected an object must be twice as "conspicuous" in a 0.1 second fixation as in a one-second fixation. That is, the contrast threshold is twice as high.[5,6] Some visual aids sometimes help an observer. Binoculars enhance an observer's ability to perform certain visual tasks under some conditions but not under others. This factor will not, however, be considered in this report.

2. (U) Structure of the Retina. (U)

A few features of the retinal structure have very significant effects on vision as it pertains to the following discussion of camouflage pattern design. Figure 2 is a retinogram of a normal 18-year old person. The dark, circular region near the center of the photograph is called the macula lutea and lies in the optical axis during fixation (i.e., when a person stares at a point). The diameter of the macula is about one millimeter and corresponds to a

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5. H. R. Blackwell, Contrast Thresholds of the Human Eye, J. Opt. Soc. Amer., 36, 624-643 (1946). This is a summary of NDRC Committee Report, Visibility Studies and Some Applications in the Field of Camouflage, Summary Technical Report of Division 16, National Defense Research Committee, Washington, 1946.

6. H. R. Blackwell and D. W. McCready, Foveal Contrast Thresholds for Various Durations of Single Pulses, Univ. of Michigan Report 2455-13-F June 1958.

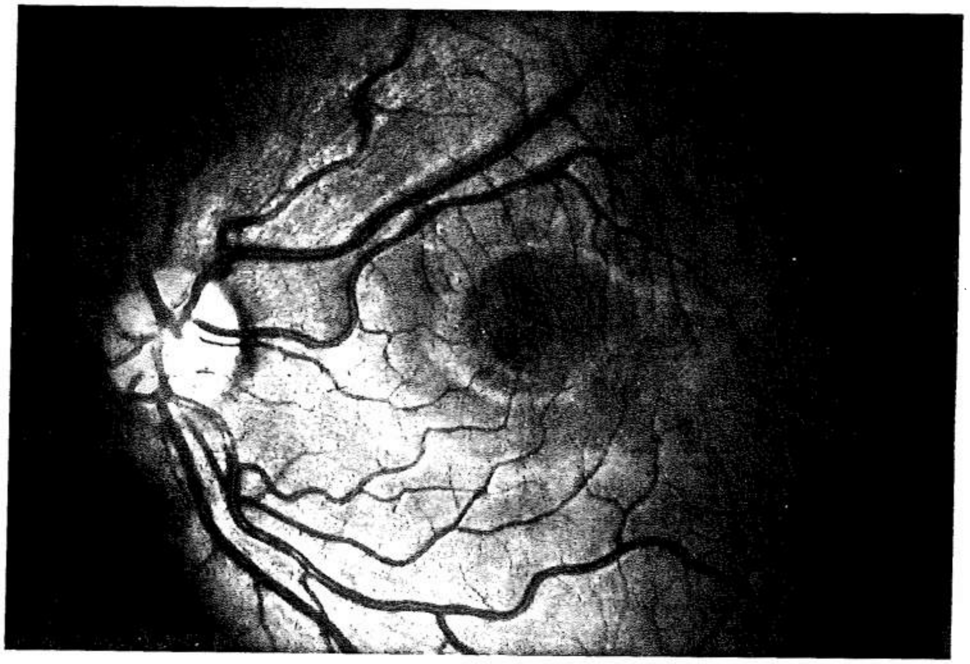

Figure 2. Normal retina. The darker area near the center is the <u>macula lutea</u>, the center of which is the <u>fovea centralis</u>.

field of view of 1.4 degrees (about 25 milliradians).

> In this area we have our keenest daylight vision, both in recognition of fine detail and the discrimination of differences in color.[7]

The bright area near the edge of the image in Figure 2 is where the optic nerve passes through the retina and is about one mm in diameter. This region contains no photo-sensitive cells and accounts for the "blind spot" found in the normal retina.

It is well known that the retina contains two types of photo-sensitive cells, rods, and cones. Because rods are much more sensitive than cones, their principal functin is to provide for night vision at light levels below threshold for the cones. Rods are primarily located in the extra-foveal areas and are virtually excluded from the fovea, which accounts for the superiority of off-axis vision at night. The <u>fovea centralis</u>, on the other hand, consists almost entirely of cones.

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7. The Science of Color, Committee on Colorimetry of the Optical Society of America, Thomas Y. Crowell, NY 1953, page 84.

> Upon the properties of this single square millimeter (the rod-free region) of the retina with its more than 50,000 cones is built the measurement of color.[8]

It is also well known that cones are of three varieties; blue-, red-, and green-sensitive. Signals from the three cells interact in some way that the brain interprets as color as well as shape. To perform their functions properly, several of each kind of cone must lie within a retinal image of an object that subtends a field of view of one milliradian (mr) square (1 degree = 17.5 mr). We shall examine later the efficiency of the eye as the retinal image becomes smaller.

3. (C) <u>Effect of Target Size on Perceived Color</u> (U)

(U) It has long been known that color mixture functions depend on the size of the retinal image. In 1964, the Commission Internationale de l'Eclairage (CIE) adopted such data for a ten-degree field to supplement those adopted in 1931 for a two-degree field. Blackwell[5] and others have quantified the effects for achromatic targets with angular subtense less than two degrees. The effects of small angular subtense on discrimination of chromaticity differences have been discussed by Middleton and Holmes[9], by MacAdam[10], by Pokorny, Smith, and Starr,[11,12] and others. In this report, the data reported by Judd and Yonemura will be used, since the data are in a convenient form and consider the combined effects of both lightness and chromaticity differences.[13]

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8. D. B. Judd and G. Wyszecki, Color in Business, Science and Industry, 3rd Ed., Wiley, NY, 1975, p. 11.

9. W. E. K. Middleton and M. C. Holmes, The Apparent Colors of Surfaces of Small Subtense - A Preliminary Report, J. Opt. Soc. Amer. 39, 582-92 (1949).

10. D. L. MacAdam, Small Field Chromaticity Discrimination, J. Opt. Soc. Am. 49 1143-1146 (1959).

11. J. Pokorny and V. C. Smith, Effect of Field Size on Red-Green Color Mixture Functions, J. Opt. Soc. Am., 66, 705-708 (1975).

12. J. Pokorny and V. C. Smith and S. J. Starr, Variability of Color Mixture Data-II. The Effect of Viewing Field Size on the Unit Coordinates, Vistion Res. 16, 1095-1098 (1976).

13. D. B. Judd and G. T. Yonemura, Target Conspicuity and its Dependence on Color and Angular Subtense for Gray and Foliage Green Surrounds, NBS Report 10120, Nov 1969.

These studies were efforts to quantify effects long known qualitatively, i.e., that as target sizes become smaller an observer's ability to discriminate yellow-blue, red-green, and dark-light differences degrades accordingly. The customary method of describing differences in color is to use color difference equations based on one of the many approximations to uniform color scales.[14] Judd used the 1964 $U^* V^* W^*$ color space and extended the equation to accommodate factors that take account of target size. Color difference, $\Delta E'$, then was defined as

$$\Delta E' = [(Ku \Delta U^*)^2 + (Kv \Delta V^*)^2 + (Kw \Delta W^*)^2]^{\frac{1}{2}} \qquad (1)$$

where Ku is the red-green weighting factor

Kv is the yellow-blue weighting factor

Kw is the light-dark weighting factor

The weighting factors are functions of angular subtense and, hence, of observation range in the context considered here. Figure 3 is Judd's Figure 4, (of Reference 13) redrawn to express angular subtense in milliradians. This figure can be used to determine the values of the weighting factors for Equation (1) for a given angular subtense. Values of ΔU^*, ΔV^*, and ΔW^* are determined from spectrophotometric data based on the CIE 1931 Standard Observer and a standard light source, Source C, for both Judd and Yonemura's paper (reference 13) and in this report. These factors may be used in evaluating the colors that have been selected for existing patterns and for estimating the maximum range at which two colored areas of a pattern of comparable size can be distinguished. They can also be used to guide in the selection of colors and choice of pattern sizes in the design of new or revised camouflage patterns.

a. (C) Four-color Camouflage Pattern. (U)

(U) To illustrate the principles, let us consider the standard 1948 US Army four-color camouflage pattern currently used in the tropical combat uniform (see upper left panel in Figure 1). This predominantly green pattern consists of a very small black area, a larger dark brown area, and two green areas, one dark and rather saturated, the other lighter and nearly neutral. The shapes and sizes of the colored areas vary considerably. A reasonable estimate of the average critical (longest) dimension, howevever, is 20 cm, the value used in this analysis for the four-color pattern. Table 1 gives the tristimulus values (Source C and the 1931, 2-degree Standard Observer) for the dark green, the light green, and the brown areas, omitting the black.

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14. D. B. Judd and G. Wyszecki, Opt. Cit., p. 324.

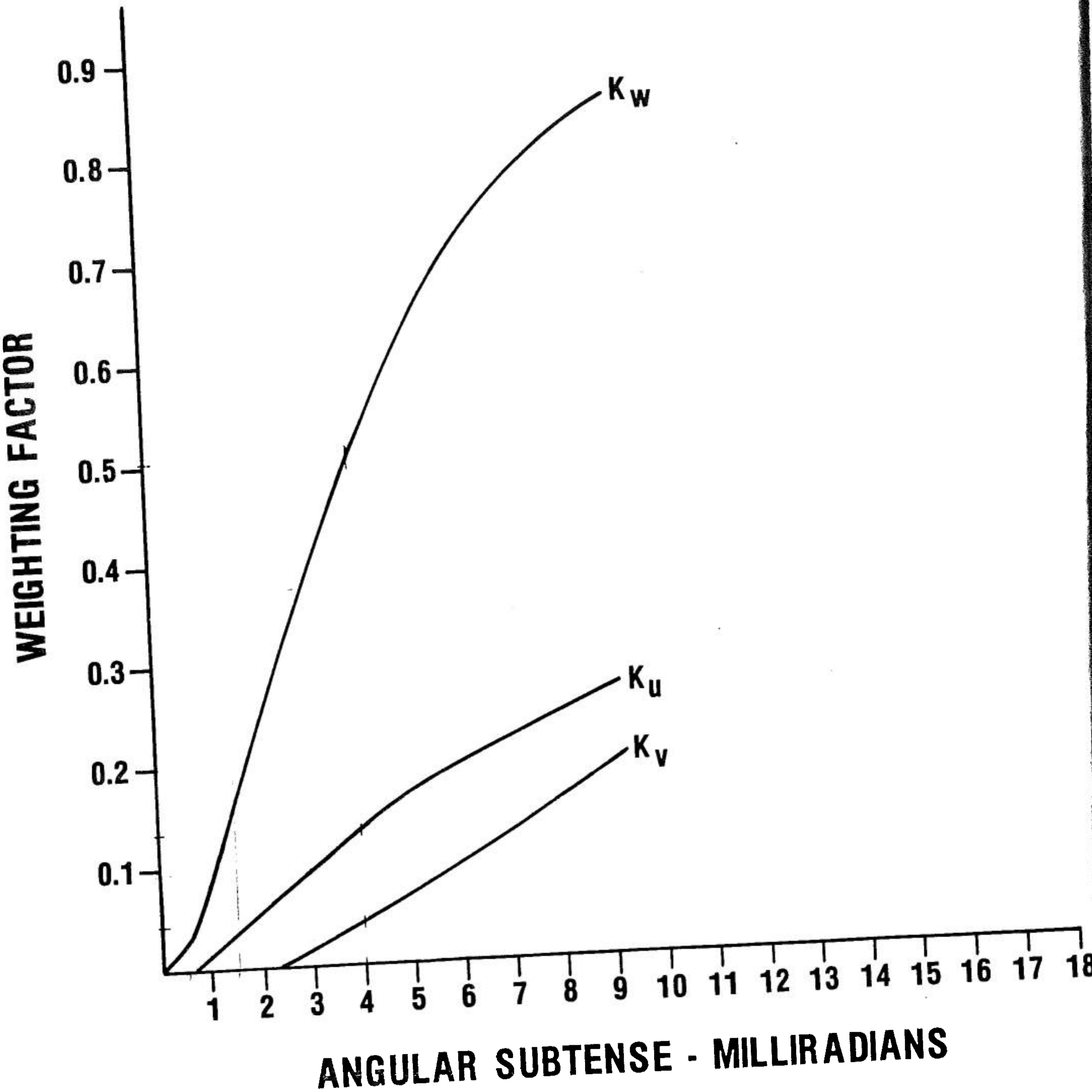

Figure 3. Weighting factors applied to 1964 W^*, U^*, V^* color difference formula.

Table 1 also presents the same type of data for the light and dark brown areas and the desert sand and khaki areas of an experimental desert camouflage pattern. (This pattern will be considered in Section 4.b.).

(U) Because it most closely resembles the monotone camouflage color, Olive Green 107, ($x = 0.3398$, $y = 0.3693$, $Y = 8.39$) let us also consider the dark green area of the pattern as the reference area. We can then calculate color differences of the light green and brown areas from the dark green reference area as functions of observation range, shown in Table 2. The short range (5.7-m) corresponds to a 2-degree (35-mr) subtense. Color differences at that range are those calculated without modifying the color difference equations.

Table 1. Tristimulus Values and Chromaticity Coordinates for Elements of Two Camouflage Patterns. (U)

	X	Y	Z	x	y
Standard Four-color Camouflage Pattern					
Dark Green	6.70	7.85	6.37	0.3204	0.3751
Light Green	12.19	13.21	9.41	.3502	.3795
Brown	5.84	5.86	4.70	.3560	.3575
Black	3.52	3.61	3.70	.3249	.3337
Experimental Six-color Desert Pattern					
Dark Brown	10.91	8.74	7.11	0.4077	0.3266
Light Brown	13.16	11.94	8.08	.3966	.3598
Khaki	25.28	25.49	20.89	.3528	.3557
Desert Tan	31.03	30.37	26.03	.3549	.3474

Note: The two small areas of the six-color patterns are not includdd because they are too small to be measured accurately.

(U) Table 2 presents the calculations of the color differences (ΔE) perceived as the 20-cm targets (brown and light green, as compared with the dark green) are viewed at ranges up to 300 meters. The table also includes the corresponding angular subtense and weighting factors derived from Figure 4. It is seen that the color difference values drop sharply at ranges even less than 100 meters. The value of the weighting factor, Kv, is zero at 100 meters and beyond, which signifies total loss of the ability to discriminate colors along the yellow-blue axis of the chromaticity plane. This is characteristic of one form of color blindness called tritanopia. Thus, by reducing the target size to 2 mr or less, tritanopia can be induced in normal observers.

(U) To understand the significance of the color differences shown in Tables 2 and 3, one needs to know the effective magnitude of one unit. The equations that define one unit in U^*, V^*, W^* color space have been adjusted so that one unit corresponds to a difference in color that is often acceptable in commercial practice. Colors that differ from a standard by less than one unit are often called "commercial matches", and are considerably larger than barely perceptible. Under ideal lighting and viewing conditions such as one would find in the laboratory, differences of about 0.2 would be considered "just noticeable" by most normal observers. Taking account of factors such as search time, atmospheric absorption and scattering, obscuration, vibration, terrain clutter, and the distractions of combat, a conservative estimate of the magnitude of a "significant" color difference in a combat environment can hardly be less than one unit.

(U) From Figure 3 it is seen that Ku also approaches zero at subtense angles of one milliradian. From the work of Judd and Yonamura,[13] therefore, we may conclude that observers with normal color vision acquire the properties of monochromacy when targets are less than one milliradian in subtense; that is: only differences in lightness can be perceived. The camouflage implications are, obviously, that patterns must not be too small if effectiveness is sought at longer ranges.

(U) Table 2. Color Differences as a Function of Observation Range for the 1948 US Army Four-color Pattern (U)

Range (m)	angle (mr)	Ku	Kv	Kw	ΔE
	Brown vs Dark Green				
300	0.67	0.006	0.000	0.048	0.2
200	1.00	.015	.000	.095	0.5
100	2.00	.060	.000	.240	1.2
50	4.00	.135	.045	.500	2.5
5.7	35.00	1.000	1.000	1.000	13.4
	Light Green vs Dark Green				
300	0.67	0.006	0.000	0.048	0.4
200	1.00	.015	.000	.095	0.9
100	2.00	.060	.000	.240	2.3
50	4.00	.135	.045	.500	4.7
5.7	35.00	1.000	1.000	1.000	11.0

(U) b. Six-color Experimental Desert Camouflage Pattern. (U)

(U) Table 3 gives similar data for the current version of the experimental 6-color desert pattern which is also shown in Figure 1. Because two of the areas are only one to two centimeters in size, only the four major areas of this pattern are considered. As Figure 1 shows, the four major areas of this pattern are larger than those in the 4-color pattern discussed above, and therefore a 30-cm critical dimension is assumed.

(~~C~~ U) Table 3. Color Differences as a Function of Observation Range for Four Colors of the Experimental Six-color Desert Camouflage Pattern (U)

Range (m)	angle (mr)	Ku	Kv	Kw	ΔE′
		Dark Brown vs Light Brown			
300	1.0	0.015	0.000	0.095	0.5
200	1.5	.035	.000	.160	0.9
100	3.0	.100	.002	.375	2.2
50	6.0	.195	.100	.700	4.2
8.5	35.0	1.000	1.000	1.000	11.4
		Khaki vs Desert Tan			
300	1.0	0.015	0.000	0.095	0.4
200	1.5	.035	.000	.160	0.7
100	3.0	.100	.002	.375	1.8
50	6.0	.195	.100	.700	3.1
8.5	35.0	1.000	1.000	1.000	6.5
		Dark Brown vs Desert Tan			
300	1.0	0.015	0.000	0.095	0.4
200	1.5	.035	.000	.160	0.7
100	3.0	.100	.002	.375	1.8
50	6.0	.195	.100	.700	3.1
8.5	35.0	1.000	1.000	1.000	6.5
		Dark Brown vs Desert Tan			
300	1.0	0.015	0.000	0.095	2.5
200	1.5	.035	.000	.160	4.3
100	3.0	.100	.002	.375	10.0
50	6.0	.195	.100	.700	18.7
8.5	35.0	1.000	1.000	1.000	30.9

(~~C~~ U) The data presented in Table 2 show that differences in chromaticity play a negligible role in the effectiveness of the 4-color pattern at observation ranges beyond 100 meters. At that range the pattern has merged into a 2-color (dark-light) pattern, as intended by the designer.[15]

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15. John H. Hopkins, private communication. At the time Mr. Hopkins designed both patterns (1948 and 1960) the quantitative data upon which this report is based were not available. As indicated to the writer, both patterns were designed to present two textures, one as seen at short range, the other at longer ranges.

As the observation range increases to 200 meters, the 2-color pattern is on the verge of blending into a monotone color. One can conclude on the basis of the above data that the 4-color pattern, as it is now constituted, loses its effectiveness as a pattern at observation ranges beyond 200 meters.

U (~~C~~) Tables 2 and 3 show, as expected, that the larger 6-color desert pattern is distinguishable as a pattern at longer observation ranges than the smaller 4-color pattern. By the assumed one-unit criterion, it holds as a 4-color pattern to over 100 meters and is effective as a 2-color, light-dark pattern at least to 300 meters.

4. U (~~C~~) <u>Optimization of Design</u>. (U)

(U) An ideal camouflage pattern is one that is effective from as short a range as possible to the limit of practical observation. The limits for a personal camouflage pattern used in this report are 50 to 300 meters. The logical approach to an ideal camouflage pattern is first to design a pattern that maximizes the range of effectiveness, one in which a two-color, light-dark pattern displays color differences over one unit at an observation range of 300 m. It would be expected that such a pattern would be rather conspicuous and ineffective at shorter ranges. The second step would require modification of the "long range" pattern to increase its effectiveness at ranges as short as 50 meters, while maintaining its effectiveness at longer ranges. Since this report does not consider the shape of individual areas of a camouflage pattern, the following considers how the effectiveness of a pattern can be improved by changing only the size and colors of a pattern.

a. U (~~C~~) <u>Size</u>. (U)

U (~~C~~) Table 4 shows the effect of increasing the dimensions of the 4-color pattern with no change in the colors. It can be seen that doubling the size of the 4-color pattern increases the range at which the brown and dark green areas can be distinguished from 100 to 200 meters. At the same time, the dark and light green areas are distinguished at 300 meters. Thus, by doubling the size alone, the maximum range at which the 4-color pattern operates as a 3-color Pattern (neglecting the black areas) has been doubled. As a 2-color, dark-light pattern, the same doubling effect is observed. Because we have neglected the atmospheric scattering, we can not quite generalize that doubling the size of a pattern will double the maximum observation range at which a pattern is effective. For large objects such as shelters, viewed at two or three kilometers, such a generalization clearly would not hold.

U (~~C~~) Although enlarging the pattern still further could be considered for the camouflage of larger objects in the field, realistic camouflage patterns for personnel are limited in size of the soldier himself and for his clothing by the manufacturing process that is used. Both his shirt and trousers are made by sewing panels together that are limited in size; moreover, pockets are sewn on the garments from rather small pieces. To have the various panels and pieces sewn together to match the patterns, as in hanging wall paper, is probably an impossibly expensive task for clothing manufacture.

U (~~C~~) Table 4. Effect of Pattern Size on Perceived Color Differences (ΔE) of Areas of the Four-color Pattern as a Function of Observation Range. (U)

Range (m)	Standard Size*	Enlarged 1.6	Double Size
	Brown vs Dark Green		
300	0.23	0.48	0.65
200	0.46	0.85	1.15
100	1.15	2.00	2.56
5.7	13.38	13.38	13.38
	Light Green vs Dark Green		
300	0.45	0.94	1.27
200	0.88	1.65	2.24
100	2.24	3.78	4.77
5.7	10.58	10.58	10.58

*Critical dimension taken to be 20 cm.

b. U (~~C~~) Color (U)

U (~~C~~) From the foregoing it is obvious that the greatest benefit that can be achieved by changing the colors is by increasing lightness differences consistent with terrain colors to the maximum extent possible. Calculations have been made on several combinations of colors in which only lightness was changed. Making the Dark Green a bit darker and the Brown a bit lighter augments differences as seen at 100 meters but does little over all for ranges of 200 and 300 meters. Of several combinations tried for maximizing effectiveness at long ranges, the best is given by the color specifications shown in Table 5.

U (~~C~~) Table 5. Tristimulus Values and Coordinates for an Optimized Verdant Pattern (U)

	X	Y	Z	x	y
Dark Green	5.12	6.00	4.87	0.3202	0.3752
Brown	8.97	9.00	7.22	.3561	.3573
Light Green	16.60	18.00	12.83	.3500	.3795

Calculations of color difference as seen close at hand and at ranges up to 300 meters are shown in Table 6 for the colors of Table 5.

(U) Table 6. Effect of Pattern Size on Perceived Color Difference (ΔE) of Areas of a Modified Four-Color Pattern (see Table 5) as a Function of Observation Range. (U)

Range (m)	Standard size	Enlarged 1.6 times	Double Size
	Brown vs Dark Green		
300	0.27	0.59	0.92
200	0.64	1.23	1.65
100	1.65	2.77	3.48
50	3.48	5.10	5.78
5.7	12.38	12.38	12.38
	Brown vs Light Green		
300	0.54	1.22	1.83
200	1.15	2.44	3.26
100	3.26	5.43	6.85
50	6.85	9.79	11.02
5.7	14.46	14.46	14.46
	Dark Green vs Light Green		
300	0.80	1.81	2.71
200	1.71	3.62	4.82
100	4.82	8.04	10.06
50	10.06	14.49	16.31
5.7	21.09	21.09	21.09

It is likely that enlarging the pattern will compromise its effectiveness at shorter ranges. Some of the areas will appear unnaturally large in certain terrains when observed at 50 or 100 meters. The second step, therefore, is to modify the larger areas by inserting small areas of different colors to improve short-range effects. As an example of one such modification, we can replace 20 per cent of each of the three major areas with ten per cent of each of the other two colors. The size of these areas should be such that they can contribute effectiveness at shorter ranges; perhaps about five cm in major dimension. These smaller areas can be expected to blend with the larger areas at ranges beyond 50 meters to produce a color perceived as monotone. As shown in Table 7 these colors will be somewhat different from the original colors.

(U) Table 7. Colors of a Four-Color Pattern Modified by Adding Ten Percent of Each of the Three Major Colors into Each of the Other Two (from data of Table V) (U)

	X	Y	Z	x	y
Dark Green	6.65	7.50	5.90	0.3317	0.3741
Brown	9.35	9.60	7.55	.3528	.3623
Light Green	14.69	15.90	11.47	.3493	.3780

Color differences perceived as a function of observation range for the colors of the modified four-color pattern (Table 7) are given in Table 8.

(U) Table 8. Effect of Pattern Size on Perceived Color Difference (ΔE) of Areas of a Four-Color Pattern Optimized as in Table 7 as a Function of Observation Range. (U)

Range (m)	Standard Size	Enlarged 1.6	Double Size
	Brown vs Dark Green		
300	0.17	0.38	0.57
200	0.36	0.76	1.02
100	1.02	1.68	2.19
50	2.13	3.07	3.47
5.7	5.04	5.04	5.04
	Brown vs Light Green		
300	0.39	0.88	1.32
200	0.83	1.76	2.34
100	2.34	3.91	4.89
50	4.89	7.06	7.97
5.7	11.50	11.50	11.50
	Dark Green vs Light Green		
300	0.56	1.25	1.88
200	1.18	2.51	3.34
100	3.34	5.60	6.97
50	6.97	10.05	11.32
5.7	15.03	15.03	15.03

The foregoing has been an attempt to illustrate certain concepts that should be taken into account when designing camouflage patterns. Some of the parameters in the analysis have been based on simplified estimates, e.g., the dimensions of the four-and six-color patterns. If these dimensions have been over-estimated, then the color differences shown in the tables should be smaller at the given ranges.

5. U (~~C~~) Conclusions (U)

Although there are uncertainties in the quantitative aspects, some practical conclusions can be drawn from the analysis.

U (~~C~~) a. To attain effectiveness in a pattern at both short and long ranges, one needs a pattern as large as practical. A small pattern should then be inserted into the larger pattern to provide camouflage effectiveness at short ranges. This is the essence of the duality of texture seen in many patterns.

U (~~C~~) b. The colors of the various areas in a pattern must be as different as possible from each other in order to maximize the range of effectiveness. The major factor in these color differences should be in lightness. One must obviously not overdo these differences but select colors from among those found in the terrain for which the pattern is intended.

(U) c. If camouflage effectiveness at long range were the only objective, one might infer that strict color control of the various areas is unimportant. This is not so, because effectiveness at shorter ranges is also a goal. Where terrain conditions permit, effectiveness of a properly designed pattern might be expected at ranges as short as 25 meters. At such distances chromaticity is a factor in concealment and a reasonable level of control is, therefore, required.

(U) d. Esthetic factors having nothing to do with combat also play a role. The procurement process assures that trousers and coats would almost never be made of the same lot of dyed fabrics. To avoid a gross mismatch, color control must be kept as tight as is commercially practical.

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