Significant Visual Properties of Some Fluorescent Pigments

D. R. HANSON and A. D. DICKSON
Minnesota Mining & Manufacturing Company, St. Paul

High object visibility is a necessary characteristic of traffic control devices and a significant factor in highway safety. Fluorescent pigments possess unique physical properties that provide high visibility characteristics not provided by conventional pigments. As a result, fluorescent colors are now used for safety markings and to a limited extent in the traffic field. This study compares the daylight visibility properties of fluorescent and conventional pigments.

Fluorescent and conventional pigments have substantially different spectral energy radiation patterns. Fluorescent pigments absorb energy from the near visible ultraviolet blue and green region of the electromagnetic spectrum and reemit this energy in a very narrow band of the spectrum. Conventional pigments simply absorb and reflect incident light. The properties of a selected group of fluorescent and conventional pigments are shown, as well as the spectral response of the human eye and various source illumination distributions.

The field study considered variations of daylight energy distribution under clear and overcast sky conditions, representative solar altitudes, and the cardinal directions. Two fluorescent and four conventional high visibility pigments were viewed against representative backgrounds. Detection and identification of fluorescent pigments are comparable to conventional high visibility pigments under optimum viewing conditions; however, fluorescent pigments show a substantial improvement as illumination levels decrease or when the target situation is least advantageous.

•NUMEROUS STUDIES by Armed Forces research groups and others have established that, under natural illumination, objects marked with fluorescent pigments have greater average conspicuity than those marked with conventional pigments. Some of this research has been directed toward specific applied sitations, such as aircraft and life raft detectability (1, 2, 3, 4, 5), whereas Blackwell (6), Siegel and Crain (7, 8, 9), Cowling and Noonan (10), and Kazenas (11) have conducted work of a more basic nature. It is not within the scope of this paper to report the specific findings of all these research efforts.

The literature cited suggests that additional efforts be made to measure the improved visibility that arises from the unusual properties of fluorescent pigments. Improved visibility appears to depend on certain daylight illumination conditions and surround. Therefore, studies were conducted to determine visibility differences under conditions representative of the traffic environment.

The theory of visibility of achromatic targets and backgrounds does not adequately explain the established conspicuity of fluorescent targets. In his study of the effect of

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color on target detectability, Blackwell (6) found that an empirical conspicuity factor was required to obtain agreement between predicted and observed target visibility. He states: "there is clear evidence that the chromatic samples are more visible than we would expect on the basis of reflectance alone." Middleton (12), however, concludes that because with increasing distance objects tend to become achromatic, "no special theory of the visual range of colored objects is necessary, and that colored marks will behave in the same way at the visual range as gray ones of the same luminance factor." Siegel and Lanterman (13) contend there is no clear theoretical indication that greater detectability can be expected from fluorescent paints. Judd and Wyszecky (14) point out that with targets of identical dominant wavelength and luminance factor, those of the greatest purity will appear brightest. These several views indicate recognition of an inherent dichotomy in the visual properties of fluorescent and conventional pigments.

This paper compares the properties of fluorescent and conventional pigments and presents results of field studies conducted to determine the magnitude of visibility differences existing between the two types of pigments.

ANALYSIS OF MATERIALS AND CONDITIONS

Six targets were selected for study. Four are commonly used high visibility conventional pigments, red, yellow, white, and international orange; two are fluorescent pigments, red-orange and yellow-orange. The colorimetric characteristics of the pigments are given in Table 1.

Conventional red is considered to afford the best contrast with the wide variety of colors found in nature (10). The particular hue chosen, insignia red, is Federal Standard No. 595-11136. The yellow used has high luminance and a wavelength approaching 555 mμ, the wavelength to which the average eye is most sensitive. White has a very high luminance and for this reason is frequently used as a high visibility marking. International orange offers an optimum balance between eye sensitivity and contrast with average backgrounds. It has a dominant wavelength matching the fluorescent yellow-orange studied, thus allowing direct comparison under identical viewing conditions.

The color properties of surfaces are graphically represented by reflectivity curves. Each of the target surfaces was examined with a Beckman DK-2 spectrophotometer and the percentage reflection of incident radiation, compared to that of a standard white surface, was calculated through the visible spectrum of radiation. The standard white surface is defined as having 100 percent reflectivity at all wavelengths. Reflectivity curves have been calculated under illumination by standard source "C" for the six target colors used (Fig. 1).

Conventional pigments work by a subtractive process in which certain wavelengths of incident energy are partially absorbed, and the remaining energy reflected. The reflectivity curves of fluo-

TABLE 1

COLORIMETRIC PROPERTIES OF TARGETS

Target	Luminance Factor (%)	Dominant Wavelength (m μ)	Excitation Purity (%)
White	94.7	476.0	1.0
Yellow	61.5	580.0	95.5
International orange	15.6	601.8	94.5
Red	10.4	660.0	57.0
Fluorescent red-orange	46.9	612.6	99.8
Fluorescent yellow-orange	68.6	602.8	99.9

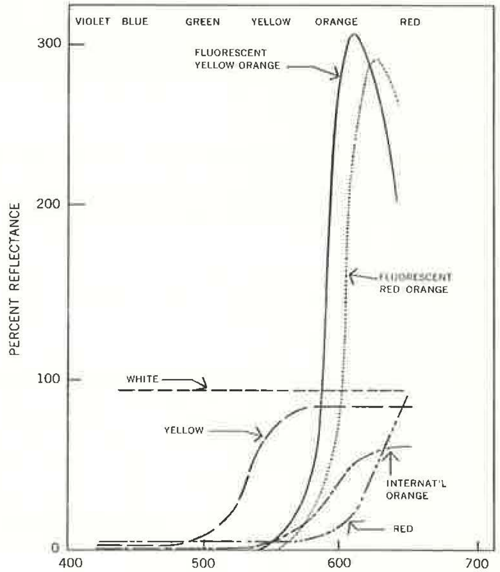


Figure 1. Reflectance curves of pigmented targets illuminated with source "C".

rescent pigmented materials show the strikingly different property of apparently returning more than 100 percent of the incident energy in a narrow spectral region. Reflectivity values can exceed 100 percent at a specific wavelength through the emission of energy absorbed at other wavelengths. This is precisely what fluorescent pigments do. Energy is absorbed in the near ultraviolet, blue and green regions of the spectrum, and is reemitted in the yellow-red region, thus adding to the energy also conventionally reflected.

The reflectance curves (Fig. 1) of yellow-orange fluorescent and international orange, which have similar dominant wavelengths, graphically illustrate the substantial gain afforded by fluorescent pigments. The energy shift noted in fluorescent pigments is characteristic of certain organic dyes having different absorption and fluorescent emission regions. The combined emitted and reflected energy, however, has only a single peak. This peak is the result of a "cascade effect" or progressive absorption and emission to the point of final energy emission. Emission curves for dyes used in fluorescent yellow-orange are shown in Figure 2.

The energy conversion process taking place in fluorescent pigments is known to have limited life. The pigments are selected primarily for their color and efficient energy conversion properties. However, recent technological advances provide improved protection to fluorescent dyes and have extended their useful life. The Armed Forces and independent industrial laboratories have established that the useful fluorescent life has been reached when the pigment loses 33 percent of its original brightness as measured on a NRL 45° fluorescence photometer (10). Fluorescent yellow-orange materials of high quality construction now have useful fluorescent life of 2 yr when exposed vertically, facing south, in Texas; fluorescent red-orange has a useful life of 2.5 yr under the same exposure conditions. Useful life of fluorescent materials is a direct function of the amount of solar radiation incident to the target surface; for this reason, exposure

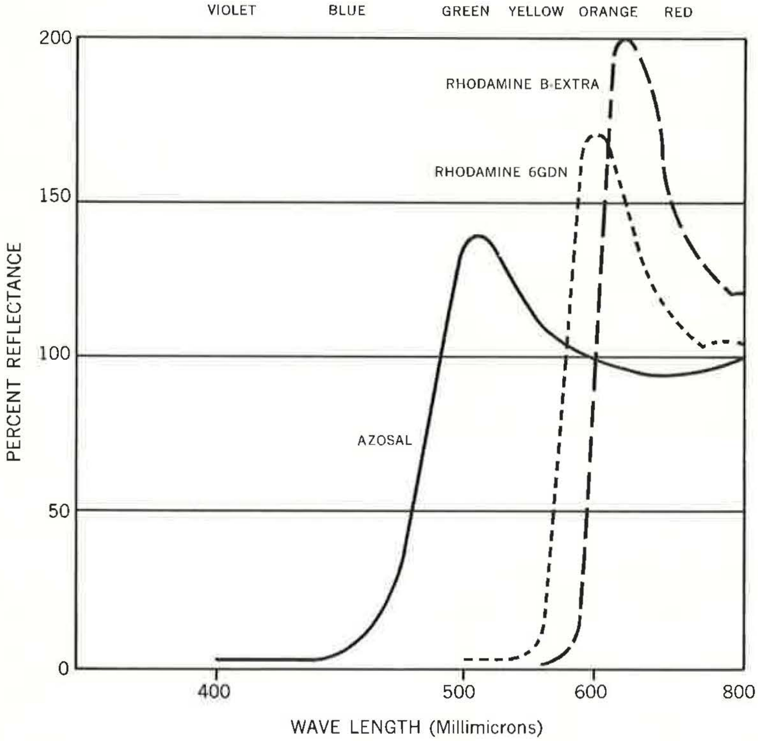


Figure 2. Emission characteristics of dyes required for fluorescent yellow-orange.

in directions other than south facing, or in more northerly latitudes, will result in greater useful life.

Incident Illumination Distribution

The fluorescent energy conversion process can be demonstrated by illuminating yellow-orange fluorescent and international orange targets on both white and black backgrounds using red, blue and unfiltered tungsten lamp light. With unfiltered tungsten light, as with daylight, both targets have good color and contrast with both backgrounds. With red light, both targets appear to have the same color and almost disappear on the white background. They appear white against the black background. With blue light, the international orange target disappears on the black background and appears black against the white background. The fluorescent target, however, shows its usual orange color and has good contrast with both backgrounds. This brightness is due to the conversion of the blue light to orange.

The observations of this demonstration are significant because natural illumination contains a greatly varying proportion of red and blue light under various directions, sky conditions and times of the day. The curves shown in Figures 3 and 4 indicate the relative spectral energy distributions of various sky conditions and several solar altitudes. Figure 3 compares the energy distributions of direct sunlight, overcast sky and north skylight. It can be seen that during the skylight condition, that is, when targets are in the shade, blue light is significantly predominant in the distribution. Figure 4 shows that on a clear day with the Sun at the zenith there is the greatest amount of total energy available and this energy is greatest in the blue region of the spectrum. Skylight is produced by the scattering of solar energy and contains a larger proportion of shorter wavelength (blue) than direct sunlight. It follows then that objects in the shade would be illuminated by greater proportions of blue light than objects illuminated directly by sunlight. As the Sun approaches the horizon, however, the blue component is filtered during its long atmospheric path and direct sunlight becomes relatively rich in red light.

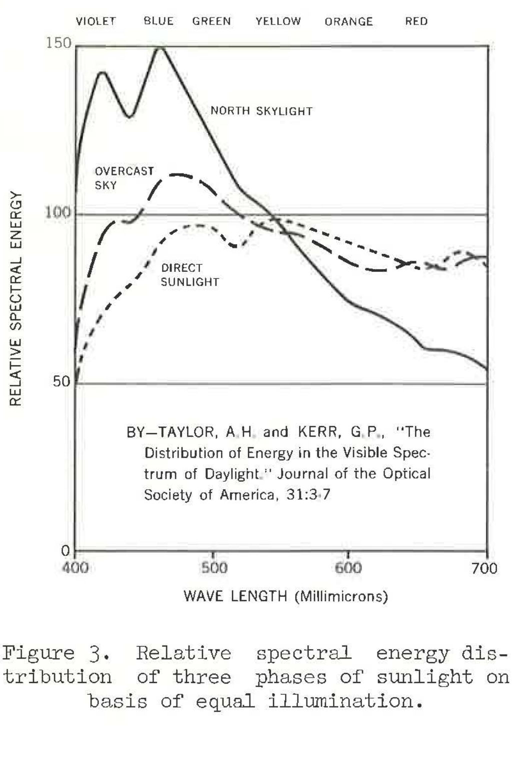


Figure 3. Relative spectral energy distribution of three phases of sunlight on basis of equal illumination.

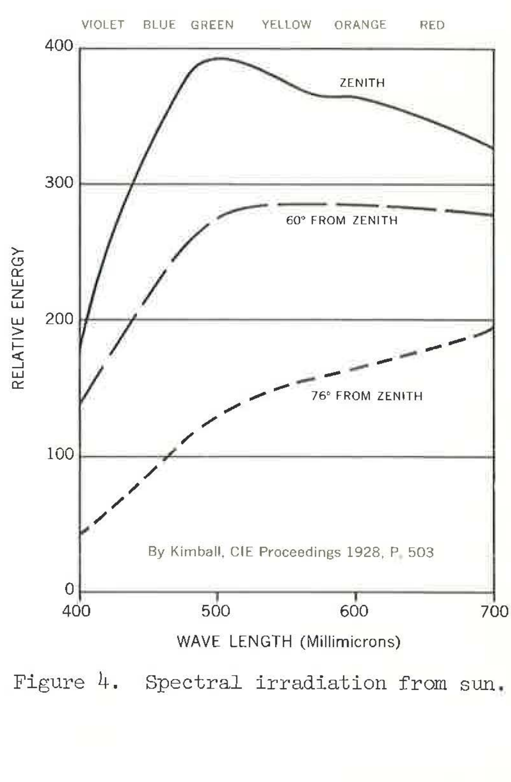


Figure 4. Spectral irradiation from sun.

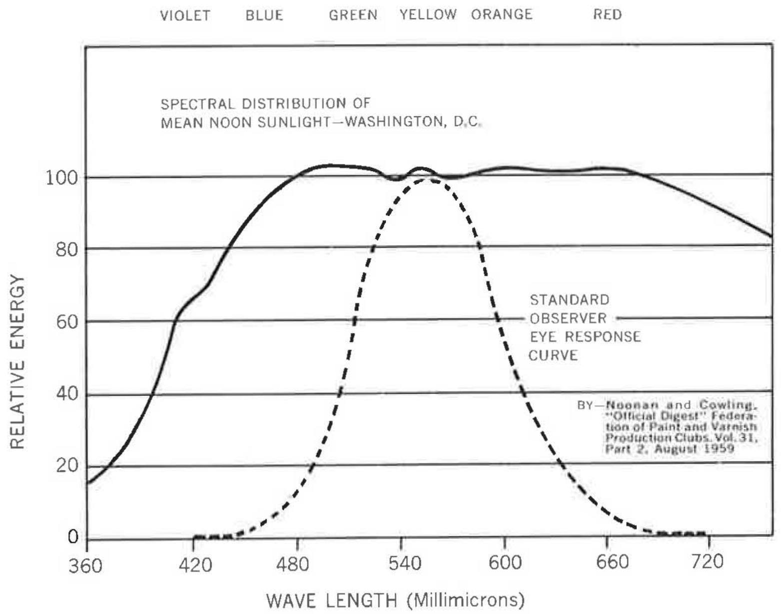


Figure 5. Comparison of spectral energy distribution with sensitivity response of average human eye.

Target-Background Contrasts

The conspicuity of a target is the measure of its effect on the viewer. The stimulus supplied to a viewer is usually measured in terms of the brightness alone with no consideration of color and is called the luminance factor. This factor considers the radiation coming from the target and the spectral sensitivity of the observer's eye. Colorimetrists have defined as standard observer (eye response) curve on the basis of many observations (Fig. 5). The eye sensitivity peaks at 555 mμ, the yellow-green region, and decreases toward both the red and blue regions.

The detectability of a target is also influenced by its brightness contrast with the background. Contrast ratio is the luminance factor of the target minus the luminance factor of the background divided by the luminance factor of the background (15). With constant intensity white illumination, each target would be detected by contrast alone. The detection distance of the targets would be in proportion to the contrast ratio. Sunlight, however, varies considerably from constant intensity white light, and one objective of this study is to evaluate the influence of solar illumination on both the distance at which the target is detected and the distance at which its hue is recognized.

FIELD STUDY

With this background information, a field study was designed that would take into account the necessary range of variables. The study considered the six targets previously discussed, three backgrounds, three time periods, and four directions, under two different sky conditions, using 19 adult male observers. The specific target size (circles 0.01 sq ft in diameter) was selected because nomographs (12) for predicting object detection distance use increments of area on a logarithmic scale and the predicted distances were appropriate for normal highway viewing distances.

Observers

In a test of vision it is essential that a significant number of observers be employed, because variations of response among observers, and by the same observer viewing the same target on different occasions, may be substantial. The average number of

TABLE 2

OBSERVER ACUITY

Acuity	No. Observers
20/17	14
20/18	6
20/20	5
20/22	2
20/29	1
Total	28

TABLE 3

COLORIMETRIC PROPERTIES OF BACKGROUND PANELS

Background	Luminance Factor (%)	Dominant Wavelength (m μ)	Excitation Purity (%)
White	82.6	567.0	2.0
Tan	34.9	581.2	44.6
Olive Drab	8.6	573.2	23.5

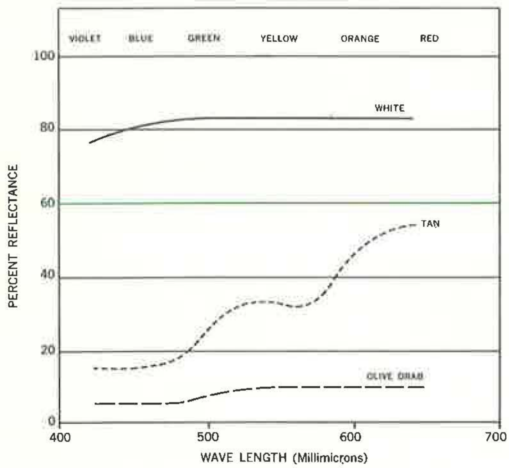


Figure 6. Reflectance curves of background materials.

TABLE 4

TARGET VS BACKGROUND CONTRAST RATIOS

Target	Background		
	Olive Drab	Tan	White
White	10.0	1.71	0.11
Fluorescent yellow-orange	6.96	0.96	-0.17
Yellow	6.15	0.76	-0.26
Fluorescent red-orange	4.45	0.34	-0.43
International orange	0.81	-0.55	-0.81
Red	0.21	-0.70	-0.87

observers used, 19, comprised a sufficiently large group to establish statistical reliability. Each observer was checked for visual acuity on a Bausch and Lomb Ortho Rater and for color blindness using a S. Ishihara color plate book. The observers had normal biocular acuity (Table 2). Of three observers with red-green color confusion, two were very mild, one more severe. Most observers participated in each set of observations.

Background Colors

The background colors selected were white, tan, and olive drab. Their colorimetric properties are given in Table 3; reflectance curves are shown in Figure 6. These three background colors were chosen because they offer not only representative maximum, intermediate and minimum brightness levels but also a variety of background colors encountered in nature: white represents snow, bright overcast sky and buildings; tan and olive drab represent the colors of fields, shrubbery and wooded backgrounds of many varieties. The tan and olive drab colors selected are U.S. Army Corps of Engineers' Standard Camouflage Colors (16) Nos. 6 and 9, respectively. Target vs background contrast ratios are given in Table 4.

Conduct of Test

Representative viewings by direction were obtained by facing the targets north, south, east and west. The study was conducted during three 1-hr time periods—noon, 3:00 PM, and 6:00 PM, with observations commencing ½ hr prior to the time period noted. The series is thus representative of solar altitudes for all daylight hours, because AM viewings would be for all practical purposes a duplication of PM viewings. Observations were made on Sept. 3 and 9 under two sky conditions, clear and solidly overcast. The observation conditions are, therefore, representative of the daylight range under which devices employing the target materials would be used.

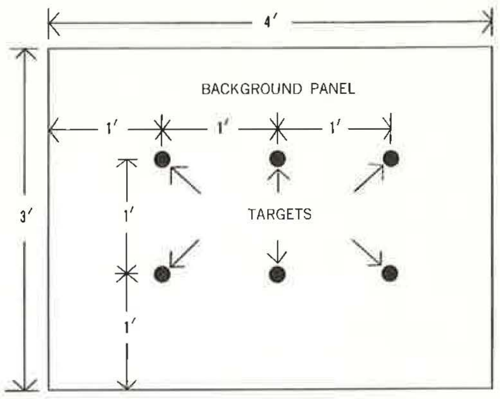


Figure 7. Background panel and target layout.

The six target colors, 0. 01 sq ft circles, were placed in a random sequence on panels of the three background colors. The panels (Fig. 7) 3- by 4-ft in size, were mounted on top of a stationary automobile and presented to the observers one at a time in a random manner. Observations began from a distance of 2, 000 ft, at which no target was detectable. Observers approached the panels in automobiles, traveling at a speed of 5 mph, and recorded two distances, the distance at which each of the targets became visible, or detection range and the distance at which each target could be identified by chromatic hue, or recognition range. Approaches were made on the east-west range until all three backgrounds had been viewed in each direction. The observers then followed the same procedure on the north-south range. A total of 16, 400 individual observations were made.

RESULTS AND ANALYSIS

Mean detection and recognition distances are shown for each direction, time period, sky condition and background in Appendix A. Additionally, mean distances were calculated for each target by day for time of day, direction and background, and combined for both days. The over-all means for the entire study were also computed for each target by day and for both days.

Inspection of the over-all means in Table 5 shows that the fluorescent yellow-orange target was detected at the greatest distance and that is was recognized by hue identification first on both the overcast and the clear sunny day. The mean differences of detection and recognition ranges existing between fluorescent yellow-orange and any other target were statistically significant. All targets were detected at a greater distance on the sunny day; however, the loss in detectability distance of the overcast day is greater for conventional pigments than for fluorescent pigments. This indicates that fluorescent pigments provide visibility properties less sensitive to reductions in illumination. Although international orange and fluorescent yellow-orange have similar dominant wavelengths and high excitation purities (Table 1), a substantial difference exists in both recognition and detection range. The target with the greatest detection range, fluorescent yellow-orange, is followed by yellow. It is noteworthy that both have similar luminance factors, dominant wavelengths and excitation purity. The supe-

TABLE 5

MEAN DETECTION, RECOGNITION RANGES AND RANK ORDER OF 0.01-SQ FT CIRCULAR TARGETS[a]

Target	Both Days				Overcast Day				Clear Sunny Day			
	Detection		Recognition		Detection		Recognition		Detection		Recognition	
	Range (ft)	Rank	Range (ft)	Rank	Range (ft)	Rank	Range (ft)	Rank	Range (ft)	Rank	Range (ft)	Rank
Yellow	570	2	315	4	553	2	311	4	587	2	319	4
Fluorescent red-orange	556	4	394	2	545	3	391	2	567	4	396	2
International orange	505	5	242	5	490	5	242	5	519	5	242	5
Red	489	6	190	6	476	6	192	6	502	6	187	6
White	559	3	342	3	537	4	345	3	581	3	338	3
Fluorescent yellow-orange	604	1	441	1	595	1	438	1	612	1	443	1

[a]Over-all means.

TABLE 6

MEAN DETECTION AND RECOGNITION RANGES OF 0.01-SQ FT CIRCULAR TARGETS[a]

Target	Range (ft)					
	Both Days		Overcast Day		Clear Sunny Day	
	Detection	Recognition	Detection	Recognition	Detection	Recognition
North facing:						
Yellow	563	308	566	311	559	305
Fluorescent red-orange	557	398	557	402	557	394
International orange	488	206	491	204	484	207
Red	476	134	488	139	464	130
White	547	355	536	353	558	317
Fluorescent yellow-orange	607	457	617	460	596	453
East facing:						
Yellow	507	301	558	335	455	266
Fluorescent red-orange	513	382	559	428	467	336
International orange	454	209	498	243	410	175
Red	432	160	475	190	388	130
White	489	332	509	357	468	306
Fluorescent yellow-orange	540	436	602	480	477	391
South facing:						
Yellow	633	344	611	321	654	366
Fluorescent red-orange	620	457	587	437	632	476
International orange	543	236	508	223	578	248
Red	520	164	476	153	564	174
White	615	369	592	360	638	378
Fluorescent yellow-orange	689	524	678	514	699	533
West facing:						
Yellow	662	366	592	344	731	387
Fluorescent red-orange	636	475	596	456	676	493
International orange	565	284	525	277	605	290
Red	538	216	505	210	570	222
White	655	421	588	404	722	437
Fluorescent yellow-orange	699	541	651	518	747	564

[a]Means by direction.

riority of fluorescent yellow-orange is more pronounced when the recognition ranges are compared, indicating the relative importance of high reflectance (Fig. 1).

Target Comparison by Direction

Table 6 presents the data for the over-all averages by direction. It is apparent that fluorescent yellow-orange has the greatest detection and recognition range of the targets studied. The mean difference in recognition range between fluorescent yellow-orange and the other targets is substantial, whereas the differences in mean detection ranges are not all significant. These differences are compared graphically (Fig. 8).

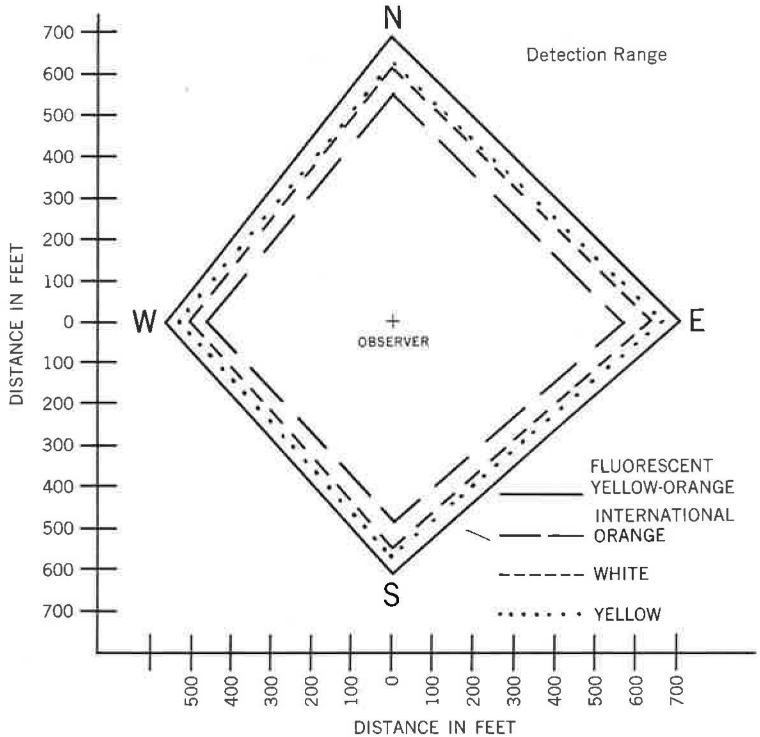
Target Comparison by Background Color

Table 7 gives the mean target detection and recognition ranges by background color. There is statistical significance between practically all mean detection range differences on any given background, and the range of the target depends on the background being considered. The fluorescent yellow-orange target has the greatest over-all detection range, although it is not greatest on any particular background. The factors influencing detection range are luminance contrast ratio, color and reflectance.

The mean recognition ranges of the fluorescent targets are significantly greater than those of the conventional targets. The recognition distance varies directly as the background color becomes darker (Fig. 9). An analysis of variance (Appendix B) of the variables considered in this study confirms that recognition range is closely dependent on background.

Target Comparison by Time of Day

Table 8 gives the mean detection and recognition ranges for the three time periods during which observations were made. Fluorescent yellow-orange has the greatest mean detection and recognition ranges. The differences in these ranges between fluo-



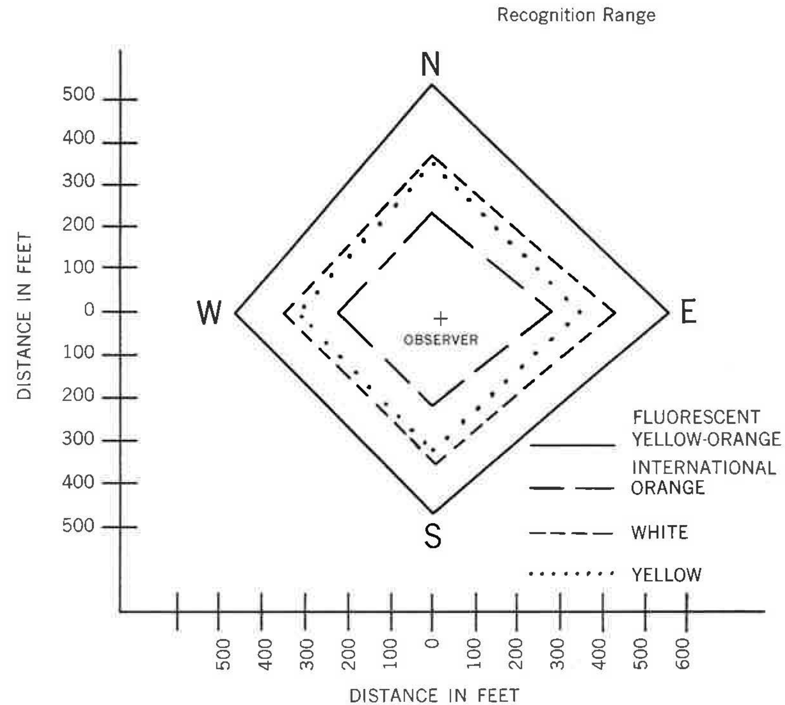


Figure 8. Mean detection and recognition ranges of 0.01 sq ft circular targets by direction.

TABLE 7

MEAN DETECTION AND RECOGNITION RANGES OF 0.01-SQ FT CIRCULAR TARGETS[a]

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

[a]Means by background.

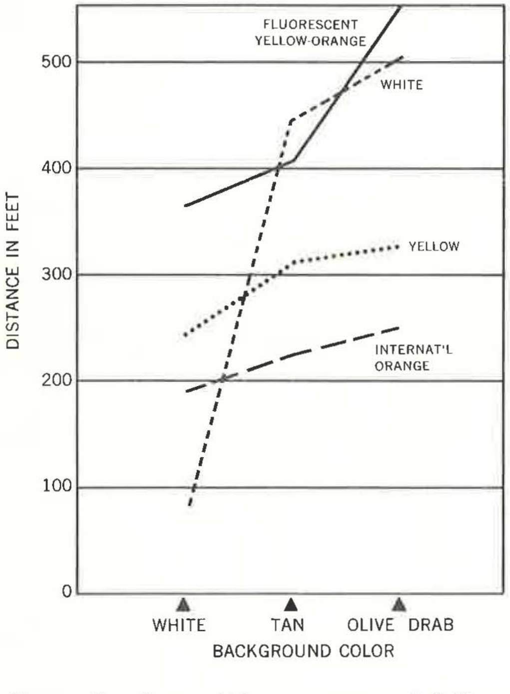


Figure 9. Recognition ranges of 0.01 sq ft circular targets by background color.

rescent yellow-orange and the other targets are statistically significant for all conditions except for the detection range on a clear sunny day at 3 PM. Figure 10 shows graphically the data for several of the targets.

Further Analyses

The analysis of variance (Appendix B) shows that of the three variables—time, direction and background—time had the least significant effect. To examine the data more closely, a specific time was selected, held constant, and the data for the remaining two variables compared. Figures 11 and 12 give the detection and recognition ranges for chromatically comparable targets. Distances are given for south facing targets on each background. The detection ranges indicate that distance is primarily a function of luminance contrast. The recognition ranges show a definite advantage for fluorescent yellow-orange. The differences in mean recognition range are significant.

In the previous discussion concerning source distribution and its effect on fluorescent and conventional pigments it was indicated that fluorescent pigments would be more advantageous during conditions of predominant blue light (overcast or illumination by skylight) than when red light is predominant. The following analysis supports this conclusion. The recognition range of fluorescent yellow-orange was compared to those of international orange and conventional yellow under four specific conditions:

TABLE 8

MEAN DETECTION AND RECOGNITION RANGES OF 0.01-SQ FT CIRCULAR TARGETS[a]

Target	Range (ft)					
	Both Days		Overcast Day		Clear Sunny Day	
	Detection	Recognition	Detection	Recognition	Detection	Recognition
(a) Noon, CST						
Yellow	609	350	581	348	636	351
Fluorescent red-orange	593	438	574	442	611	433
International orange	541	250	518	263	563	236
Red	505	188	497	210	513	165
White	595	384	548	375	641	393
Fluorescent yellow-orange	641	498	628	498	654	498
(b) 3 PM, CST						
Yellow	633	345	642	344	621	345
Fluorescent red-orange	615	454	621	449	609	458
International orange	548	240	542	239	556	240
Red	531	163	518	160	543	165
White	621	397	614	402	627	392
Fluorescent yellow-orange	670	517	684	511	655	523
(c) 6 PM, CST						
Yellow	531	292	523	289	538	294
Fluorescent red-orange	528	393	530	403	525	382
International orange	443	209	449	204	437	214
Red	436	154	437	145	434	162
White	511	307	501	323	520	291
Fluorescent yellow-orange	587	451	593	467	580	434

[a]Means by time of day.

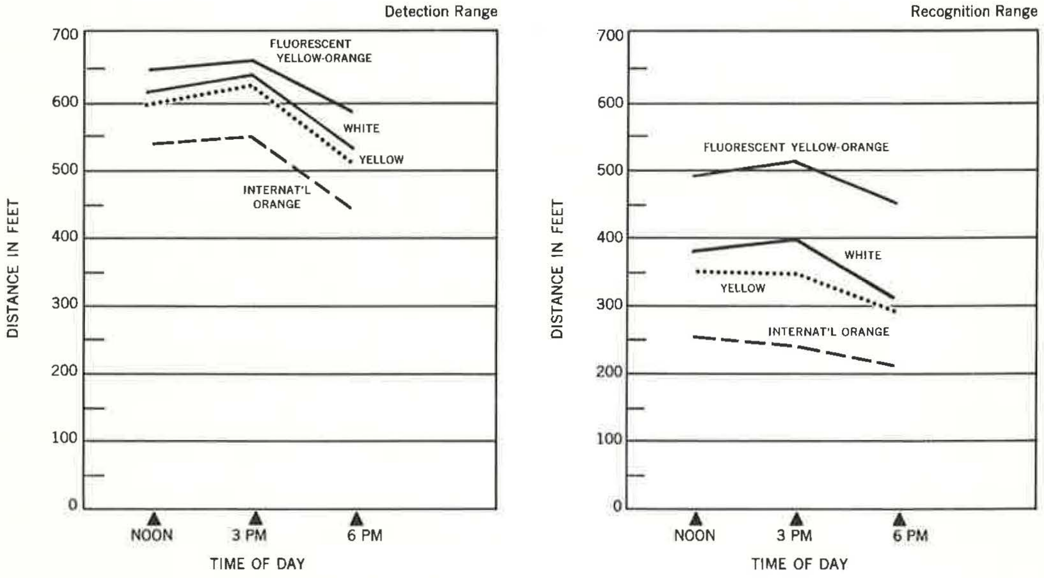


Figure 10. Mean detection and recognition ranges of 0.01 sq ft circular targets by time of day.

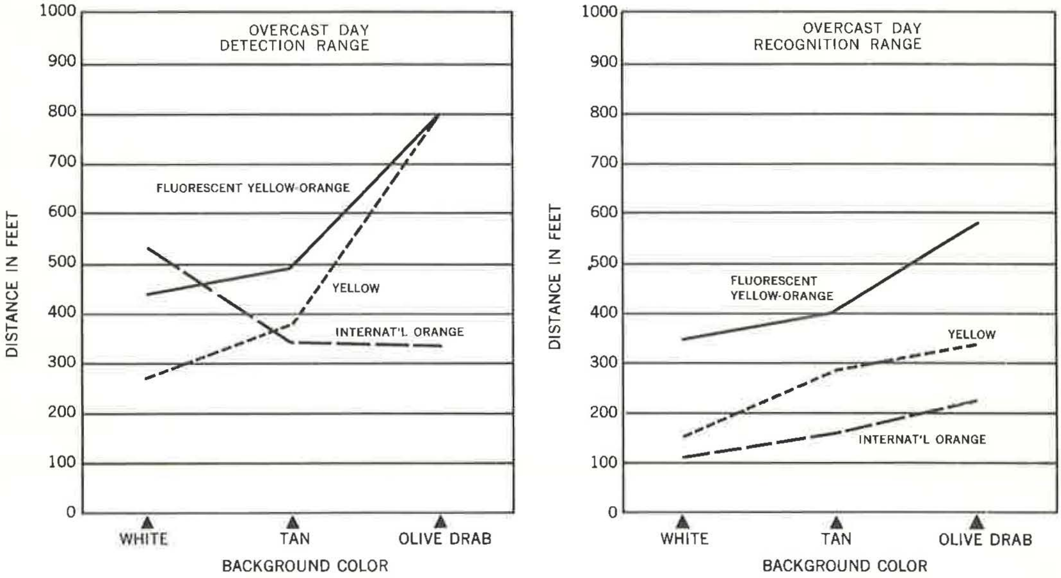


Figure 11. Mean detection ranges of 0.01 sq ft circular targets at 6 PM with targets facing south on overcast day.

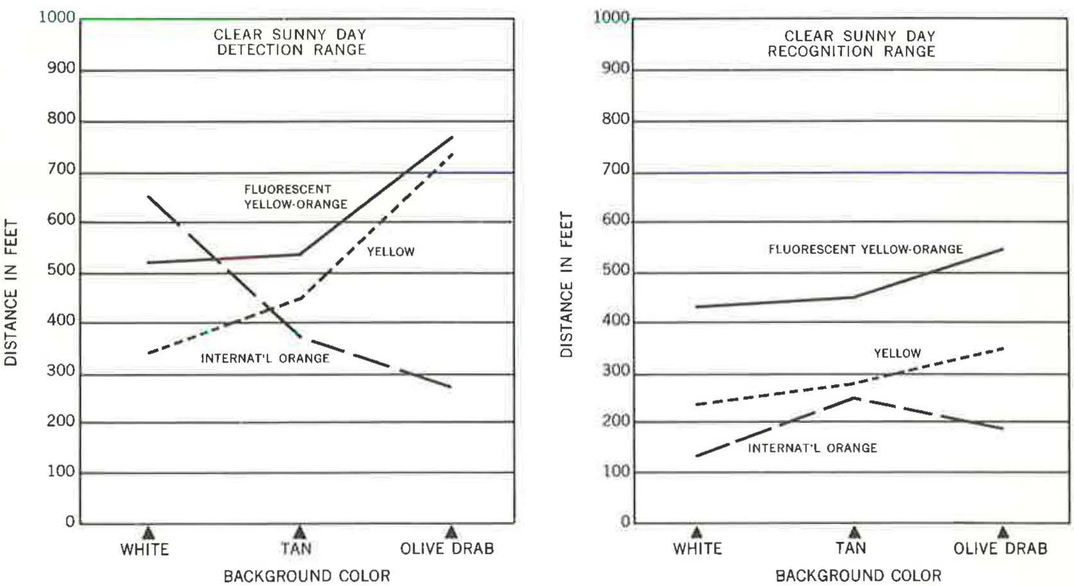


Figure 12. Mean recognition ranges of 0.01 sq ft circular targets at 6 PM with targets facing south on clear sunny day.

TABLE 9

RECOGNITION RANGE DISTANCES AND RATIOS

Condition	Predominant Illumination	Recognition Range: Fluorescent Yellow-Orange (ft)	International Orange (ft)	Ratio[a]	Conventional Yellow (ft)	Ratio[b]
South facing at 6 PM	Blue	523	187	2.8	334	1.6
East facing at 3 PM	Blue	500	193	2.6	278	1.8
South facing at noon	Red	810	404	2.0	600	1.3
West facing at 6 PM	Red	742	442	1.7	572	1.3

[a]Fluorescent yellow-orange to international yellow.
[b]Fluorescent yellow-orange to conventional yellow.

1. South facing on a clear sunny day at 6 PM with the targets in the shade and illuminated by skylight—a condition of predominant blue illumination;
2. East facing on a clear sunny day at 3 PM with target illumination by skylight—a condition of predominant blue illumination;
3. South facing on a clear sunny day at noon with direct sunlight—a condition of predominant red illumination;
4. West facing on a clear sunny day at 6 PM with direct sunlight—a condition of the most predominant red illumination.

The olive drab background was used in all cases. Recognition ranges and their ratios for the targets are given in Table 9. The ratios illustrate the superiority of fluorescent yellow-orange to international orange and conventional yellow. The relative magnitude of superiority is directly dependent on the blue-red distribution of available natural illumination.

The higher luminance contrast ratio of conventional yellow provides greater recognition range than international orange and is also a color more commonly employed where high visibility is required. Although the fluorescent yellow-orange has slightly longer dominant wavelength and hue than conventional yellow, it has greater recognition range due to the increased luminance provided by the conversion process.

Target Size Extrapolation

The extrapolation of detection and recognition ranges for target sizes other than those studied is not a straight line arithmetic function of target size. This is due largely to the effect of atmospheric attenuation, which is the scattering of light caused by the presence of minute particles, such as dust, between the observer and the object. Attenuation does not, however, alter the rank order at which targets are seen if the size of targets being compared remains equal. Middleton (12) has published a series of nomographs clearly illustrating this principle. From this it can be reasonably assumed that the results of the present study would hold true for target sizes other than those studied.

SUMMARY

Well-established principles of colorimetry and vision were combined with measured properties of target materials and field studies to obtain quantitative differences of target visibility. A selection of common conventional and fluorescent target colors was compared against natural background colors under representative conditions of daylight illumination to obtain numerical values of their performance.

Comparison of the over-all means for the entire study indicated that the fluorescent yellow-orange target had detection and recognition ranges 6 and 29 percent greater, respectively, than any of the conventionally pigmented targets. The differences were statistically significant. Fluorescent yellow-orange had a recognition range 82 percent greater than international orange, its comparable conventional color.

A comparison of results by direction or time of day indicated that the fluorescent yellow-orange target had the greatest detection and recognition range. A comparison by background color establishes that contrast ratios were of primary importance in determining the rank order of detection range, with other factors, such as color contrast and target luminance, participating to a lesser extent. The only target with a consistently high detection range on all backgrounds was fluorescent yellow-orange.

Analysis of results under specific illumination conditions indicated that when blue light was predominant, the superiority of fluorescent pigments increased significantly. This illustrates the useful property of conversion of blue wavelength light to orange, inherent only in fluorescent colors. With the single exception of a white target on a tan background, fluorescent yellow-orange has the greatest recognition range for the targets and backgrounds studied. On an olive drab background the fluorescent yellow-orange target had a recognition range 3.8 times greater than the international orange target when both were in the shade at 6 PM, whereas this ratio was reduced to 2.0 when the targets were illuminated by direct sunlight at noon. Under the same conditions the fluorescent yellow-orange recognition range was 1.6 times greater than conventional yellow at 6 PM and 1.3 times greater at noon.

Under selected conditions other targets had slightly greater detection or recognition ranges; however, fluorescent yellow-orange was the only target with consistently high performance under all conditions and provided the best over-all performance. Of significance is the fact that as visibility conditions deteriorated the relative performance of fluorescent targets increased.

The principal reason for the superiority of fluorescent pigments is their unnaturally high color purity and reflectance resulting from an energy conversion process. This process causes the pigments to fade at a rate proportional to their exposure to sunlight. Recent improvements result in a useful life of 2 yr in southern states when facing south. Exposure in other directions or areas will result in a longer useful life.

The results of this study indicate that where high target visibility is the primary objective, fluorescent pigments should be given serious consideration.

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Appendix A

MEAN DETECTION AND RECOGNITION RANGES OF 0.01-SQ FT CIRCULAR TARGETS

Target	Background: White		Background: Tan		Background: Olive Drab	
	Detection Range (ft)	Recognition Range (ft)	Detection Range (ft)	Recognition Range (ft)	Detection Range (ft)	Recognition Range (ft)
(a) Overcast Day, 12 PM						
North facing:						
Yellow	420	254	408	291	736	382
Fluorescent Red-Orange	573	362	354	317	638	456
International Orange	651	125	397	216	336	257
Red	704	74	427	154	216	176
White	16	11	636	417	857	464
Fluorescent Yellow-Orange	478	369	488	416	737	511
East facing:						
Yellow	472	268	506	405	767	487
Fluorescent Red-Orange	616	433	459	403	645	550
International Orange	676	294	570	275	380	287
Red	716	260	564	314	266	205
White	27	26	719	577	850	627
Fluorescent Yellow-Orange	563	403	572	520	723	603
South facing:						
Yellow	423	201	545	362	1001	522
Fluorescent Red-Orange	597	378	473	404	797	639
International Orange	638	158	554	250	472	364
Red	599	104	623	172	373	281
White	51	39	826	562	965	545
Fluorescent Yellow-Orange	530	419	605	529	1001	707
West facing:						
Yellow	347	222	510	331	866	467
Fluorescent Red-Orange	558	348	431	417	757	605
International Orange	594	260	496	358	435	323
Red	576	223	588	319	287	245
White	111	82	675	583	928	617
Fluorescent Yellow-Orange	470	357	544	487	860	669
(b) Overcast Day, 3 PM						
North facing:						
Yellow	472	242	513	380	908	369
Fluorescent Red-Orange	680	394	468	367	675	508
International Orange	731	115	523	233	347	273
Red	778	69	527	160	275	180
White	45	22	760	521	1001	812
Fluorescent Yellow-Orange	628	403	567	480	812	573
East facing:						
Yellow	454	288	498	359	788	334
Fluorescent Red-Orange	608	390	428	366	682	507
International Orange	660	192	514	230	356	278
Red	703	106	535	177	225	188
White	62	53	639	457	873	526
Fluorescent Yellow-Orange	562	410	532	441	764	593
South facing:						
Yellow	388	232	582	323	1073	465
Fluorescent Red-Orange	646	393	437	373	836	607
International Orange	705	145	532	212	459	347
Red	698	96	582	156	285	225
White	33	17	812	446	1056	631
Fluorescent Yellow-Orange	559	403	578	469	1015	700
West facing:						
Yellow	376	264	554	375	1004	482
Fluorescent Red-Orange	644	375	480	425	832	649
International Orange	669	169	578	281	478	356
Red	672	73	659	204	343	271
White	60	39	844	580	1043	645
Fluorescent Yellow-Orange	544	410	601	504	990	701

MEAN DETECTION AND RECOGNITION RANGES OF 0.01-SQ FT CIRCULAR TARGETS (Cont'd.)

Target	Background					
	White		Tan		Olive Drab	
	Detection Range (ft)	Recognition Range (ft)	Detection Range (ft)	Recognition Range (ft)	Detection Range (ft)	Recognition Range (ft)
(c) Overcast Day, 6 PM						
North facing:						
Yellow	370	217	533	325	775	348
Fluorescent Red-Orange	544	357	420	369	680	510
International Orange	623	146	484	233	292	244
Red	712	100	523	181	187	180
White	11	9	748	488	821	521
Fluorescent Yellow-Orange	480	362	598	459	796	591
East facing:						
Yellow	366	230	410	272	653	340
Fluorescent Red-Orange	543	350	377	355	570	460
International Orange	616	153	412	211	285	231
Red	653	111	475	185	176	146
White	27	14	625	421	721	498
Fluorescent Yellow-Orange	469	362	510	433	645	508
South facing:						
Yellow	288	154	382	284	771	339
Fluorescent Red-Orange	488	321	352	320	688	510
International Orange	525	105	355	166	318	211
Red	542	50	428	132	165	128
White	2	2	562	375	845	508
Fluorescent Yellow-Orange	446	346	491	400	797	585
West facing:						
Yellow	305	209	481	342	938	390
Fluorescent Red-Orange	575	362	376	340	752	606
International Orange	618	158	415	242	431	336
Red	634	118	481	204	246	225
White	41	7	648	486	942	569
Fluorescent Yellow-Orange	484	414	511	460	901	688
(d) Clear Sunny Day, 12 PM						
North facing:						
Yellow	421	261	376	261	747	338
Fluorescent Red-Orange	705	408	279	251	522	375
International Orange	749	144	343	178	274	224
Red	666	88	382	97	148	123
White	37	30	647	403	881	472
Fluorescent Yellow-Orange	497	358	439	337	635	494
East facing:						
Yellow	580	251	397	305	892	468
Fluorescent Red-Orange	736	365	467	384	681	529
International Orange	727	147	678	201	337	283
Red	551	95	652	175	341	255
White	298	131	768	503	926	573
Fluorescent Yellow-Orange	582	385	516	462	796	612
South facing:						
Yellow	433	251	607	430	1245	600
Fluorescent Red-Orange	685	388	535	438	877	711
International Orange	746	169	687	298	532	404
Red	712	75	770	223	385	319
White	13	8	1008	619	1277	781
Fluorescent Yellow-Orange	585	430	592	505	1157	810
West facing:						
Yellow	437	266	506	334	966	443
Fluorescent Red-Orange	663	365	407	392	755	578
International Orange	729	171	513	274	437	335
Red	688	87	604	226	260	212
White	28	26	849	576	924	579
Fluorescent Yellow-Orange	551	426	603	503	879	635
(e) Clear Sunny Day, 3 PM						
North facing:						
Yellow	451	282	413	299	872	378
Fluorescent Red-Orange	653	414	364	345	666	517
International Orange	734	146	440	213	351	268
Red	763	96	493	126	206	162
White	41	32	759	487	993	542
Fluorescent Yellow-Orange	551	428	500	453	828	610
East facing:						
Yellow	443	260	386	278	629	278
Fluorescent Red-Orange	551	380	481	323	513	404
International Orange	636	138	384	199	245	193
Red	682	114	420	121	153	112
White	68	59	618	421	722	478
Fluorescent Yellow-Orange	453	391	458	418	622	500
South facing:						
Yellow	427	258	518	368	1175	539
Fluorescent Red-Orange	656	415	523	443	823	689
International Orange	742	180	675	268	468	364
Red	767	94	743	194	397	317
White	71	43	988	602	1102	635
Fluorescent Yellow-Orange	588	453	544	481	1052	767

MEAN DETECTION AND RECOGNITION RANGES OF 0.01-SQ FT CIRCULAR TARGETS (Cont'd.)

Target	Background					
	White		Tan		Olive Drab	
	Detection Range (ft)	Recognition Range (ft)	Detection Range (ft)	Recognition Range (ft)	Detection Range (ft)	Recognition Range (ft)
(e) Clear Sunny Day, 3 PM (Cont'd.)						
West facing:						
Yellow	385	245	610	411	1234	579
Fluorescent Red-Orange	619	383	531	451	948	760
International Orange	721	212	655	296	555	422
Red	647	92	748	237	401	333
White	83	75	1005	677	1254	752
Fluorescent Yellow-Orange	552	409	617	547	1149	856
(f) Clear Sunny Day, 6 PM						
North facing:						
Yellow	462	265	446	313	868	356
Fluorescent Red-Orange	666	375	408	365	759	510
International Orange	629	172	464	241	354	284
Red	768	113	498	189	233	186
White	165	117	596	367	955	426
Fluorescent Yellow-Orange	542	414	549	430	855	572
East facing:						
Yellow	187	150	232	193	331	197
Fluorescent Red-Orange	260	189	202	189	302	252
International Orange	278	134	184	138	184	138
Red	318	66	209	122	131	100
White	92	91	301	228	388	254
Fluorescent Yellow-Orange	215	189	270	247	363	301
South facing:						
Yellow	344	237	438	279	722	334
Fluorescent Red-Orange	576	402	385	339	588	454
International Orange	640	131	381	245	278	187
Red	630	88	493	172	120	97
White	19	18	665	351	742	411
Fluorescent Yellow-Orange	508	414	528	431	764	523
West facing:						
Yellow	288	225	748	412	1356	572
Fluorescent Red-Orange	641	398	530	463	993	647
International Orange	698	167	450	289	700	442
Red	675	114	547	297	576	400
White	62	30	1034	600	1242	600
Fluorescent Yellow-Orange	554	422	613	529	1201	742

Appendix B

ANALYSIS OF VARIANCE FOR MEAN DETECTION AND RECOGNITION RANGES OF 0.01-SQ FT CIRCULAR TARGETS

Variable	Overcast Day			Clear Sunny Day		
	Degrees of Freedom	Mean Square		Degrees of Freedom	Mean Square	
		Detection Range	Recognition Range		Detection Range	Recognition Range
Direction target faced	3	455,633	465,207	3	10,860,200	3,642,490
Time of day	2	2,635,100	846,535	2	4,283,700	1,349,475
Background color	2	9,993,200	14,564,190	2	14,023,150	16,725,825
Target color	5	1,726,000	8,111,802	5	1,827,240	9,924,018
Direction × time	6	429,900	215,770	6	4,741,950	1,127,103
Direction × background	6	649,617	179,105	6	2,118,517	734,521
Time × background	4	44,300	46,402	4	101,075	261,798
Direction × target color	15	37,773	24,994	15	61,520	54,378
Time × target color	10	23,260	45,196	10	40,100	109,079
Background × target color	10	12,418,190	1,900,834	10	15,976,690	1,823,426
Direction × time × background	12	102,767	42,042	12	611,700	254,004
Direction × time × target color	30	87,867	17,052	30	37,627	24,342
Direction × background × target color	30	317,867	18,943	30	271,953	31,924
Time × background × target color	20	27,865	21,774	20	183,480	41,454
Error	3,253	13,073	21,870	4,014	12,547	15,542
Total	3,407			4,169		