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EFFECTS OF BACKSCATTERED LIGHT ON TARGET LIGHT DETECTABILITY IN A GROUND TEST ENVIRONMENT

PROJECT NO. 110-512R

prepared for

FEDERAL AVIATION AGENCY
SYSTEMS RESEARCH AND DEVELOPMENT SERVICE

by

APPLIED PSYCHOLOGY CORPORATION
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EFFECTS OF BACKSCATTERED LIGHT ON TARGET LIGHT DETECTABILITY IN A GROUND TEST ENVIRONMENT

Prepared for

Federal Aviation Agency
Systems Research and Development Service
Washington 25, D. C.

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July 1962

Applied Psychology Corporation
Arlington, Virginia
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ABSTRACT

Field tests were conducted to determine how ability to detect target lights is affected by backscattered light (light reflected back to the pilot from his own exterior lights), under VFR atmospheric conditions.

Backscatter was generated by a light with a peak intensity of 5500 candles. It was varied in color (red, green, white), lateral displacement (0 and 15 feet), flashing mode (flashing or steady burning), and beam alignment with the target. Target light colors were also varied (red, green, white). Subject viewed the target both foveally and peripherally. Atmospheric transmissivity was measured during the tests.

Results indicate that backscatter has little effect on detectability of target lights in atmospheric transmissivities of about 20% per mile and greater. Differences in threshold could, in the main, be accounted for by atmospheric transmissivity and differential sensitivities of the eye. The striking differences in the subjective appearance of different backscatter colors and modes of flashing suggest that other effects such as distraction, fatigue, and disorientation may not be negligible, even though target detectability is not affected.

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ACKNOWLEDGMENTS

Appreciation is extended to the contract monitor, Eugene E. Pazera; to Wayne D. Howell and Philip R. Marshall of NAFEC who administered the tests; to those persons who gave up their evening hours on short notice to serve as observers; and to Dr. C. E. Leberknight of Kopp Glass Company for furnishing the glass color filters used in the test equipment.

SUMMARY OF THE PROJECT

More than 85% of all mid-air collisions have occurred during VFR operations. Since in all likelihood a substantial majority of flights will continue to take place under Visual Flight Rules for some years to come, the Federal Aviation Agency in July 1959 established a program calling for comprehensive research into visual aids for preventing mid-air collisions.

The principal areas being investigated by the contractor, the Applied Psychology Corporation, are paints, exterior light systems, smoke and vapor trails, optical devices, training procedures, and a determination of those items of information needed by pilots for making reliable avoidance-maneuver decisions.

The approach consists of a progression from laboratory work, through field tests, to flight testing. Experimental studies have been conducted to derive those quantitative data regarded as prerequisite to efficient and practical field tests. The field tests have then been designed to assess promising devices and techniques through ground-based observations; as such, they served as economical screenings prior to flight tests.

In-flight evaluations have been reserved for final testing of proposed solutions and for investigating operational problems.

Technical Reports have been, and will be, issued as statements of particular experiments or analytical studies; Summary Reports will be issued as summarizations of all work done in the various broad areas of investigation (e.g., paints, exterior light systems).

The present report is a combination of Technical Reports 6, 9, and 14.[1] Other reports, both published and planned for publication are listed below:

Technical Reports

No. 1 Analysis of the Usefulness of Coded Information in Visual Collision Avoidance

No. 2 Comparative Conspicuity of Several Aircraft Exterior Paint Patterns

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[1] The title has been modified from that listed in previously published reports.

No. 3 Aircraft Flight-Attitude Information as Indicated by Exterior Paint Patterns

No. 4 Field Study of Threshold Ranges for Aircraft Detection and Color Identification

No. 5 Pilot Judgments of Simulated Collisions and Near Misses: A Comparison of Performance with Uncoded and Two-Tone Coded Models

No. 7 Outdoor Test Range Evaluation of Aircraft Paint Patterns

No. 8 Flight Simulator Tests of Altitude-Coded Lights

No. 10 & 11 Pilot Judgments of Aircraft Range and Relative Altitude: Ground-to-Air and Air-to-Air Observations

No. 12 Distance Estimation of Frequency-Coded and Uniformly Flashing Lights[1]

No. 13 Conspicuity of Selected Signal Lights Against City-Light Backgrounds[2]

No. 15 Altitude Evasion in Visual Collision Avoidance[3]

No. 16 Flight Tests of Altitude-Coded Aircraft Lights

Summary Reports

The Role of Paint in Mid-Air Collision Prevention

The Role of Range and Altitude Judgment in Mid-Air Collision Prevention

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[1] This title replaces the previously listed "Evaluation of the Conspicuity of Aircraft Smoke Trails: A. Ground-to-Air Observations" which will not be published.

[2] This title replaces the previously listed "Evaluation of the Conspicuity of Aircraft Smoke Trails: B. Air-to-Air Observations" which will not be published.

[3] Title changed from that listed in previously published reports.

The Role of Visible Trails in Mid-Air Collision Prevention[1]

The Role of Exterior Lights in Mid-Air Collision Prevention

The Role of Optical Devices in Mid-Air Collision Prevention

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1 Title modified from that previously listed.

TECHNICAL REPORTS NOS. 6, 9, and 14

EFFECTS OF BACKSCATTERED LIGHT ON TARGET LIGHT DETECTABILITY IN A GROUND TEST ENVIRONMENT

Introduction

Much present comment about aircraft navigation light systems permitted by Civil Air Regulations (CAR) centers about their relatively low intensity. It is frequently argued that, in this day of higher-performance aircraft, the intensity of lights displayed for navigation or collision-avoidance purposes should be increased in order to improve the possibility of being seen at greater distances.[1] For the pilot who detects such lights, any advantage in distance will be meaningful in terms of precious seconds, especially if other characteristics of the detected lights can give him information that will help him evaluate the collision danger and take effective evasive action if needed.

One factor that will impose a limit on navigation light system intensity is backscatter, the light from a pilot's own exterior lights that is reflected back to him by particles in the atmosphere. Most people experience an exaggerated sample of this phenomenon whenever they drive an automobile through fog at night. The pilot flying Visual Flight Rules (VFR) does not encounter such concentrations of atmospheric particles; but his speed is usually greater, and in some cases his lights are revolving or oscillating beacons which give a perceivable sweeping motion to the backscatter. In extreme cases, backscatter may induce vertigo; in less extreme cases, milder forms of disorientation.

This report describes a series of studies to determine the effects of backscatter on pilot visual performance. The purpose of these experiments was to determine the effect of steady and flashing backscatter on the foveal and peripheral detectability of target lights in VFR atmospheres. The tests reported here were conducted at a ground field test station. Ground haze often differs from haze found in the air, and these differences may result in differences in the characteristics of backscatter. The ground tests are considered to be a useful preliminary to flight testing because of the considerably greater ease with which important variables can be measured or controlled. It is, of course, important to exercise caution in applying the results of such tests to operational situations.

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1 It should be noted that CARs establish minimum intensities and therefore there is no present regulatory restriction on the use of higher-intensity lights.

Background

All pilots are familiar with backscatter, particularly when flying into clouds or fogs with their exterior lights on. Often the effects of backscatter become so distressing as to compel the pilot to turn one or more of his exterior lights off. Some qualitative characteristics of backscatter are readily apparent. Lateral displacement reduces backscatter: wingtip position lights are less bothersome than lights mounted closer to the pilot. Beam cutoffs inboard help reduce backscatter. In general, reducing the intensity of the light directed into the pilot's field of view helps reduce backscatter. There is a good deal of basic data available on the scattering properties of the atmosphere, relating scatter to intensities, angle, scattering agents in the atmosphere, the color of the light, etc. (Middleton, 1958). The data suggest that the properties are variable and complex, and difficult to apply to the problem of visual collision avoidance. For example, the atmosphere is sometimes reported to exhibit significant color selectivity in transmittance (and backscatter) (Gibbons, Laughridge, Nichols, & Krause, 1962; Curcio & Durbin, 1959), and sometimes is reported essentially non-selective (Curcio & Durbin, 1959).

Particle size can be related to scattering and selectivity. If the particles are small compared to the wavelength (Rayleigh scattering in pure air, for example), σ, the scattering coefficient, varies inversely as the fourth power of the wavelength, suggesting much less backscatter for red than for green or blue. If the particles are large compared to the wavelength, then σ is independent of the wavelength. "The intermediate case, particle size comparable with the wavelength of light, is very complex and the attenuation coefficient can vary markedly with small changes in either variable." (From Curcio and Durbin, 1959).

Curiously, visual observation of the apparent selectivity of backscatter, which may be carried out easily, for example by comparing the backscatter from red and green wingtip position lights, suggests that backscatter is strongly selective under virtually all conditions.

For the above reasons it was felt desirable to investigate the properties of backscatter under controlled conditions that would permit direct application of the results to the pilot's problem in visual collision avoidance.

Backscatter Test I

Experimental Equipment

The tests were carried out at the Visibility Test Range

(VTR) of the National Aviation Facilities Experimental Center (NAFEC), FAA, located in a desolate area about 30 miles north of the Center at Warren Grove, N. J. The Observer Building at the VTR has an enclosed room for the observers from which they observe the target lights about 2000 feet away on a line of sight which averages about 30 to 40 feet above the gently rolling terrain. A track a few feet above the observers is mounted just outside the observing side of the building, and carries the backscatter light, which may be set at any lateral separation from the observers, up to 70 feet. (In this test, two displacements were used: zero and 15 feet.)

The backscatter light could be made Aviation red or Aviation green (within the limits for these colors as defined by Federal Standard No. 3, Aeronautical Lighting Colors, March 21, 1951). The peak intensity, with either color, was about 5500 candles, and the beam divergence, to the 10% point, was about 46 degrees horizontally and about 9 degrees vertically. For part of the test the backscatter light was aimed so that the peak of the beam was aligned with the target. For the rest of the test, the beam was aimed 19-1/2 degrees to one side so that the observers looked at the target through a part of the beam which was about 20% of peak intensity. The light was not flashed in this test.

The target light assembly consisted of three individual target light units mounted with uniform spacing on a bar about 7 feet long. The bar could be rotated around its center to one of four positions: horizontal, vertical, and to either 45-degree position. With the target about 2000 feet from the observers, its angular subtense was about 12 minutes. The target lights could be made Aviation red, green, or white, and in any color, could be set at any of a series of intensities from 0.022 to 0.50 candles. In this test the following intensity steps were used: 0.029, 0.054, 0.087, 0.16, and 0.29 candles.

A transmissometer with a 750-foot base line was used to measure the transmissivity of the atmosphere at intervals during the tests. The transmissometer path crossed the observer line of sight at an angle near the observer building and was at approximately the same height above ground. The atmospheric conditions during the test were approximately bracketed within the meteorological designation "light haze," equivalent to a range of transmissivities from 0.21 to 0.54 per mile. The lower limit (0.21 per mile) is approximately equivalent to a visibility of 3 miles, the present limiting condition for general VFR operations below 14,500 feet.

Two observers. seated side by side, were tested at one time. The alignment of the backscatter light with respect to the observers was with reference to a point midway between them and the distance between them was about 2-1/2 feet.

Test Procedures

Five subjects completed two test sessions in each of which one observation was obtained for each possible combination of the parameters:

Backscatter light:	Red or green; Peak aimed at target, or to one side; Beam not laterally displaced, or displaced 15 feet.
Target light:	Red, green, or white; Intensity at any of 5 levels.

Thus each observer made 120 observations in each of two sessions, and there was a total of 10 observations for each possible combination.

The settings of the backscatter light were not randomized, but for each combination of the backscatter light variables, the target light settings of color, intensity, and bar position were randomized.

The subjects were shown each target setting for a period of 5 seconds. They were then asked to identify the color of the target light and the position of the bar. The accuracy of the results for color identification and for bar position were recorded and scored separately.

No fixation light was provided. However, although the immediate area in the neighborhood of the target light was dark and featureless, ground marks not too separated in angular distance from the target were more or less visible due to illumination by the backscatter light, so that the observers could localize the target fairly well before it was turned on.

Observers were adapted for at least 15 to 20 minutes before the start of tests, and were thus adapted to a level determined by ambient natural illumination and by the backscatter. The immediate foreground, relatively brightly illuminated by stray light from the backscatter light was screened from the observers.

Results and Discussion

Very few of the differences among the variables were statistically significant, and those that were statistically significant were small in magnitude, or showed no consistent trend, and were not of operational consequence.

A typical set of results is shown in Fig. 1, which shows the accuracy of bar position identification at each target intensity for 3 target colors and two backscatter conditions. The backscatter light settings represented in this figure are, by appearance, the two extreme conditions: (1) green, aimed at the target and in line with it; (2) red, aimed away from the target, and displaced 15 feet laterally from the observers. The first condition seemed to produce maximum backscatter, the second, minimum, within the range covered in this test.

In Fig. 1, the white target seems to be less visible through the maximum backscatter, the green target somewhat less visible, but the red target seems slightly more visible. None of these differences is consistently demonstrated in the other data, except that the detectability of the white target seems generally higher with red backscatter than with green. (The difference shown in Fig. 1 was the largest obtained.)

Tables 1 and 2 have been provided to indicate the general similarity among average detection scores for the various test conditions. A perfect score in any cell of Tables 1 and 2 would have been 2.0. Inspection will show that the differences were indeed small throughout all test conditions.

As might be expected from mean scores such as these, analysis of variance computations yielded few F ratios that achieved statistical significance at or beyond the .01 level. The only consistent differences were among the observers as individuals. The summary of the analyses of variance is presented in Table 3.

For practical purposes then, steady backscatter does not appear to affect the ability of a pilot to detect the lights of another aircraft foveally (at least insofar as this is related to his ability to identify a target bar position), or to identify the light color in VFR atmospheres. This conclusion is based on data obtained in a ground test under artificial conditions, which, however, were subject to a high degree of control in many respects, particularly in those relating to the photometric characteristics of the lighting equipment used and to the geometry of the equipment-observer layout. On the other hand, while the atmospheric transmissivity was measured during the tests, the transmissometer path and the observer-target path were different (although intersecting), and it was not practicable to make measurements of droplet size or distribution, or for that matter, even the atmospheric particle composition.

The results are nevertheless important, since the backscatter light intensity, 5500 candles, was appreciably higher

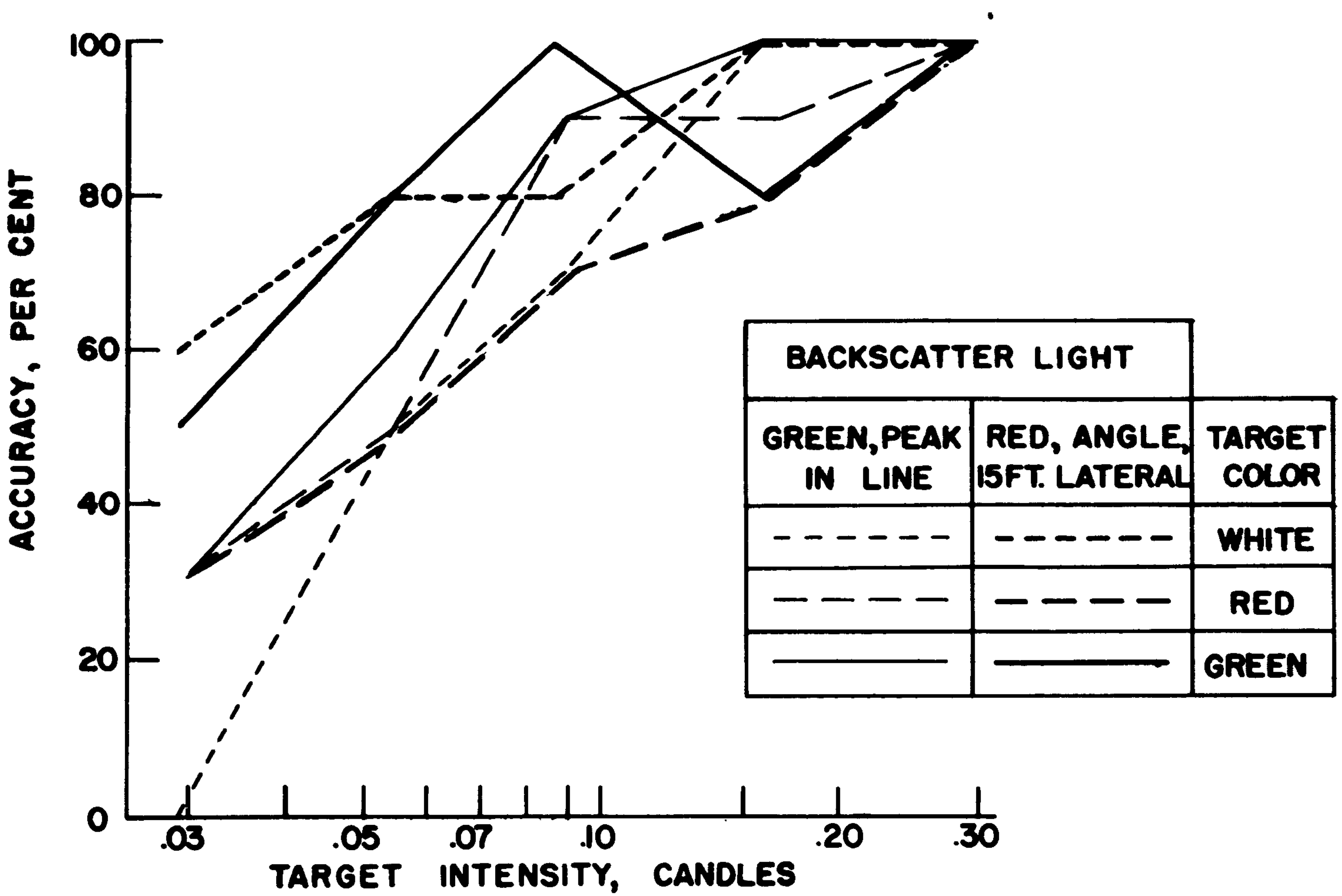

Fig. 1. Accuracy of target bar position identification for two backscatter light conditions.

Table 1

Accuracy of Target Light Perception Through Steady Backscatter; Average Color Identification Scores[a]

Target Light Color	Red Backscatter			Green Backscatter		
	Beam Alignment[b]			Beam Alignment		
	0°	19.5°	Both	0°	19.5°	Both
Red	1.54	1.46	1.50	1.50	1.50	1.50
Green	1.48	1.70	1.59	1.48	1.52	1.50
White	1.34	1.24	1.29	1.22	1.50	1.36
All Colors	1.45	1.46	1.46	1.40	1.50	1.45

a Maximum possible score (perfect identification) was 2.00.

b Beam alignment was such that the peak intensity of the beam was directed at the target (0°), or to one side of the target so only 20% of peak intensity was directed at target (19.5°).

Table 2

Accuracy of Target Light Perception

Through Steady Backscatter; Average Target Bar

Position Identification Scores[a]

Target Light Color	Red Backscatter			Green Backscatter		
	Beam Alignment[b]			Beam Alignment		
	0°	19.5°	Both	0°	19.5°	Both
Red	1.50	1.38	1.44	1.42	1.36	1.39
Green	1.48	1.68	1.58	1.54	1.48	1.51
White	1.64	1.68	1.66	1.30	1.54	1.42
All Colors	1.54	1.58	1.56	1.42	1.46	1.44

[a] Maximum possible score (perfect identification) was 2.00.

[b] Beam alignment was such that the peak intensity of the beam was directed at the target (0°), or to one side of the target so only 20% of peak intensity was directed at target (19.5°).

Table 3

Summary of Statistical Tests of Main Effects and Interactions of Variables

Source of Variance	Backscatter Light Overhead: Position Scores	Backscatter Light Overhead: Color Iden. Scores	Backscatter Light Displaced 15 ft.: Position Scores	Backscatter Light Displaced 15 ft.: Color Iden. Scores
A. Backscatter Light Color	**	0	0	0
B. Target Light Color	0	0	0	0
C. Backscatter Light Angle	0	0	**	0
D. Subjects	**	0	**	**
E. Target Intensity				
AxB	0	0	0	0
AxC	0	0	*	0
AxD	0	0	**	0
AxE	0	0	0	0
BxC	0	0	0	0
BxD	0	*	**	*
BxE	0	0	0	0
CxD	0	0	0	0
CxE	0	*	0	0
DxE	0	0	**	0
AxBxC	*	0	0	0
AxBxD	0	0	**	0
AxBxE	0	0	0	0
AxCxD	0	0	0	0
AxCxE	0	0	0	0
AxDxE	0	0	**	0
BxCxD	0	0	**	0
BxCxE	0	0	0	0
BxDxE	0	0	**	0
CxDxE	0	0	**	0
AxBxCxD	0	0	*	0
AxBxCxE	0	0	**	0
AxCxDxE	0	0	**	0
AxBxDxE	0	0	**	0
BxCxDxE	0	0	**	0
AxBxCxDxE	(not tested)		(not tested)	

** Significant at the .01 level.
* Significant at the .05 level.
0 Not statistically significant.

than that of any navigation lights now in use. It may thus be concluded that substantial increases in the intensity of presently available navigation lights will not, because of backscatter, significantly reduce the pilot's ability to detect the lights of another aircraft foveally, or to identify their color, within the range of VFR operation.

During the course of the test work, it was noted consistently that the green backscatter light produced much more apparent backscatter than the red backscatter light, so much so that the negative results were surprising. Analysis suggests an explanation for this effect. While the two backscatter lights were essentially equal as measured photometrically, this equality is based on photopic measurement--representing cone vision characteristic of foveal viewing. Peripherally the lights are strongly unequal, with the peripheral sensitivity for red being much less than it is for green. Thus green backscatter is seen as filling the entire field of view while red backscatter, equally effective foveally but very much less so peripherally, seems strikingly smaller in magnitude. To the moderately dark-adapted eye, with peripheral rod vision a major mode of seeing, the difference is overwhelming. Our results suggest that this difference in observed backscatter is more apparent than real insofar as foveal viewing is concerned.

Backscatter Test II

Background

The second investigation is a logical extension of the first study which determined the effect on target light detection of placing a steady-burning, red or green backscatter-generating light. Backscatter Test II extended the investigation to include both steady and flashing backscatter generating lights, and the use of a single flash-coded target light instead of a bar target. Thus, the parameters investigated were:

1. Color of the target light (red or green);
2. Viewing mode (foveal or peripheral vision);
3. Color of the backscatter light (red, green, or white); and
4. Mode of the backscatter light (off, steady, or flashing).

Experimental Equipment

Backscatter Test II was also conducted at night at the Warren Grove Visual Test Range using the same equipment as Test I except for the target light.

A single target light flashing codes, was located on a pole about 4000 feet from the Observer Building. It was adjustable for 14 different intensity levels (.016, .028, .046, .076, .125, .21, .35, .59, .98, 1.66, 2.7, 4.6, 7.5, and 12.6 candles) and, by the use of appropriate filters, for red and green colors. A white light of low intensity, located in close proximity to the target light, was presented as a fixation point during the intertrial period during the foveal vision test. This light was automatically extinguished when the target light was presented. A white light of low intensity, located 10 degrees to the right of the target light but at a distance of approximately 350 feet from the Observer Building, was presented continuously as a fixation light during the peripheral vision test. The backscatter generating light (BGL) was located directly over the viewing positions and aimed at the target light.

The subjects' apparatus was a box containing three buttons and a model airplane. Momentary depression of the buttons was indicated on a response panel in the downstairs room where a data recorder tabulated results. The operation of the response apparatus was as follows:

1. Depression of left button indicated "target light not seen;"

2. Depression of middle button indicated "target light seen, but code unrecognized;" and

3. Bank of airplane and depression of right button indicated "saw target light and interpreted code" (left bank meant dash-dot-dot, level meant dot-dash-dot, and right bank meant dot-dot-dash).

Test Procedures

Tests were conducted on six nights. All test conditions for one viewing mode were presented as a block of trials.

The experimental design required that both colors of the target light be tested under conditions of "No Backscatter" prior to and following each viewing mode section. The order of presenting the "No Backscatter" trials was: red target light first and green target light second. The order of presentation of the various backscatter conditions was randomized for each of the sessions.

Each combination of the four parameters comprised an experimental run. Each run consisted of an ascending series of trials in which the intensity of the target light was increased one intensity level per trial. Although the intensity of the target light could be set at 14 discrete steps, the actual run usually did not cover more than seven different intensity levels.

Three presentations of a code constituted a trial. The sequence of codes within a run was randomized such that no two successive trials had the same code. Each run had a different code sequence. Subjects were tested under all experimental conditions.

The 17 subjects were tested in two groups of six, and one group of five. All had 20/20 visual acuity (corrected), and normal color vision. They spent a half hour dark-adapting before the start of the experiment, during which they were given an initial briefing acquainting them with the purpose of the test, the special conditions of the test, and the technique for utilizing the response apparatus. Two practice runs were given to familiarize them with experimental equipment and procedures; followed by the two runs with no backscatter and then the experimental runs.[1]

Results and Discussion

The cumulative percentages of subjects correctly identifying the coded target light at each intensity level are shown in Figs. 2 through 9. The data presented in Figs. 2 through 5 are based on 11 subjects tested on nights when the transmissivity averaged approximately 48-70% per mile; Figs. 6 through 9 are based on six subjects tested when the transmissivity averaged approximately 21 to 32% per mile. (Transmissivities of 48 to 70% per mile correspond to transmissions at the target distance of 4000 feet of 57 to 76%. Transmissivities of 21 to 32% per mile correspond to transmissions of 30 to 42%.)

The figures reveal surprisingly little variation between the various backscatter conditions for a given colored target light and viewing mode. That is, the six curves representing the various backscatter conditions appear to vary around some central curve which would be characteristic of foveal or of peripheral vision for red and for green target lights.

The average code interpretation thresholds for each target light color and viewing mode (obtained by summing medians of the six backscatter conditions) are presented in Table 4. These data indicate that under high transmissivity conditions the foveal interpretation thresholds are approximately the same for green and red target lights. The interpretation thresholds for peripheral vision are above those for foveal, with the red threshold being approximately twice that for green. At the lower transmissivities, all thresholds were raised. (The transmission over the 4000-foot target distance was about one-half that at the higher range of transmissivities.) As shown in the right

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1 In this test, the observers were asked to identify the flashed code of the target light; they were not asked to identify its color as in Test I.

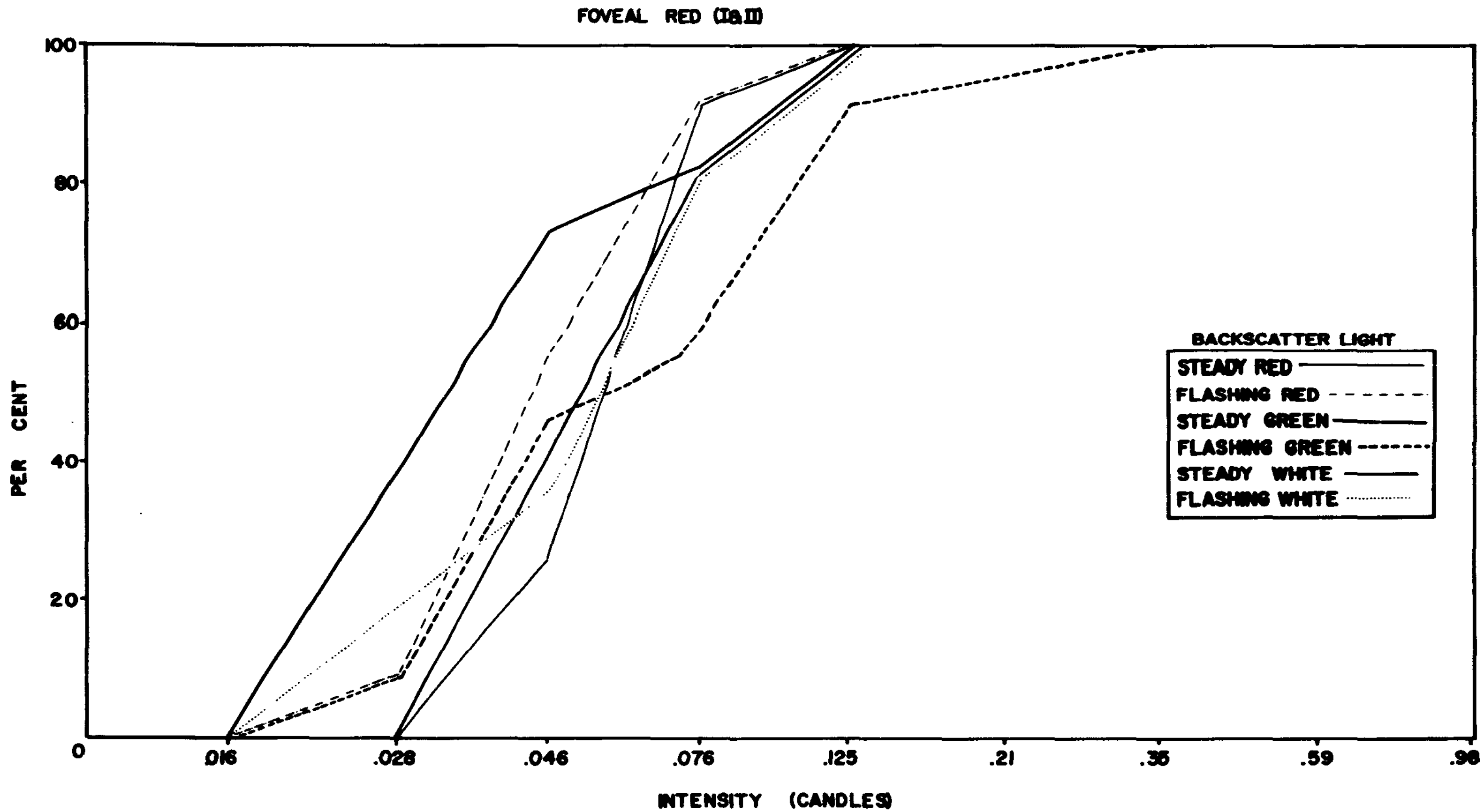

Fig. 2. Cumulative percentage of correct identifications for a red, coded target light viewed foveally under six conditions of backscatter light on nights with high transmissivity (48-70% per mile). Curves are based on eleven subjects (Groups I and II).

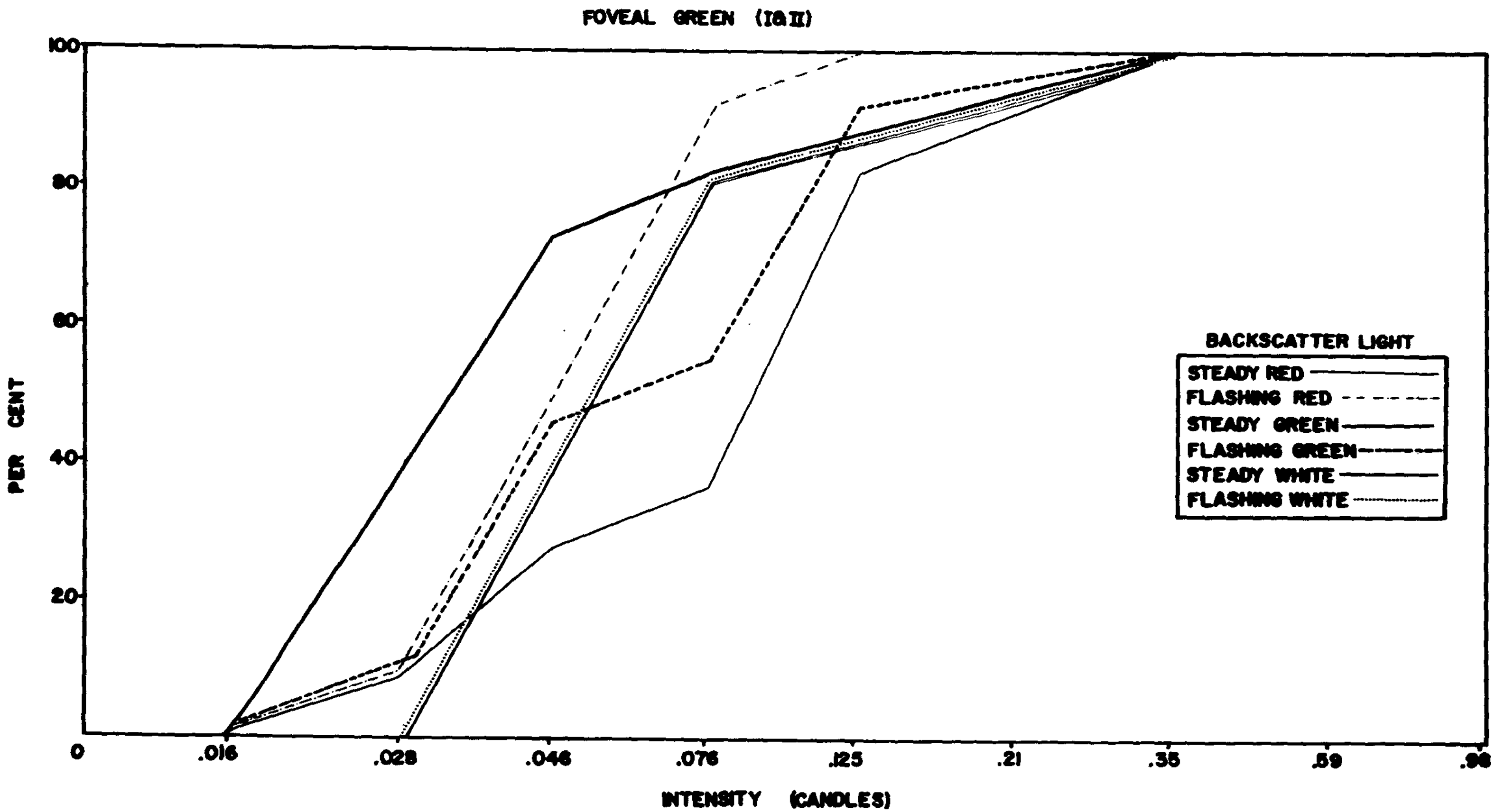

Fig. 3. Cumulative percentage of correct identifications for a green, coded target light viewed foveally under six conditions of backscatter light on nights with high transmissivity (48-70% per mile). Curves are based on eleven subjects (Groups I and II).

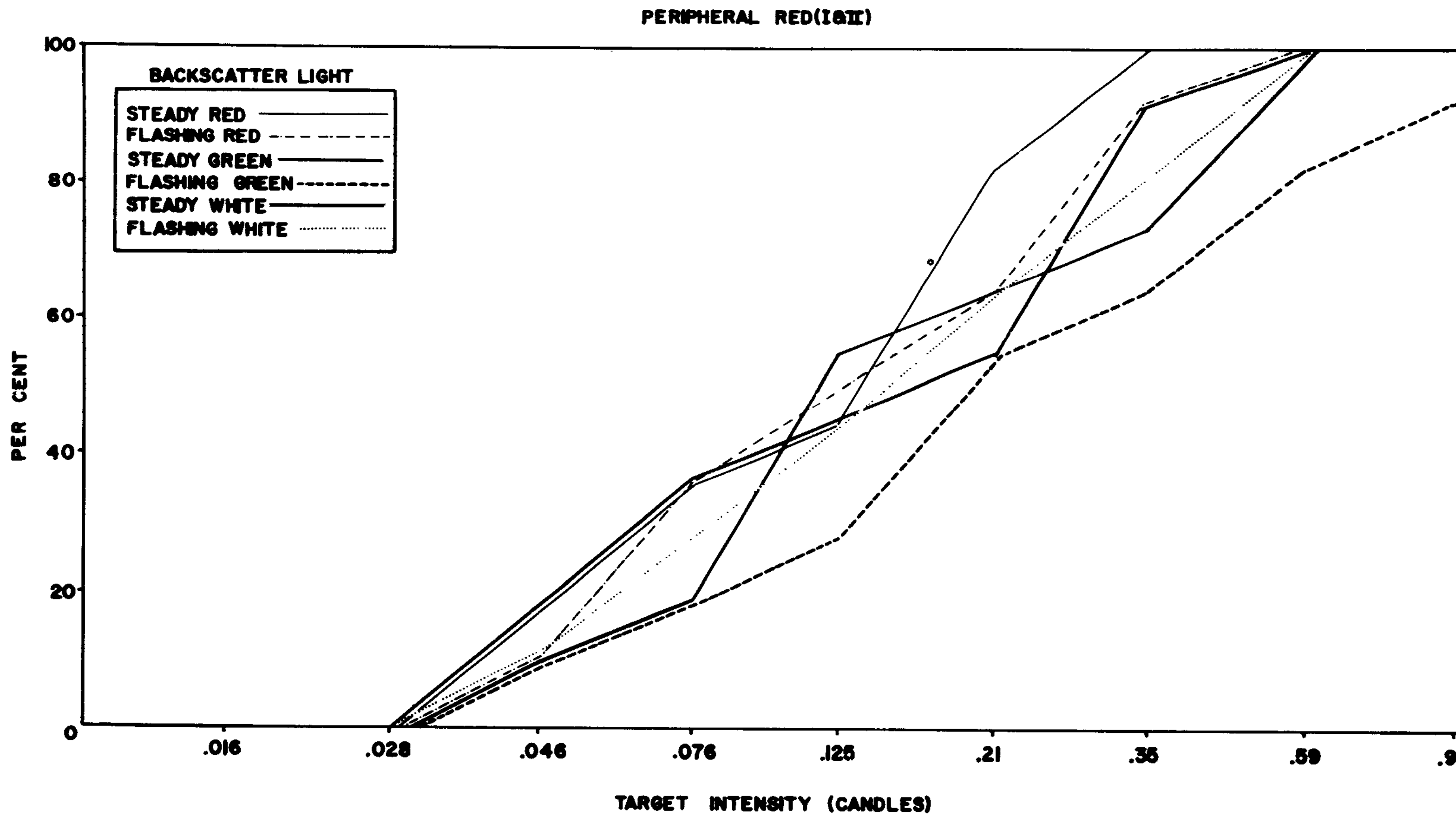

Fig. 4. Cumulative percentage of correct identifications for a red, coded target light viewed peripherally under six conditions of backscatter light on nights with high transmissivity (48-70% per mile). Curves are based on eleven subjects (Groups I and II).

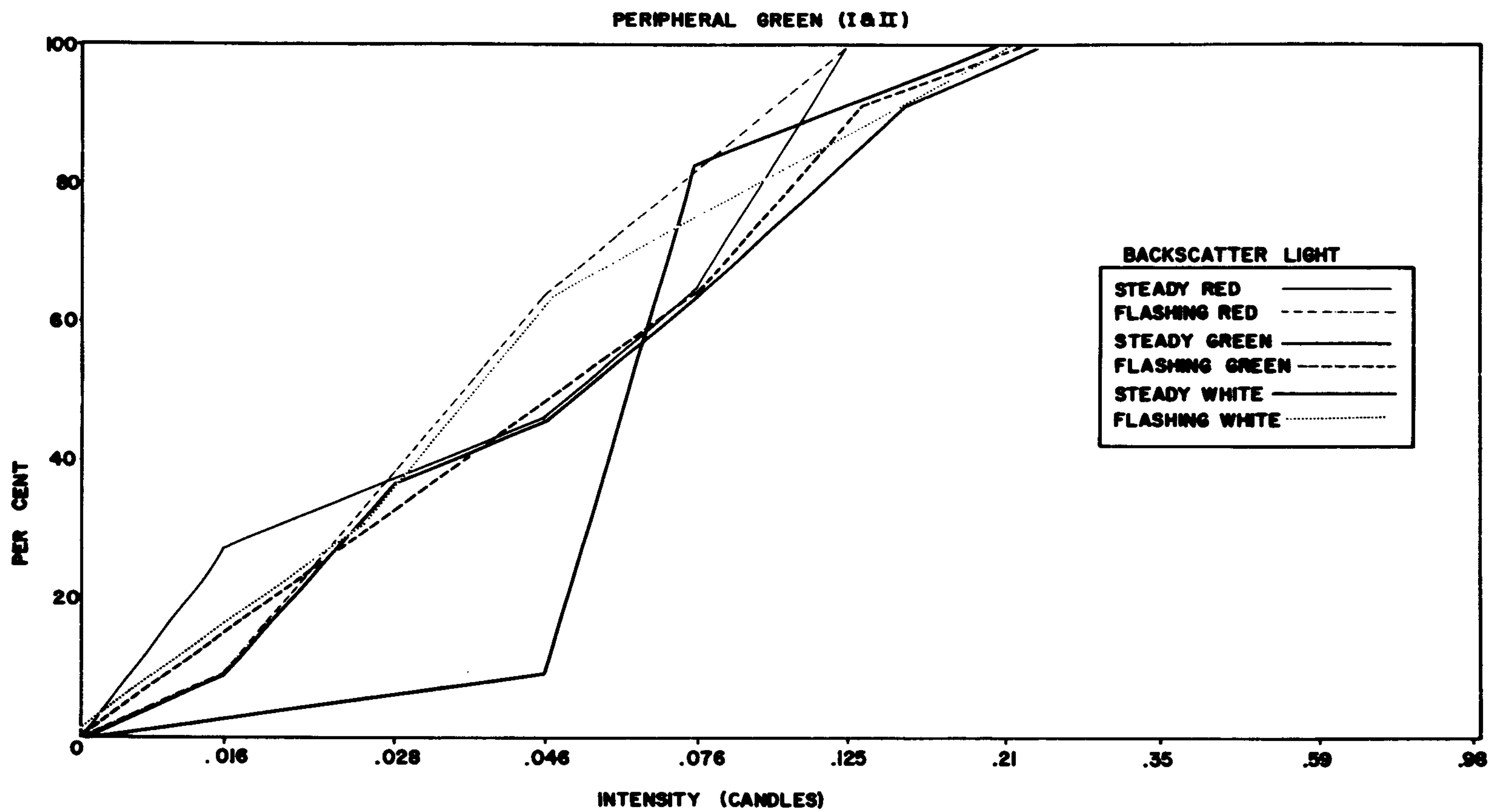

Fig. 5. Cumulative percentage of correct identifications for a green, coded target light viewed peripherally under six conditions of backscatter light on nights with high transmissivity (48-70% per mile). Curves are based on eleven subjects (Groups I and II).

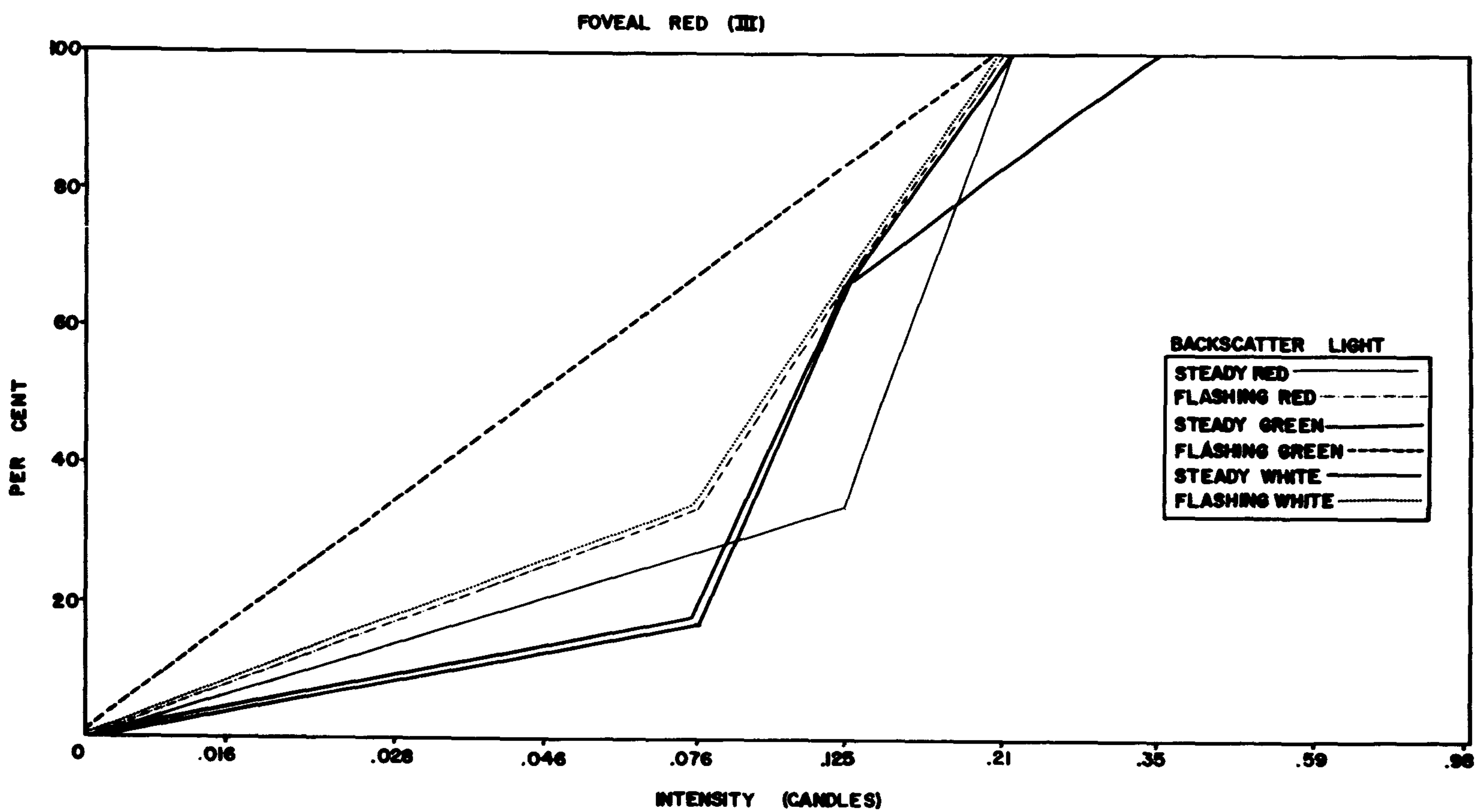

Fig. 6. Cumulative percentage of correct identifications for a red, coded target light viewed foveally under six conditions of backscattered light on nights with low transmissivity (21-32% per mile). Curves are based on six subjects (Group III).

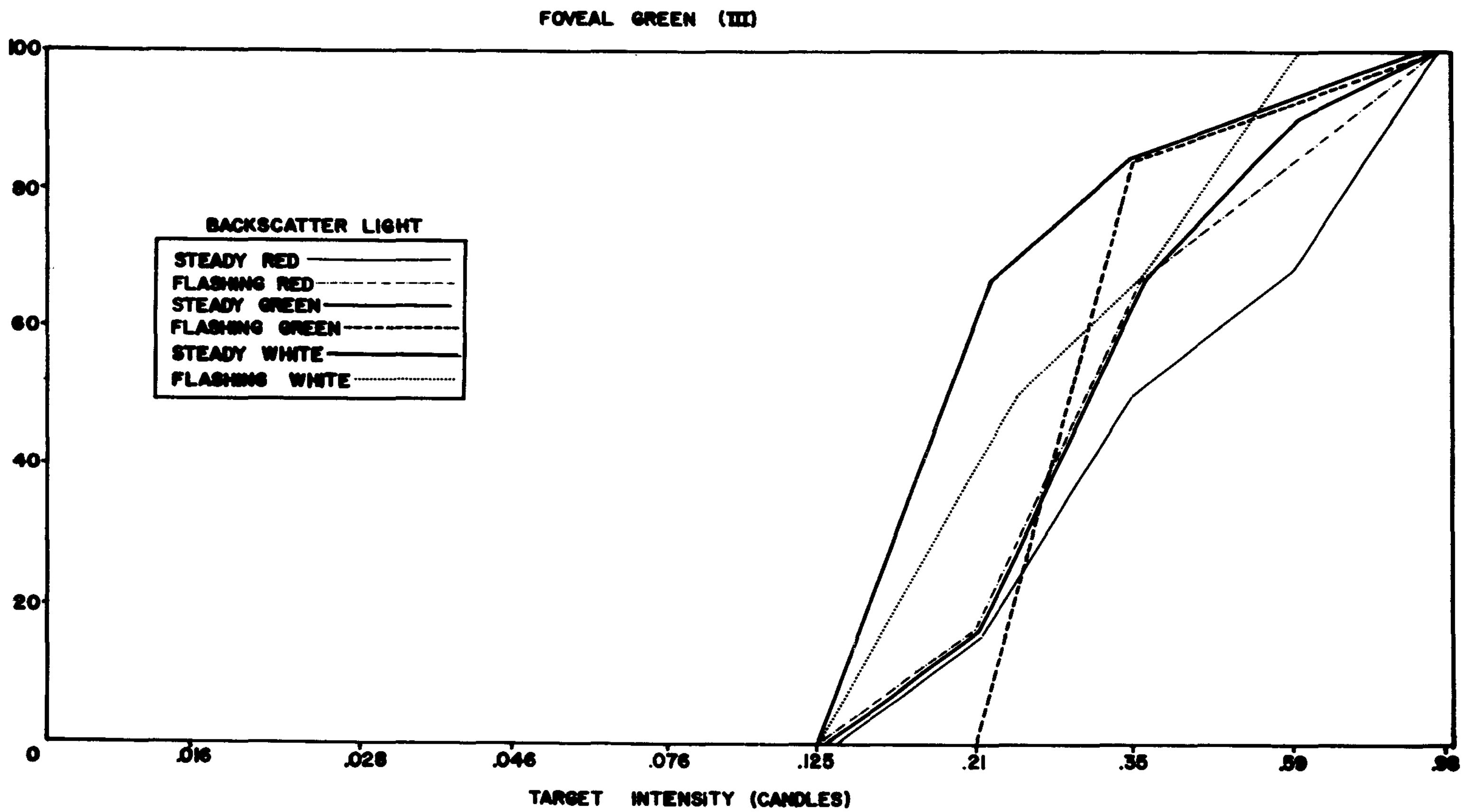

Fig. 7. Cumulative percentage of correct identifications for a green, coded target light viewed foveally under six conditions of backscattered light on nights with low transmissivity (21-32% per mile). Curves are based on six subjects (Group III).

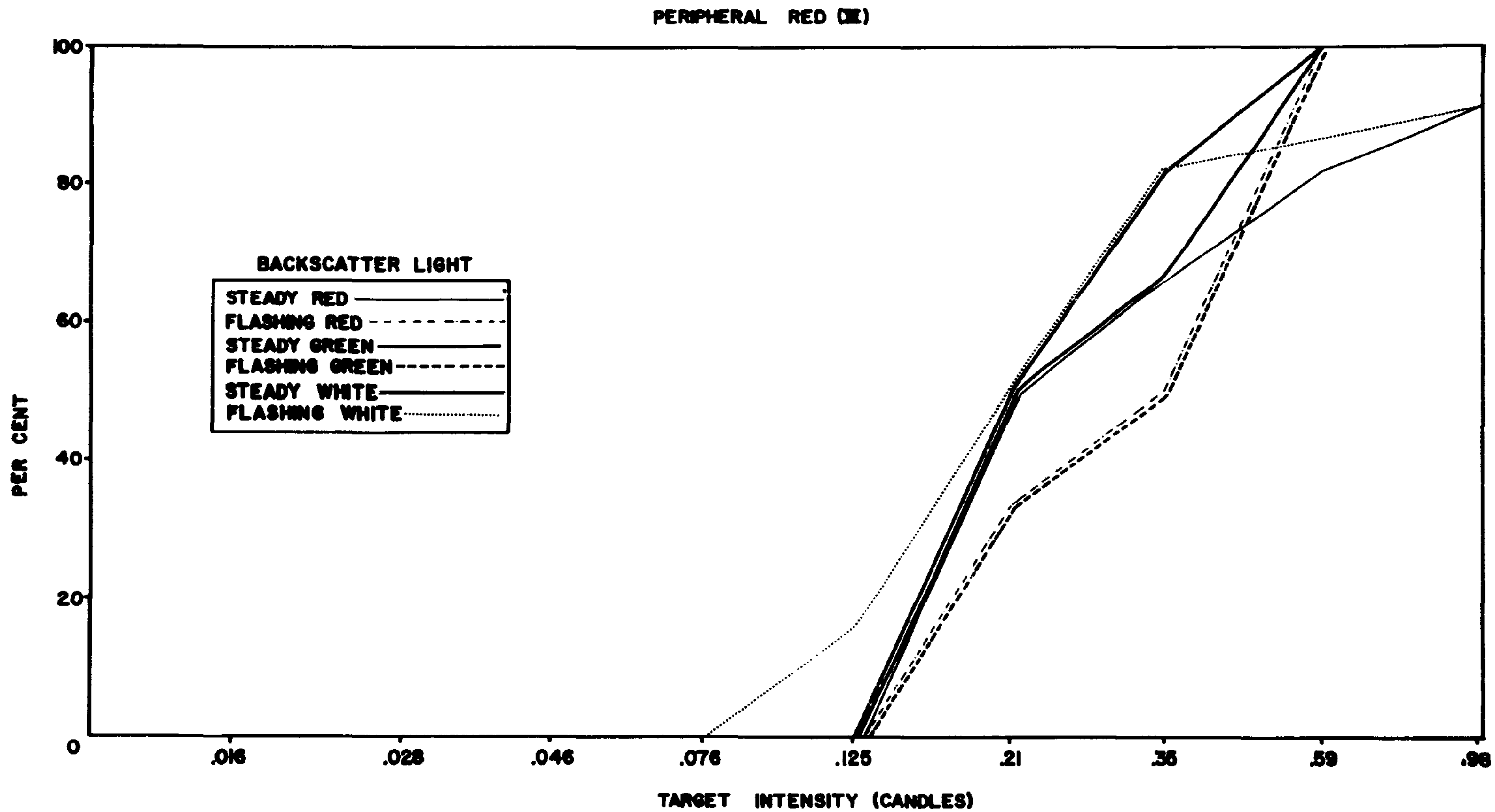

Fig. 8. Cumulative percentage of correct identifications for a red, coded target light viewed peripherally under six conditions of backscattered light on nights with low transmissivity (21-32% per mile). Curves are based on six subjects (Group III).

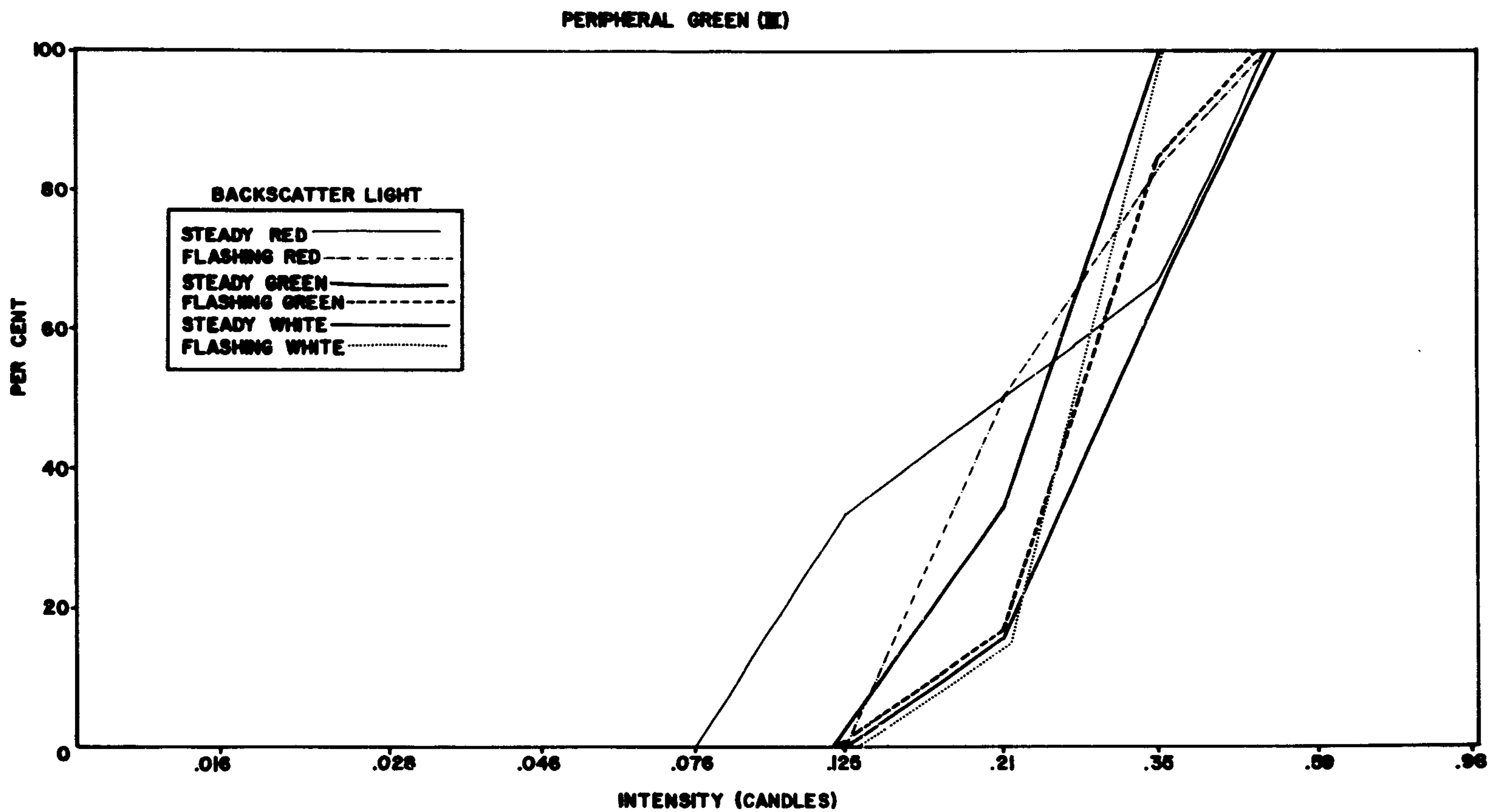

Fig. 9. Cumulative percentage of correct identifications for a green, coded target light viewed peripherally under six conditions of backscattered light on nights with low transmissivity (21-32% per mile). Curves are based on six subjects (Group III).

Table 4

Interpretation Thresholds (in candles) for a

Coded Light Signal as a Function of Transmissivity

Target Light Color	Viewing Mode	Transmissivity (1) 48-70% per mile[a]	Transmissivity (2) 21-32% per mile[b]	Ratio of Columns (2)/(1)
Red	Foveal	.050	.100	2.0
	Peripheral	.146	.269	1.8
Green	Foveal	.055	.258	4.7
	Peripheral	.079	.251	3.2

[a] Based on 11 subjects.

[b] Based on 6 subjects.

Table 5

Analysis of Variance of Difference Scores

for 48-70%/mile Transmissivity

Source		Sum of Squares	df	Variance	F
Viewing Mode	A	35.4	1	35.40	0.32
Target Color	B	218.8	1	218.80	7.97*
Backscatter Color	C	275.3	2	137.65	3.15
Backscatter Mode	D	35.0	1	35.00	1.91
Subject	E	1969.1	5	393.82	
	AXB	144.2	1	144.20	0.59
	AXC	87.4	2	43.70	0.28
	AXD	6.4	1	6.40	0.08
	AXE	555.2	5	111.04	
	BXC	132.0	2	66.00	0.54
	BXD	54.0	1	54.00	0.77
	BXE	137.2	5	27.44	
	CXD	263.3	2	131.65	2.22
	CXE	868.0	10	86.80	
	DXE	91.7	5	18.34	
	AXBXC	21.3	2	106.55	0.80
	AXBXD	62.8	1	62.8	2.55
	AXBXE	1217.4	5	243.48	
	AXCXD	44.4	2	22.2	1.56
	AXCXE	1549.6	10	154.96	
	AXDXE	389.2	5	77.84	
	BXCXD	146.1	2	73.05	9.48**
	BXCXE	1213.1	10	121.31	
	CXDXE	592.4	10	59.24	
	BXDXE	351.4	5	70.28	
	AXBXCXD	0.1	2	0.05	.001
	AXBXCXE	1327.7	10	132.77	
	AXBXDXE	123.2	5	24.64	
	AXCXDXE	142.6	10	14.26	
	BXCXDXE	154.1	10	15.41	
	AXBXCXDXE	656.9	10	65.69	

* Significant at the .05 level

** Significant at the .01 level

hand column of Table 4, the thresholds for red were doubled, which can be accounted for solely by the reduced transmission. However, thresholds for the green target were raised by a factor of 3 to 5.

The additional increase of the green threshold beyond the expected factor of 2 may be accounted for by selectively lower transmission for green light and correspondingly higher backscatter.

It is of interest to separate the effects of transmissivity and backscatter. In order to accomplish this, transmissivity effects on thresholds were partialed out by taking the difference between the intensity level of the first correctly identified code when the backscatter light was on and when it was off. These "difference scores" represent, therefore, the effects of backscattered light, since the only difference between the two conditions is the presence or absence of backscattered light. Positive differences result if backscattered light raises the interpretation threshold; negative differences result if backscattered light lowers the threshold.

Results of the analyses of variance of the difference scores for 48-70% per mile transmissivity are presented in Table 5, and for 21-32% per mile transmissivity in Table 6. Only two statistically significant differences were found (both at higher transmissivity) corroborating the conclusions obtained by inspection of Figs. 2 through 9 that there were few consistent differences.

The results of this experiment are, therefore, similar to those of the first test of the effects of backscatter. The color of the backscatter generating light itself and its characteristic (whether flashing or steady) did not materially affect subjects' ability to detect targets in VFR atmospheres. Differences in target detectability that were found were largely attributable to atmospheric attenuation and sensitivity differences in the eye. Almost no differences were statistically significant.

Summary

Field tests of the effects of backscattered light on target light detectability in VFR atmospheric conditions were conducted controlling many variables known to produce more or less backscatter. Different colors of backscatter generating light and target light were used, and were studied when flashing and when steady. The lateral displacement of the backscatter light was varied, as was the direction of the beam. Subjects viewed the target both foveally and peripherally. Atmospheric transmissivity was measured during the test.

Table 6

Analysis of Variance of Difference Scores

for 21-32%/mile Transmissivity

Source		Sum of Squares	df	Variance	F
Viewing Mode	A	82704.2	1	82704.2	1.28
Target Color	B	935.3	1	935.3	0.01
BGL Color	C	75869.6	2	37934.8	1.19
BGL Mode	D	3432.0	1	3432.0	0.10
Subjects	E	68207.4	5	13641.4	
	AXB	4612.7	1	4612.7	0.28
	AXC	66900.3	2	33450.1	0.80
	AXD	39567.8	1	39567.8	1.44
	AXE	322253.5	5	64450.7	
	BXC	90502.9	2	45251.4	1.31
	BXD	21097.6	1	21097.6	1.25
	BXE	399139.0	5	79827.8	
	CXD	184056.0	2	92098.0	1.65
	CXE	319659.4	10	31965.9	
	DXE	177496.5	5	35499.3	
	AXBXC	110740.4	2	55370.2	1.68
	AXBXD	28532.8	1	28532.8	1.16
	AXBXE	82756.9	5	16551.4	
	AXCXD	34443.7	2	17221.8	0.17
	AXCXE	415767.9	10	41576.8	
	AXDXE	137389.9	5	27478.0	
	BXCXD	30647.2	2	15323.6	0.15
	BXCXE	344716.1	10	34471.6	
	CXDXE	558223.4	10	55822.3	
	BXDXE	84503.5	5	16900.7	
	AXBXCXD	113176.8	2	56588.4	1.15
	AXBXCXE	329944.4	10	32994.4	
	AXBXDXE	122489.1	5	24497.8	
	AXCXDXE	1037831.4	10	103783.1	
	BXCXDXE	1020497.1	10	102049.7	
	AXBXCXDXE	493046.7	10	49304.7	

Results indicate that insofar as target detectability is concerned, backscatter does not have much effect in VFR flying. Differences in threshold could, in the main, be accounted for by lowered atmospheric transmissivity and sensitivity characteristics of the eye. Nothing in these tests, however, dealt with other possible effects of backscatter such as distraction, fatigue, disorientation, and so forth. The striking differences in the subjective appearance of different backscatter colors and modes of flashing suggest that these effects might not be negligible. These tests were conducted under static conditions. Motion of the backscatter generating light may well produce more pronounced effects on both target detectability and psychomotor performance. In denser atmospheres than those covered in these tests, backscatter effects are much more pronounced, and are often so overwhelming that pilots feel compelled to turn off their lights, particularly their anti-collision lights.

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