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Depth perception of coloured lights in motion under difficult seeing conditions.

James Joseph Sheridan
University of Windsor

DEPTH PERCEPTION OF COLOURED LIGHTS IN MOTION
UNDER DIFFICULT SEEING CONDITIONS

A Thesis

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by

James Joseph Sheridan, Jr.

Approved by:

Raymond M. Daly

Paul L. Connolly

ABSTRACT

This study attempted to test perception of motion in depth of four monochromatic lights (blue, green, amber, and red) under difficult seeing conditions. A circular light 3/4 inch in diameter was turned on and moved toward or away from the subject. His task was to judge the direction of movement.

The experimental setting was scaled to a car following situation at a distance of 300 feet. Tests were carried out under different seeing conditions. These included simple dark, fog, glare, and combinations of fog and glare.

Two experiments were run. Experiment I employed lights of equal intensity and Experiment II used lights of equal brightness. A total of 44 S's were tested.

Results showed that judgements of direction on red and amber were statistically more accurate than judgements on blue and green. This perception is important in the car following situation. Red and amber appear to be more suitable colours for automobile tail lights.

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CHAPTER I

INTRODUCTION

1. The Problem

There has been a growing concern in recent years that present tail light systems on road vehicles should be improved. One of the problems being researched is the selection of appropriate colours for the system. Allen (1964) has recommended the use of green tail lights. The Automobile Manufacturers Association (AMA) has been considering this alternative. According to Mr. A. J. Doty[1] of the AMA, there are several questions about the use of green which have not been answered. For example, what are the consequences of having some cars (newer models) equipped with green tail lights and others (older models) with red rear running lights. Will this confuse drivers? What are the psychological meanings of red and green in the driving situation?

An additional problem with green is that six per cent of the male population is not able to see green while only one per cent fails to see red. Cole and Brown (1966), Nathan, Henry and Cole (1964), and Shirley (1966) have examined the efficiency of traffic lights systems with colour defectives. Their recommendations have been to retain the existing red, yellow, green arrangement with only slight modifications.

Most of the available evidence indicates that red is the most efficient colour under a wide range of conditions (Connolly 1966). Furthermore, Connolly (1966 and 1967) has pointed to the extreme complexity

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[1] A. J. Doty, personal communication, November 20, 1967.

of the visual environment and to the intricacy of the driver's task. It is apparent that a great deal of research, testing many conditions and combinations of these is necessary before sound recommendations can be made concerning the proper use of colour in rear vehicle lighting systems.

One aspect of this problem which has not been studied is the thresholds for motion in depth for different colours. This becomes important in night driving on rural roads where the dominant cues to the distance of a preceding car are supplied solely by its tail lights. Two similar situations are fog and glare. These are the factors of primary interest in this study.

2. Cues in Depth Perception

There are several variables affecting depth perception of moving and stationary targets. Dichman, Preston and Mull (1944) showed that distance discrimination of two square black targets improved under bright light as opposed to dim light. Similar results were reported by Lit and Hamm (1966). As retinal illuminance decreased, threshold for depth increased.

Hirsch and Weymouth (1947) found that with stationary targets at distances of 61, 122 and 183 meters, the ratios of monocular to binocular thresholds are 2.81, 2.04, and 1.77 respectively. This function should converge at approximately 1,000 feet by extrapolation. They also discovered that employment of moving targets improved monocular discrimination but had no effect on binocular threshold. The same authors examined the relationship of visual acuity to distance discriminations. Those subjects having better acuity had lower thresholds for depth discrimination (Hirsch and Weymouth 1948).

Van Vorhees Lloyd (1953) studied the role of stimulus area and brightness in depth perception. He demonstrated that perceived distance varied inversely with the area and intensity of the stimulus. The brightness variable was especially effective for the stimulus of smaller areas.

William M. Smith (1955) tested the effects of monocular and binocular vision, brightness level, and apparent size on sensitivity to apparent movement in depth. He found binocular vision to be superior. In this experiment, the subject was 12 feet 8 inches from the stimulus. Consistent with Lloyd's findings, he obtained an increase in sensitivity with brighter targets. Similar results for brightness are reported by Baker and Steedman (1961). Their subjects were located 25 feet from the stimulus target. An additional observation of Baker and Steedman was that longer viewing times were needed when targets were moved slower.

The perception of real movement as a function of angle of approach was examined by Brown, Naylor and Michels (1962). Ability to detect movement increased with an increase in angle off-line of sight.

Teichner, Kobrick, and Dusek (1956) studied the effects of target separation (from $\frac{1}{2}$ to 4 inches) and distance (from 10 to 100 feet) on binocular depth perception. No significant differences were obtained for target separation.

An extensive study on the distance perception of automobile tail lights was carried out by Parker, Gilbert and Dillon (1964). All tests were performed at night on an airport runway. One car approached another at speeds of 20, 30 or 40 miles per hour. The preceding car was equipped with a set of tail lights which could be manipulated in several ways. Area, brightness, and visual angle between the two lights could be controlled such that an observer in the approaching car has the use of only one cue at a time. This permitted the experimenters to analyze separately the effects of increase in area, brightness, and angle between the tail lights. The change in brightness and separation of the two tail lights were the dominant cues in this situation. A control condition was used in which all three cues were applied to the driver (the normal approach condition). Performance of the subjects was significantly superior to all other conditions. This led the authors to suggest that change in brightness and angle between lights work additively, at least in part. There was no difference in performance with change in approach speed for any of the conditions tested.

3. Apparent Movement

Smith (1951 and 1952) demonstrated that sensitivity to apparent movement in depth is not influenced by stimuli characterized as possessing the property of movement nor by the dimensionality of the stimulus.

The literature on apparent movement deals principally with motion in the frontal plane. J. F. Brown (1931a) carried out a series of experiments on the thresholds for visual movement and the perception of velocity using squares or dots moving in a homogeneous field. Phenomenal velocity appears to have four phases. Very slow movement of a target or pattern is perceived indirectly. It is inferred by the observer when he detects a change in position of the target from its original starting point. The next type of movement is perceived directly. The target is moved at intermediate speeds. When speed is increased further, backward movement appears. Finally, at very high rates of target speed, the stimuli fuse into a gray line.

In another series of experiments (Brown, 1931b), he demonstrated that phenomenal velocity was a function of several variables including size of the surrounding field and size of the targets, distance between the targets, homogeneity of the surrounding field, and distance of the object in motion. Furthermore, he showed that lower thresholds for movement corresponded to the conditions which increased phenomenal velocity. For example, if apparent speed of an object was high in a certain setting, the sensitivity for movement in that situation was also high.

Later Wallach (1939) derived a principle of constant speed from the work of Brown. The perceived speeds in transposed movement fields are the same when their relative displacements in those fields are equal.

R. H. Brown (1955) found that threshold values for velocity discrimination followed the Bunsen-Roscoe Law for time exposures up to one second. Perceived movement persistence in the Ganzfeld was studied by Miller (1961). He measured the time delay between the actual stopping of the stimulus target and the subject's judgement that it had stopped. This time delay decreased as angular velocity of the target increased. Delay was greater for smaller target size. He inferred from this that larger objects appear to move faster.

4. Colour and Depth Perception

Several studies have reported the effects of colour on apparent size (Warden and Flynn 1926, Gundlach and MacCoubrey 1931, Wallis 1935, Taylor and Sumner 1945, Besan and Dukes 1953, and Sato 1962). They concur that size of yellow and red targets are overestimated. However, none of the forementioned controlled for brightness. This is true regarding studies of "advancing" and "retreating" colours.

In reviewing the literature it is not clear whether apparent depth is affected by colour. Luckiesh (1918) found that seven of nine observers saw red as nearer than blue. Pillsbury and Schaefer (1937) had 11 out of

15 subjects report blues as appearing nearer.

A pilot study with five members of the perception class at the University of Windsor as subjects was carried out in order to investigate this notion of "advancing" and "receding" colours. It served to "debug" the apparatus as well. The subjects were familiar with the apparatus design. They were told that a light would be moved toward or away at very slow speeds. The task was to report whether the light was approaching or receding. Five coloured lights were used with dominant wavelengths of 450, 500, 550, 600 and 650 mμ. There was a marked tendency to judge stationary lights of shorter wavelengths (450 and 500 mμ) as "receding" and to judge the stationary lights of the longer wavelengths (550, 600 and 650 mμ) as "approaching." However, the "approaching" lights were more intense than those judged to be receding.

Edwards (1953) took a large sample (190 subjects) and tested the effect of colour on apparent depth using the Howard-Dolman Apparatus. He failed to find any significant effect of colour. Mount, Case, Sanderson, and Brenner (1956) in their experiments on colour and depth expressed the view that saturation produced apparent nearness. Each colour sampled appeared closer than a neutral gray matched for brightness. Stelmack (1965) had similar findings with regard to saturation. Colours of high saturation (Munsell Chroma 10) appeared consistently nearer than colours of low saturation (Munsell Chroma 4). However, Stelmack also found a significant hue effect, in colours equated for chroma and value, with yellow being the nearest appearing colour.

5. Theory of Colour and Depth

The principal explanation given for the effect of colour on apparent depth has been chromatic aberration. Refractive index decreases as wavelength increases. Thus a blue light which falls on the fovea enters the lens at a point further out from center than a red light. This has been examined by Over (1962). He used red, green, and blue lights equated for intensity. Observers perceived red, green and blue in that order, as being nearer (significant at the .001 level).

Luckiesh (1938) and more recently Kohler (1962) and Kishto (1965) produced a reversal of this depth phenomenon with artificial pupils set close together. Kishto found that with the naked eye, the colour stereoscopic effect reversed under different background illumination. At low levels blue appears nearer while at high levels red appears nearer. Luckiesh and Kishto had a number of subjects who did not perceive differences in depth, and some for whom the effect was reversed. Vos (1966) attributes these reversals or exceptions to the Stiles-Crawford Effect (Vos 1960).

These concepts do not explain the results of Stelmack (1965) who investigated colour and depth with Munsell targets equated for brightness and saturation. The nearest appearing colour was yellow (significant at the .01 level). In summary, there is no adequate theory of colour and depth at this writing.

6. Fog and Glare

The simple effects of fog and glare are well known. Mili (1935) stated that fog reduces the apparent brightness of a light beam by diffusion. This diffusion creates a background of light which reduces the contrast between the signal beam and its surround. This factor becomes more critical in daylight due to the bright background furnished by the sun and sky. For this reason a light beam is more effective in night fog.

National Bureau of Standards Handbook 95 states that a red light penetrates fog better than any other colour, including white.

Glare reduces the visibility of objects beyond the glare source. The effect of glare diminishes with a decrease in intensity and an increase in visual angle between the target and the glare source. Connolly (1966) comments on the efficiency of red light under conditions of veiling glare. It has been his observation that red penetrates most effectively in this condition.

7. Predictions

It is clear that no very firm conclusions can be drawn from the data available at present. However, if it can be assumed--and this seems at least a reasonable guess--that the nearer a light appears to be, the easier it will be to detect its relative motion, then it may be expected that

(1) for coloured lights of equal intensity in the simple dark condition the brighter appearing lights will have lower thresholds for movement

(2) for coloured lights of equal brightness the sensitivity to motion in depth under simple dark conditions will be greatest for yellow, red, green and blue in that order

(3) in the simulated fog condition, sensitivity to motion in depth will be greatest for red followed by yellow, green and blue due to relative wavelength

(4) in the glare condition, motion in depth will be perceived first for red. The order of the remaining colours must be determined by testing.

CHAPTER II

APPARATUS AND CALIBRATION

1. Apparatus

A side view of the apparatus is presented in Figure 1. The cart is moved back and forth along a set of tracks by means of a pulley and weights system.. The maximum travel of the cart in one direction is 40 inches. The vehicle supports a Bausch and Lomb spot lamp with a 100 watt incandescent bulb. A six foot lucite rod, 3/4 inch in diameter is fastened to the front of the cart. The rod is placed inside an aluminum pipe one inch in diameter. The pipe is supported at one end by the cart and at the other by a race of barings mounted in the wall. The wall separates the control room from a 42 foot windowless room. The light shines down through the lucite rod into the windowless room. The end of the rod is roughened sufficiently so that it appears as a flat surface light located at the end of the rod.

A series of four Bausch and Lomb monochromatic interference filters are placed between the light source and the end of the rod producing lights of different colours. The predominant wavelengths of these filters are 500, 550, 600 and 650 mu. The intensity of the light was controlled by means of a variable transformer.

The target light can be moved toward or away from the observer. This was accomplished with the system of pulleys and weights attached to the front or rear of the vehicle depending on the direction desired.

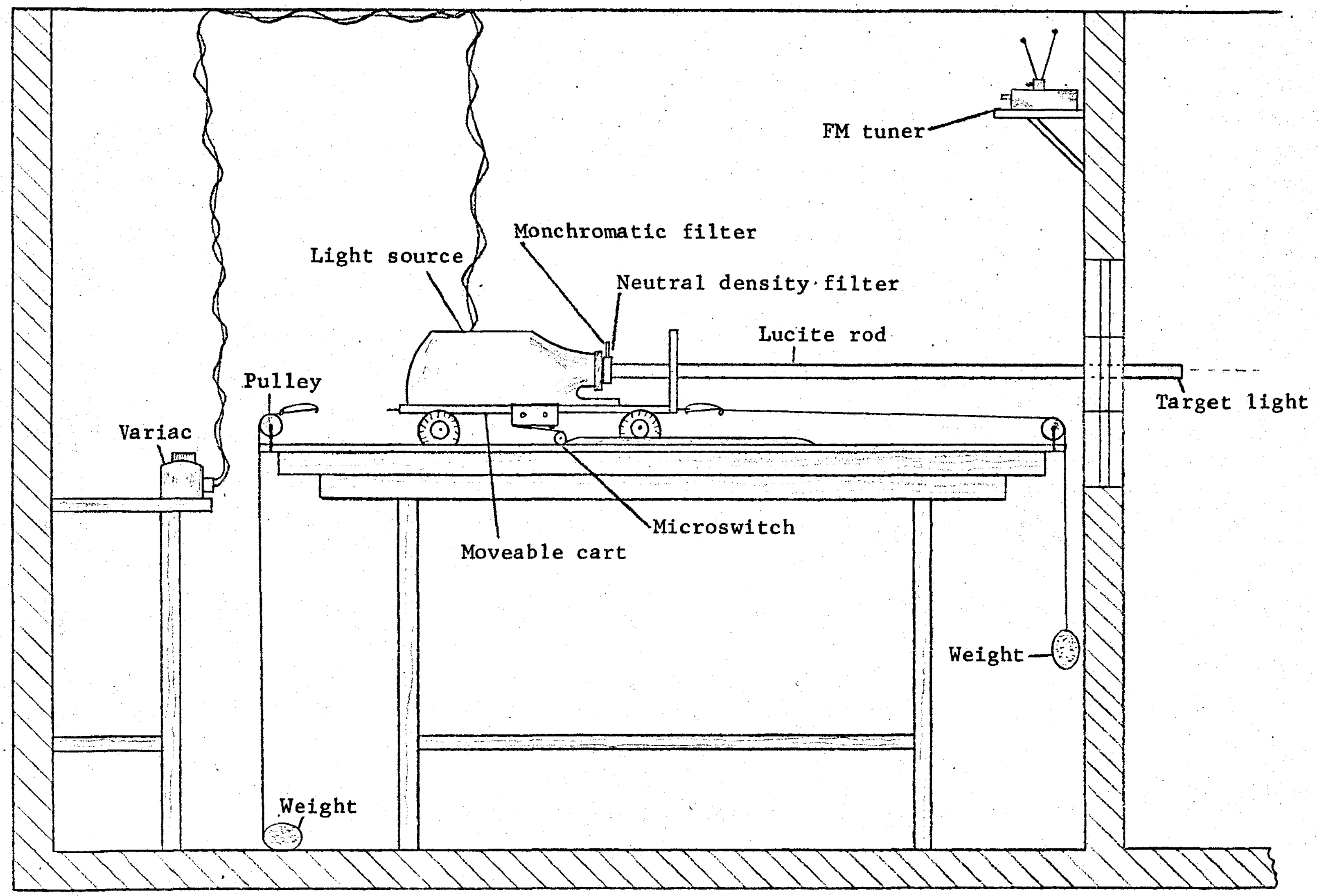

Fig. 1 Sideview of apparatus

A microswitch controlling the light source was located at the side of the cart. The switch was set for "normal off." In order to turn the switch on a small plank 31 inches long was slid underneath the switch arm. The plank was sufficient in height to trip the switch. The light was turned off when the switch arm reached the end of the plank and returned to its "normal off" position. The plank was marked in inches. This permitted E to adjust the cart travel with light on to any chosen distance.

The sound system consisted of an amplifier, FM tuner, earphones, a speaker and two microphones. S and E were able to speak with each other and at the same time listen to an FM radio station.

2. Stimulus Setting and Dimensions

Figure 2 is a plan view of the apparatus in the experimental rooms. S is seated 20 feet from the stimulus target when it is extended to its most forward position. It was decided that this should be the minimum distance from S to the target at its nearest point in order to eliminate accommodation cues.

The starting point of the target light on all trials was 21.92 feet from S. With a 3/4 inch round light this was equivalent to a 10 inch tail light at a distance of 292.27 feet.

The eye level of S was set $\frac{1}{2}$ inch above that of the target. The target itself dropped slightly on "toward" movements and rose slightly on "away" movements. The change in height of the target over the entire 40 inches of travel was one inch. This provided the observer with a viewing angle similar to that of a driver who is watching a set of tail lights at a distance of 300 feet. A movement of the target for a distance of 20 inches is equivalent to a movement of 21.91 feet at 292.27 feet.

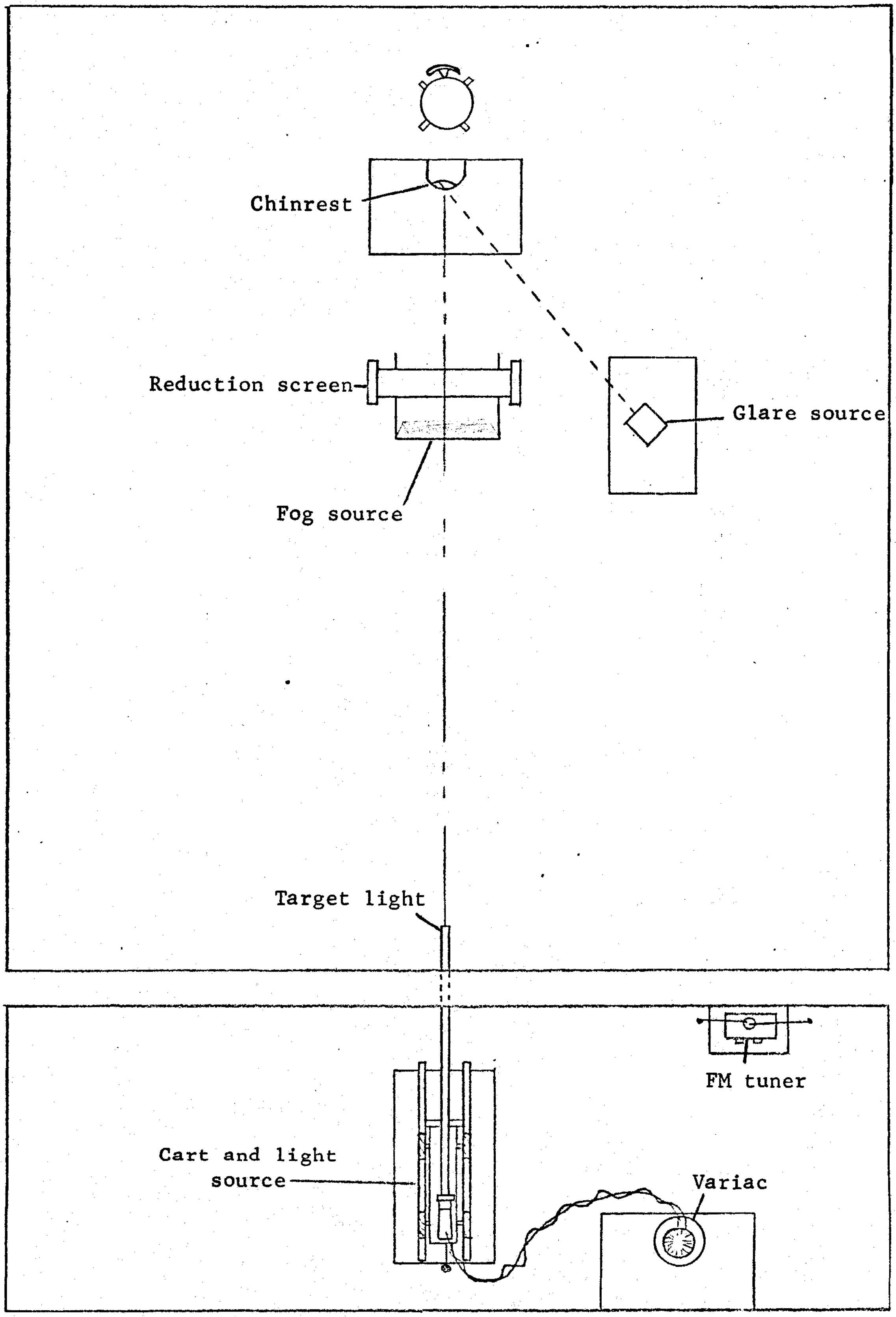

Fig. 2. Plan view of experimental room with apparatus

S viewed the target with his head in a chin rest. His chair was adjustable for height so that S was able to assume a comfortable position in the chin rest.

A reduction screen was employed in order to reduce the possibility of the observer obtaining extraneous cues. This was found necessary in the glare condition. The ends of the room were visible due to the illumination present. The screen was placed 6 feet 4 inches in front of S and it had an opening of five inches in height and 12 inches wide.

The fog sources were hung six feet-eight inches in front of S. The "thin" fog was produced by two layers of light guage polyphrane plastic. The "thick" fog was produced by one sheet of C-I-L plastic two millimeters thick.

The glare source was a Stansi Model S3147 high intensity light source with a 50,000 candle power lamp. The diameter of the opening was ½ inch. The intensity produced at the eye was .033 milliwatts per square centimeter. It was located 26 degrees left of straight ahead at a distance of 9 feet 3 inches inches from S.

3. Calibration Procedures

Two experiments were carried out, one with lights of equal intensity and one with lights of equal brightness. A YSI Kettering Model GS radiometer was used to measure the intensity of the lights. The intensity readings were expressed in milliwatts per square centimeter. Intensity of the light source was controlled by means of a variable transformer (variac).

The first step in calibration for equal intensity was to discover the maximum output of the light source with the 500 mμ (blue-green) filter in place. An incandescent bulb produces relatively less light of shorter wavelengths. If the maximum output for shortest wavelength is known, then appropriate adjustments for output of the longer wavelengths can be made.

An output of .08 milliwatts per square centimeter was obtained for the 500 mμ filter. The corresponding variac setting was recorded. The outputs of the other filters were checked and the appropriate variac settings were adjusted and recorded for equal intensity to the 500 mu output.

This procedure was followed for Experiment II with lights of equal brightness. Lights of different wavelengths were matched for brightness with reference to the Standard Observer Luminous Efficiency Curve for photopic vision (Walsh 1958). Table 1 shows the relative luminous efficiency for each wavelength and the corresponding intensities for equal brightness.

TABLE 1

Luminous Efficiencies and Corresponding Intensities for Equal Brightness

Wavelength	Relative Percent Efficiency	Intensity*
500 (blue-green)	34.5	.080
550 (green)	100	.028
600 (amber)	67	.041
650 (red)	11.5	.242

*Readings given in milliwatts per square centimeter.

The intensity of the lights presented to S were reduced by a 7.5 per cent neutral density filter. (Readings were not taken with the filter in place because outputs were too small to be measured accurately on the radiometer).

An estimate of the actual light intensities presented to S are given in Table 2.

TABLE 2

Estimated Intensities in Milliwatts for Lights Presented to S in Experiments I and II

Wavelength	Experiment I	II
500	.0008	.00080*
550	.0008	.00028
600	.0008	.00041
650	.0008	.00242

*Figures are corrected for radiometer sensitizer head which has an improvement factor of 7.5.

4. Cart Speed

The speed of the cart was measured to the nearest hundredth of a second, in six inch segments. The speed was adjusted by varying the weights. This was facilitated by the fact that the weights consisted of bags of shot. Any amount could be added or taken away in order to increase or decrease vehicle speed. Table 3 shows the mean travel time over six inch settings in both directions.

TABLE 3

Vehicle Travel Time in Seconds over Successive Six Inch Segments

Segment	1	2	3	4
Toward	.52	.40	.36	.33
Away	.52	.39	.35	.32

The scaled values in feet which correspond to the road dimensions specified in the stimulus setting along with travel time are shown in Table 4.

TABLE 4

Scaled Distances in Feet Corresponding to Actual Movement in Inches of the Target Light and Travel Time

Actual Movement (inches)	Travel time (sec.)	Scaled distances (feet)
24	1.61	26.30
20	1.38	21.91
16	1.15	17.53
12	.92	13.15
8	.65	8.77

When these conditions are applied to the car following situation, the cart speed can be said to represent the difference in speed between the preceding car and the following car. These scaled speeds are presented in Table 5. The front car (car A) is slowing down or accelerating from 60 mph. and the second car (car B) is following at 60 mph.

TABLE 5

Average Scaled Speed of Cart Corresponding to Actual Movement of the Target Light

Movement (inches)	Accelerating	Deaccelerating
0-8	59.06	51.04
8-12	76.22	43.78
12-16	79.04	40.96
16-20	79.04	40.96
20-24	79.04	40.96

The stimulus setting is therefore similar to a night driving situation where a car is following another at a distance of 290 feet. The road is straight and level. Both cars are traveling at 60 mph. The first car then slows to approximately 40 mph or accelerates to almost 80 mph. Ss were asked to judge whether the target light moved toward or away from them. Two experiments were carried out. Experiment I was performed with lights of equal intensity and Experiment II with lights of equal brightness.

CHAPTER III

EXPERIMENT I. EQUAL INTENSITY

Subjects. The Ss were 11 males and 13 females ranging in age from 18 to 33 years. All Ss had minimum acuity of 20/40 (with or without glasses). This is the minimum requirement for obtaining a driver's permit in the Province of Ontario. The Ss were volunteers from Assumption High School of Windsor, Adult Education Centre of Windsor, or the class in introductory psychology at the University of Windsor. None of the Ss were found to be red-green colour-blind.

Procedure. Each S was tested for acuity, stereopsis, and red-green colour blindness on a Bausch and Lomb Modified Orthorater. Ishihara figures were used for the colour blindness test.

Following the vision test S entered the 42 foot windowless room. The room was completely dark except in those cases where the effect of glare was being tested. S was seated at a comfortable height in the adjustable chair.

He received a set of instructions which familiarized him with the chinrest, earphones, and with his task. Instructions are found in Appendix A.

S was told that a light would come on in front of him. This light would remain stationary for a short duration and then move either toward or away from him and go off. His task was to report the direction of movement.[1]

During the session S listened to an FM radio station of his choice. The volume was adjusted to his level of comfort.[2]

There were three principal reasons for the use of a radio in this experiment. First, the results of Blackwell (1953) showed that better, more stable thresholds were obtained when Ss were permitted to listen to a radio. Secondly, the presence of radio music and voices would help prevent boredom. Finally, there was a certain amount of noise produced by the movement of the target light. Some of this was masked by the radio.

One specific cue to depth was provided for S in the instructions. He was told that the position of his eyes was slightly higher than that of the target light. His line of sight was pitched slightly downward. This is similar to the car following situation. The driver looks slightly downward at a set of tail lights on an automobile traveling in front of him.

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[1]A pilot study was carried out in which the target light was presented for short durations (one second or less). The light was in motion for the entire time of presentation. Most Ss reported that the light appeared to get larger and then smaller regardless of direction of movement. They reported a difficulty in focusing on the light itself due to the brief duration of exposure.

[2]A tape recording of continuous music was played for four Ss in the pilot study. Three of the four complained about this aspect of the session. One S reported feeling dizzy and asked for a rest. He indicated that the music bothered him. Two Ss reported feeling "isolated" without any voices present in the lab setting. This was the first time in twenty hours of testing that there were serious complaints about the session from the subjects. Therefore, the radio was employed.

A dark adaptation period of five minutes followed the instructions. A signal was given to S and the trials commenced.

Each S underwent two sessions lasting 45 to 55 minutes. A session contained 200 trials, 50 with each of four colours. The coloured lights employed in this experiment had predominant wavelengths of 500, 550, 600, and 650 mμ (blue, green, amber and red). These lights were of equal intensity.

The target light traveled over five different distance settings, 8, 12, 16, 20 and 24 inches. Two directions of movement were used (toward and away). The five distances and two directions of movement yield a total of ten stimulus settings. A constant stimulus method was employed with ten trials per setting. A series of 100 trials was presented for each of the four colours. Therefore each S was exposed to 400 trials. These were divided into two sessions of 200 trials each in which 50 judgements were made on each of the four colours. The order of the colours was randomized for each S in his first session. The order of the colours in the second session was reversed.

There were six groups of four Ss. Each group viewed all colours under one of six seeing conditions as shown in Table 6.

TABLE 6

Seeing Conditions for Each Group
in Experiment I

Group	Seeing Conditions
I	darkness
II	thin fog
III	thick fog
IV	glare
V	thin fog, glare
VI	thick fog, glare

At the conclusion of the second session, S was asked a set of four questions. These concerned the extent of his driving experience, colour preference, ease of judgement as influenced by colour, and his own personal observations about the experiment. This post session interview is shown in Appendix B.

A minimum period of one day transpired between the two experimental sessions. All Ss were tested in the afternoon between the hours of 12 and 6 p.m.

CHAPTER IV

EXPERIMENT II. EQUAL BRIGHTNESS

Subjects. The Ss were 11 males and 9 females from the introductory psychology class at the University of Windsor. They ranged in age from 19 to 30 years. All Ss had minimum acuity of 20/40 (with or without glasses). None of the Ss were red-green colour blind.

Procedure. The procedure was identical to that of Experiment I with the following exceptions. Experiment II was carried out using coloured lights of equal brightness estimated from the luminous efficiency curve.

The thin fog condition was eliminated in Experiment II.[1]

S was told explicitly in the instructions that the light would appear to drop slightly as it moved toward him.[2]

There were four groups of five Ss. The seeing conditions for each group are summarized in Table 7.

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[1]The "thin fog" condition in Experiment I yielded essentially the same results as the "no fog" condition in Experiment I.

[2]This was done for the purpose of obtaining a better estimate of threshold by supplying more information in the situation.

TABLE 7

Seeing Conditions for Each Group
in Experiment II

Group	Seeing Conditions
I	darkness
II	fog
III	glare
IV	fog, glare

CHAPTER V

RESULTS

The number of correct responses for each stimulus setting were calculated for the purpose of estimating threshold values in terms of distance traveled by the stimulus light. However, the data did not lend itself to calculation of thresholds. There were large individual differences between Ss which often produced zero and 100 per cent correct responses at some stimulus settings. Furthermore, in some cases the percentages of correct responses per setting did not follow a trend.

It was decided that the data be analyzed according to the number of correct responses by S under the set of conditions in which S was tested.

1. Experiment I

A three factor analysis of variance with repeated measures on the last factor was carried out on the number of correct responses. The three factors were: (1) glare (two levels), (2) fog (three levels), and (3) colour (four levels). Results are presented in Table 8.

TABLE 8

Analysis of Variance of Total
Correct Responses in Experiment I

Source	SS	df	MS	F
Between Ss	9615.990	23		
Glare	1675.010	1	1675.010	4.49*
Fog	1277.583	2	538.792	1.45
Glare x Fog	155.583	2	77.792	.21
Ss within groups	6707.813	18	372.656	
Within Ss	2467.750	72		
Colour	572.531	3	190.844	8.06*
Glare x Colour	203.449	3	67.816	2.86*
Fog x Colour	237.751	6	39.625	1.67
Glare x Fog x Colour	1175.582	6	29.264	1.24
Colour x Ss within groups	1278.437	54	23.675	

*Significant at the .05 level.

The effect of glare was significant at the.05 level. The overall mean correct responses per person in the no glare seeing conditions was 259.75. The mean for glare conditions was 293.17. Ss were more accurate with glare present.

The main effects of colour, and a glare by colour interaction were significant at the .05 level.

A comparison of overall means for colour in Experiment I is presented in Table 9.

TABLE 9

Newman-Keuls Test for Mean Correct Responses per Colour in Experiment I

Mean	66.00	69.63	70.63	71.21
Colour	550	500	650	600
550	---	3.63*	4.63*	5.21*
500		---	1.00	1.88
650			---	.58
600				---

*Significant at the .05 level

Over all seeing conditions in Experiment I, judgements on amber (600) red (650) and blue (500) were more accurate than judgements on green (550). These differences were significant at the .05 level.

In Table 8 there was a significant glare by colour interaction. Figure 3 is a plot of mean correct responses per colour under glare and no glare seeing conditions. The most apparent differences between the glare and no glare conditions is in the case of red (650). In the no glare conditions, the mean for red was 64.00. In the glare conditions the mean was 77.25.

Two Newman-Keuls comparisons of means were carried out for the effect of colour in the no glare and glare conditions. The test for the no glare conditions is contained in Table 10.

TABLE 10

Newman-Keuls Test for Colour in the No-glare Conditions in Experiment I

Mean	61.33	64.00	66.83	67.58
Colour	550	650	500	600
550	---	2.67	5.60*	6.25*
650		---	2.85	3.58
500			---	.75
600				---

*Significant at the .05 level.

The results in Table 10 indicate that, in the no glare seeing conditions, amber (600) and blue (500) were more accurate than green (550) (significant at the .05 level).

The comparison of means of colour in the glare conditions is presented in Table 11.

TABLE 11

Newman-Keuls Test for Colour in the Glare Conditions in Experiment I

Mean	68.67	72.42	73.83	77.25
Colour	550	500	600	650
550	---	3.75	5.16*	8.58*
500		---	1.41	4.83*
600			---	3.42
650				---

*Significant at the .05 level.

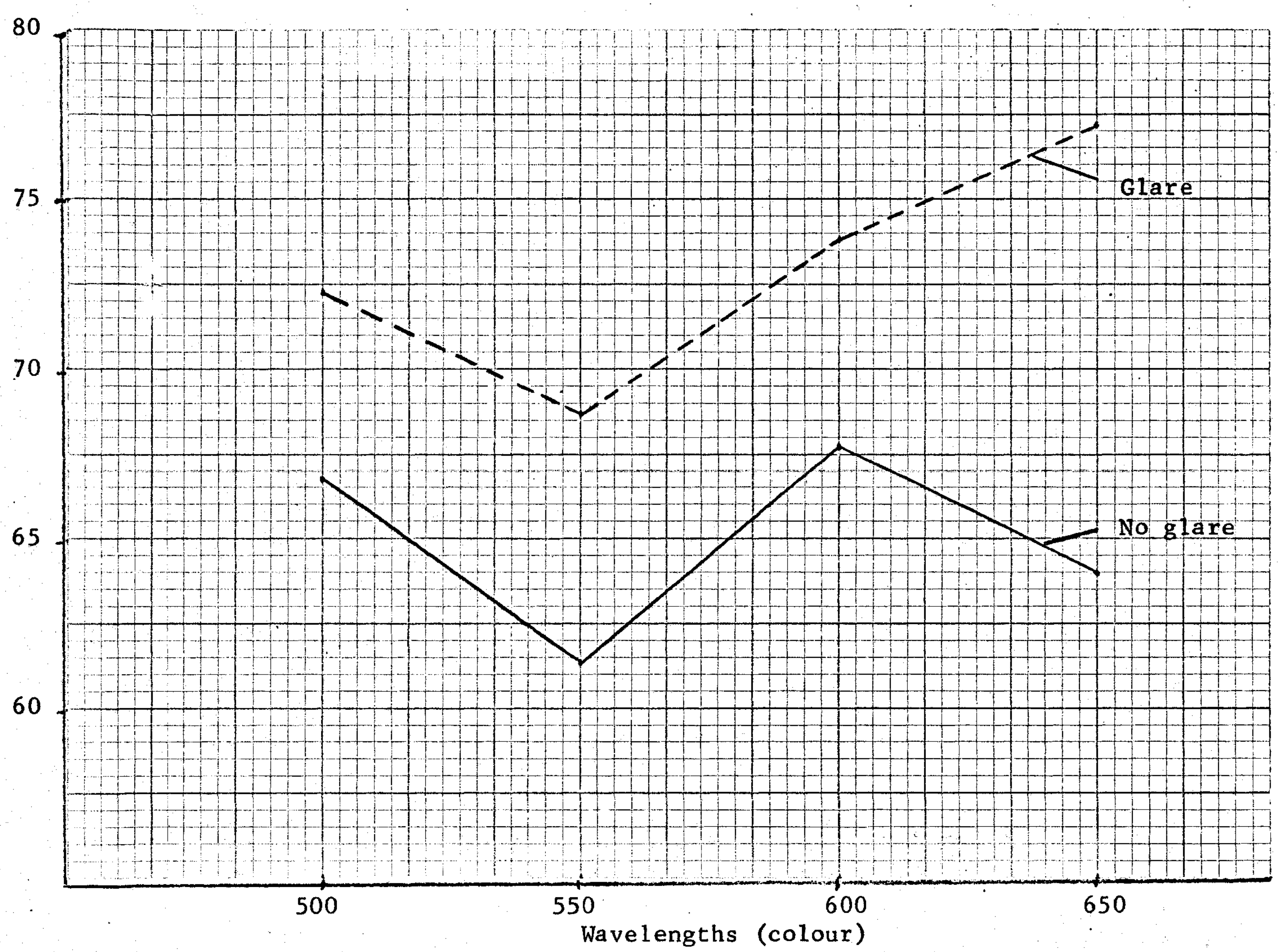

Fig. 3. Mean correct responses for glare and no glare seeing conditions as a function of wavelength in Experiment I

In the glare conditions, judgements on red (650) were more accurate than judgements on green (550) or blue (500). Amber (600) was better than green (550) and red (650) was better than blue (500) (significant at the .05 level).

Ss were most accurate on red in the glare conditions followed by amber, blue and green. In the no glare conditions, the order of accuracy was amber, blue, red and green. This appears to be the effect of the glare by colour interaction.

An analysis of variance was carried out on the number of correct responses per subject for each of the eight series of 50 trials in the experimental sessions. This provided a study of the practice effect. The results are presented in Table 12.

TABLE 12

Analysis of Variance of Number of Correct Responses per Subject for each Series of 50 Trials in Experiment I

Source	SS	df	MS	F
Between Ss	4596.563	23		
Within Ss	3303.250	168		
Practice	663.739	7	94.818	5.08*
Residual	2639.521	161	16.208	

*Significant at the .05 level

The effect of practice was significant at the .05 level. A trend analysis was executed to study the components of the practice effect. Results are presented in Figure 4.

A series of F tests for linear, quadratic, cubic and higher order components in the practice effect curve in Figure 4 was carried out. Table 13 contains a summary of these tests.

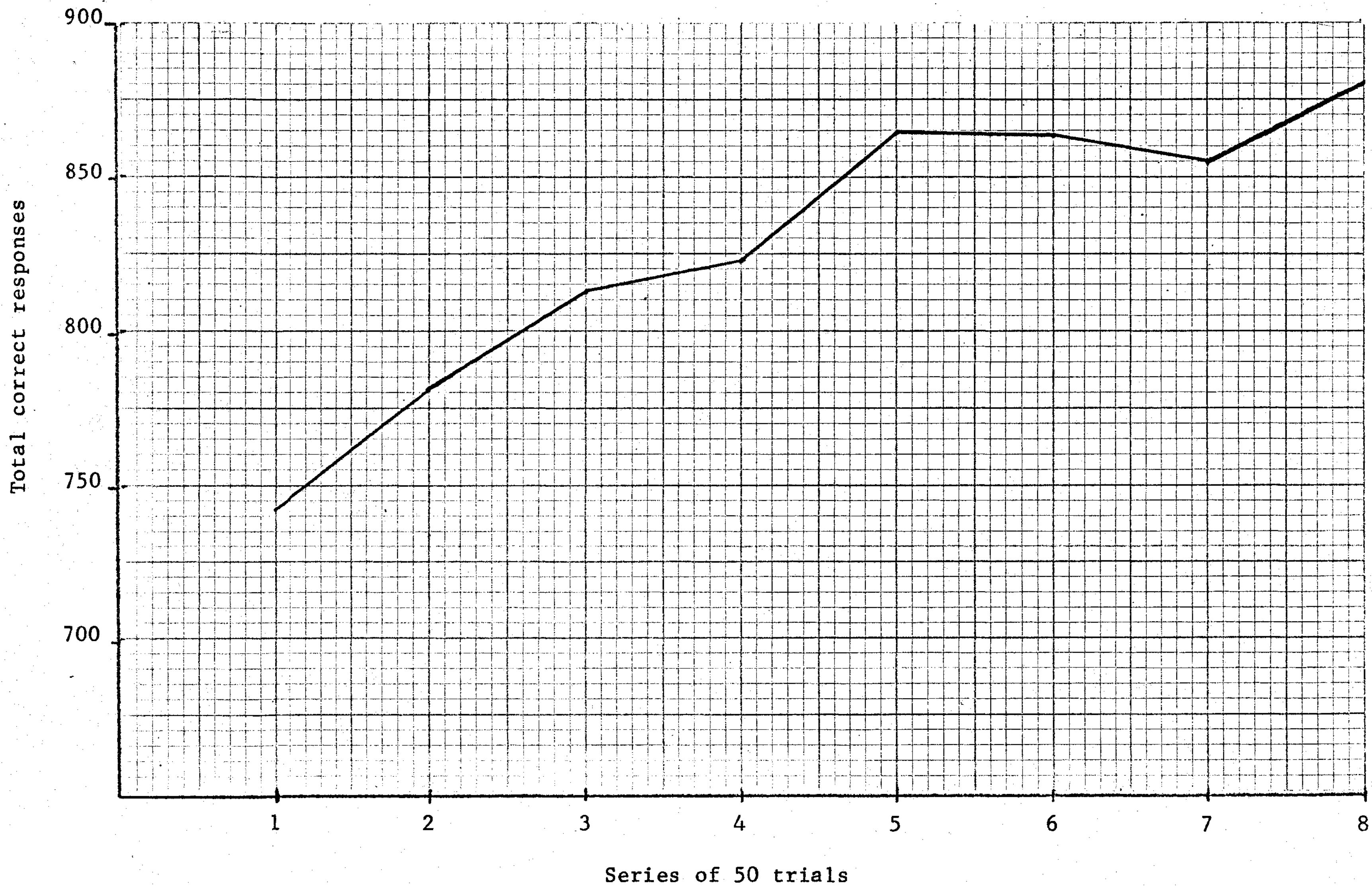

Fig. 4. Total correct responses per 50 trial segment in Experiment I.

TABLE 13

F Tests for Linear, Quadratic, Cubic and Higher Order Components in the Practice Effect Curve for Experiment I

Component	df	MS	F
Linear	1	578.198	35.61*
Quadratic	1	54.787	3.38
Cubic	1	3.646	.22
Higher Order	4	6.774	.42
Residual	161	16.208	

*Significant at the .05 level

The trend analysis indicates a strong linear component and a small quadratic component which does not reach significance at the .05 level. In Experiment I performance improved linearly with practice.

2. Experiment II

An analysis of variance with three factors was carried out on the total number of correct responses in both directions in Experiment II. The results are presented in Table 14.

TABLE 14

Three Factor Analysis of Variance of the Total Correct Responses in Experiment II

Source	SS	df	MS	F
Between Ss	7511.387	19		
Glare	699.612	1	699.612	2.37*
Fog	63.012	1	63.012	.22
Glare x Fog	2073.113	1	2073.113	7.09*
Ss within groups	4675.650	16	292.228	
Within Ss	4672.000	60		
Colour	2651.692	3	883.897	25.31*
Glare x Colour	185.183	3	61.728	1.77
Fog x Colour	62.383	3	20.794	.60
Glare x Fog x Colour	96.792	3	32.264	.92
Colour x Ss within groups	1675.950	48	34.916	

*Significant at the .05 level

The main effect of colour was significant at the .05 level. A Newman-Keuls test was run on the means for colour. The results are contained in Table 15.

TABLE 15

Newman-Keuls Test for Mean Correct Responses by Colour (wavelength) in Experiment II

Mean	63.05	66.95	73.85	77.80
Wavelength	550	500	600	650
550	---	3.90*	10.80*	14.75*
500		---	6.90*	10.85*
600			---	3.95*
650				---

*Significant at the .05 level.

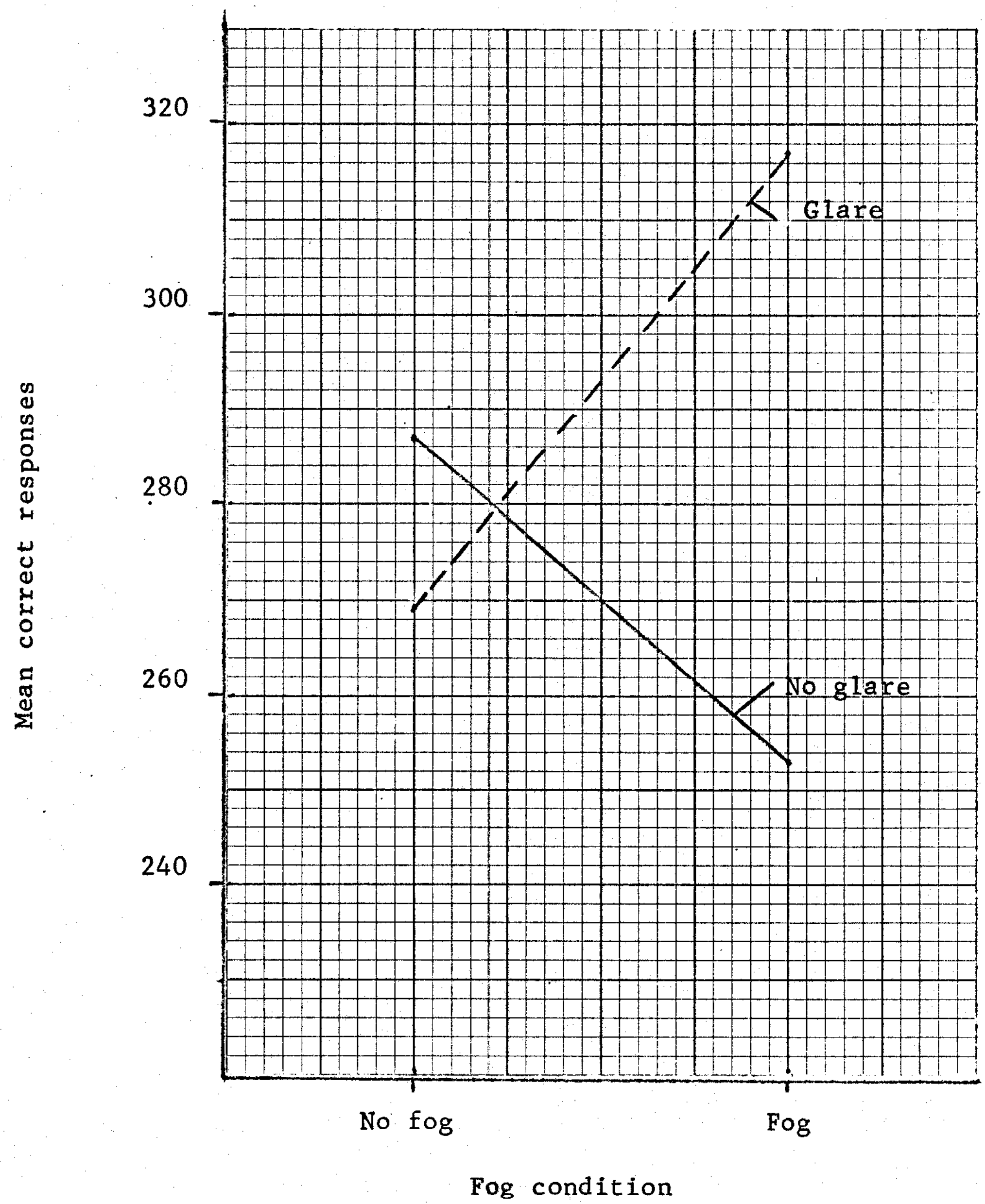

Fig. 5 Mean correct responses in the glare and no-glare conditions as a function of fog condition

In the simple dark condition, the red and amber were better than the green and blue. However, these differences were not significant at the .05 level.

Table 17 is a comparison of means of colour in the simple fog condition.

TABLE 17

Newman-Keuls for Colour in the No-glare and Fog Seeing Condition

Total	53.8	64.0	67.0	68.2
Colour (wavelength)	550	500	600	650
550	---	10.2*	13.2*	14.4*
500		---	3.0	4.22
600			---	1.2
650				---

*Significant at the .05 level

Green was found to be inferior to the other three colours in the simple fog condition.

Table 18 is a comparison of means for colour in the glare and no fog condition.

TABLE 18

Newman-Keuls Test for Colour in the Glare-no fog Seeing Condition

Total	58.8	62.4	70.0	78.4
Colour (wavelength)	550	500	600	650
550	---	3.6	11.2*	19.6*
500		---	7.6	16.0*
600			---	8.4
650				---

*Significant at the .05 level

TABLE 20

Analysis of Variance of the Number of Correct Responses per Subject for Each Series of 50 Trials in Experiment II

Source	SS	df	MS	F
Between Ss	4047.819	19		
Within Ss	3654.375	140		
Practice	142.144	7	20.306	.77
Residual	3512.231	133	26.408	

The effect of practice was not significant at the .05 level in Experiment II.

3. Additional Results from Experiments I and II

Two analyses of variance were carried out on the number of "toward" responses per colour in Experiments I and II. The results are presented in Table 21 and Table 22.

TABLE 21

Analysis of "toward" Responses per Colour in Experiment I

Source	SS	df	MS	F
Between Ss	7936.238	23		
Within Ss	3249.250	72		
Colour	118.781	3	3.959	.87
Residual	3130.469	69	4.537	

The effect of colour on number of "toward" responses was not significant in Experiment I.

TABLE 22

Analysis of "toward" Responses per Colour in Experiment II

Source	SS	df	MS	F
Between Ss	6106.550	19		
Within Ss	3747.000	60		
Colour	241.450	3	80.483	1.31
Residual	3505.550	57	61.500	

The effect of colour on number of "toward" responses was not significant in Experiment II.

Two t-tests for unmatched samples were carried out to compare the overall performance of men and women in Experiments I and II. The results are presented in Table 23.

TABLE 23

T-tests for Overall Accuracy of Men and Women in Experiments I and II

Experiment	X Women	X Men	t
I	281.23	270.38	.66
II	269.78	288.64	-.72

There was no sex difference in the ability to perform this task.

The mean correct responses out of 400 trials was calculated for Ss listening to CKLW and WKNR, and for Ss listening to CKWW and WCAR. The results are contained in Table 24.

TABLE 24

Mean Correct Responses by Radio Station
In Experiments I and II

Experiment	CKLW-WKNR	CKWW-WCAR
I	265.00	262.64
II	287.67	281.35

The choice of radio station did not appear to affect performance of the task.

The effects of age, acuity, stereopsis and number of years driving on accuracy were studied. Pearson product correlations were calculated for each of these four factors with accuracy. Table 25 is a summary of these correlations.

TABLE 25

Pearson r's for Age, Acuity, Stereopsis
and Number of Years Driving with Accuracy

	Age	Acuity	Stereopsis	Years Driving
Exp. I	-.01	-.03	.09	-.01
Exp. II	.10	.31	.02	.07

None of the obtained correlations were significant at the .05 level. Performance of this task did not appear to be affected by age, acuity, or number of years driving.

CHAPTER VI

DISCUSSION

This chapter is divided into four parts. In the discussion of Experiment I, interpretation is concerned with an explanation of those results only. The discussion of Experiment II includes references to the results of Experiment I. The third section of this chapter is a brief discussion of the additional results reported in Section 3 of the Results Chapter. The final section lists suggestions for further research and a cautious recommendation about rear vehicle lighting.

1. Experiment I

An unexpected finding in Experiment I was that Ss tested in the glare seeing conditions were more accurate than those tested in the no-glare conditions in Experiment I. The location of the glare source may have been a factor. It was positioned 9 feet 3 inches away from S at an angle 26 degrees left of his line of sight (Figure 2). The glare source remained stationery throughout the experiment session. This constant source of light, positioned in front of S, slightly to the left of his line of sight may have been a useful cue to depth perception and motion of the target light. It is well known that estimates of distance in depth are easier when made with reference to a standard stimulus.

Although the glare by fog interaction was not significant in Experiment I, the performance of Ss in each of the seeing conditions merits inspection. Table 26 shows the mean correct responses for each seeing condition in Experiment I.

TABLE 26

Mean Correct Responses per S in Each Seeing Condition in Experiment I

Seeing Condition	Mean Correct Responses
Simple dark	257.75
Thin fog	272.25
Thick fog	249.25
Glare	300.50
Thin fog and glare	310.50
Thick fog and glare	268.50

The mean for the thick fog and glare condition is similar to the three means in the no glare conditions. A possible explanation for this is that the thick fog source may have been effective in reducing the accuracy of Ss in that seeing condition. The result in the glare-thick fog condition is the net effect of glare providing a cue to depth and the thick fog reducing visibility.

The main effect of colour was significant at the .05 level in Experiment I as shown in Table 8. Over all conditions, judgements on amber, red, and blue were more accurate than judgements on green (Table 10).

In the no glare conditions, blue and amber were more accurate than green (Table 11). On the other hand, in the glare conditions, red and amber were better than green, and red was better than blue (Table 12).

Tables 27, 28 and 29 are Newman-Keuls tests for means of colour in the three glare seeing conditions of Experiment I.

TABLE 27

Newman-Keuls Comparison of Means for Colours
in the Simple Glare Condition in Experiment I

Mean	71.55	75.00	75.75	78.25
Wavelength	550	500	600	650
550	---	3.45	4.20	6.70
500		---	.75	3.25
600			---	.50
650				---

None of the differences between means was significant at the .05 level in the simple glare condition of Experiment I.

Table 28 is a Newman-Keuls test for colour in the glare-thin fog condition.

TABLE 28

Newman-Keuls Comparison of Means of Colour
in the Glare-thin fog Condition in Experiment I

Mean	73.25	75.50	79.25	82.50
Wavelength	550	500	650	600
550	---	2.25	6.00	9.25*
500		---	3.75	7.00
650			---	3.25
600				---

*Significant at the .05 level

In the glare-thin fog condition, amber (600) was better than green (550).

Table 29 is a comparison of means for colour in the glare-thick fog condition.

TABLE 29

Newman-Keuls Comparison of Means for Colour in Thick fog-glare Condition in Experiment I

Mean	61.25	66.25	66.85	74.25
Wavelength	550	600	500	650
550	---	5.00	6.60	13.00*
600		---	.60	8.00
500			---	7.40*
650				---

*Significant at the .05 level

Red (650) was found better than green (550) and blue (500), significant at the .05 level. The difference between red (650) and amber (600) did not reach significance due to the ordered comparison of means.

From the results in Tables 27, 28, and 29, it appears that red (650) is least affected by the presence of thick fog. There is one obvious explanation in this case. The longer wavelength of red undergoes less scatter through fog than the other colours used. This would tend to keep the image of the red target sharper in the thick fog condition.

2. Experiment II

a. Main effects

The overall effect of colour was significant at the .05 level.

The appropriate intensities for the brightness match in Experiment II were obtained by increasing the intensities of red, amber, and blue to match the brightness of the green. Therefore, the red, amber, and blue target lights in Experiment II were brightner than the red, amber and blue lights used in Experiment I. This applies particularly to the red (650) which was increased in intensity by a factor of 10. This may account in part for greater overall accuracy of Ss in Experiment II. It may also be part of the reason why performance on red, amber and blue were comparatively more accurate than green in Experiment II.

The research of W. M. Smith (1955) indicates that brightness plays a role in depth perception. With an increase in brightness of a target, there is an increase in accuracy of depth perception.

Smith's work was done with white light. The results of the present research show that judgements of lights of equal brightness and different wavelengths differ in accuracy. However, two lights differing in brightness and equal in wavelength may differ in accuracy.

The change in instructions in Experiment II may have produced an increase in accuracy. The linear trend component was significant on the eight blocks of 50 trials each in Experiment I indicating an improvement in performance with practice. No practice effect was found in Experiment II.

Ss in Experiment II were told explicitly that the target light would appear to drop slightly as it came toward them since they were looking down on this light. Ss in Experiment II had more specific information about the task at the outset. This may account for the absence of a practice effect in Experiment II and therefore, the increased accuracy of Ss in Experiment II. The procedures used in the two experiments were identical in all other aspects. Furthermore, S was given no information about the correctness of his judgements.

Although the effect of glare was not significant in Experiment II, the difference between the means was in the same direction as Experiment I. Ss in the no glare seeing conditions had a mean number of correct responses of 269.8 and those in the glare conditions had a mean of 293.5.

There was a glare by fog interaction in Experiment II. The mean correct responses for Ss tested in the simple glare condition is slightly higher than Ss in the simple fog condition (269.6 - simple glare and 253.0 - simple fog). The simple glare mean is slightly lower than the simple dark condition mean of 286.6. In Experiment I, the mean for simple glare was higher than the mean for simple dark conditions. The instructions in Experiment II which contained directions for a specific cue may have produced a set in S whereby he directed his attention only to that specified cue and did not exploit the glare source as a reference point as in Experiment I. In other words, the perceiving of the light as "dropping" as it came toward S may be the dominant cue in Experiment II, especially since S's attention was directed upon it. This may have masked the effect of the glare source as a cue in Experiment II.

The most interesting finding in the glare by fog interaction is that, in the presence of both thick fog and glare in Experiment II performance was at its highest level of accuracy. One explanation of this is in terms of the experimental set-up. The fog was produced by hanging a sheet of plastic between S and the target light. In the glare conditions the light from the glare source was not completely absorbed by the flat black background placed behind S and by the black velvet cloth wrapped around the chin rest. Some of this remaining light reflected back through the reduction screen onto the fog source. S viewed the fog source and stimulus light through this reduction screen. The screen had a rectangular opening of 5 x 12 inches. What S saw was the target light "framed out" by the outline of the reduction screen opening. Therefore, the combination of thick fog and glare produced this frame for the stimulus which made judgements of movement easier. Wallach (1939), J. F. Brown (1931), and J. W. Miller (1961) found similar results.

This may not have been so effective a cue in Experiment I for two reasons. First, due to the instructions in Experiment I, S's may not have attended to this particular cue to depth. Even though the target light appeared to drop or rise slightly with reference to the outlined frame, Ss in the first experiment may not have interpreted this as a cue to depth. Secondly, individual Ss in the thick fog and glare group in Experiment II may have been more skillful in the performance of the experimental task.

The "framing out" of the target stimulus did not occur in the simple glare condition because the light reflected back through the reduction screen opening was not reflected back again by any surface (such as the fog source). Instead, the reflected light was absorbed over the larger area of the flat black wall on which the target light was mounted.

b. Colour

The overall effect of colour was significant at the .05 level in Experiment II. The individual comparisons of means showed significant differences between all four colours used, with the order of accuracy being red, amber, blue and green.

W. M. Smith (1955) showed that increased brightness of a target increased accuracy of depth perception. There are two possibilities in terms of brightness which may have affected the results.

It is well known that, with a certain amount of adaptation to a light of a particular hue, the apparent brightness of its complimentary is enhanced (Woodworth & Schlosberg, 1954). This enhancement may well have operated on three of the four colours used in this research. Table 30 is a list of the wavelengths employed and their complimentaries.

TABLE 30

Colours and Their Complimentary Wavelengths*

Colour (in wavelength)	Complimentary
500	None
550	None
600	488.8
650	492.2

*Taken from the Handbook of Colorimetry

Although the blue (500) has no complimentary, it is within 12 millimicrons of having amber (600) and red (650) as complimentaries. A wavelength of 492 has a complimentary of 640.2. One might expect a brightness enhancement of blue after a series of trials with amber or red had been presented. Conversely, some enhancement of amber and red occured after the presentation of a series of blue trials. This effect would be greatly diminished for green (550). It has no complimentary wavelength and no single wavelength approaches it as a complimentary. This may have contributed to the overall lack of accuracy of judgements of green.

Due to the fact that these experiments were carried out in dark or nearly dark conditions, a partial Parkinje shift may have occurred, if the targets lights were not of sufficient brightness. This would contribute almost exclusively to making blue appear brighter.

The spectral transmittance of the experimental fog source is not known. In further research this should be specified as was done by Kinney, Luria, and Weitzman (1967). They found that visibility of different wavelengths in water varied with the different waters sampled. For example, longer wavelengths of orange and red were more visible in the murky Thames River while blue and green were more easily seen in the clear waters of Morrison Springs.

The order of accuracy for colours may also have been influenced by the "arousing potential" of each colour. The work of G. D. Wilson (1966) showed that a red stimulus of equal or less brightness produced significantly higher GSR activity than a green light. He attributes this difference in "arousal" to cultural and environmental factors. He says that wavelengths at the extremes of the spectrum such as reds and violets are associated with or used to signify danger whereas green is a "safe" colour and is located in the middle of the spectrum. He predicts that the "arousal values" for colours will be $R > O > I > G < B < I < V$. The predicted order of "arousal values" for the colours used in the present research is red, amber, blue and green which is identical to the order of colours in accuracy for Experiment II.

A. J. Fisher (1967) has suggested that distance judgements of red and amber may be more accurate than those on blue and green due to experience. Drivers are used to focusing on red lights. He says:

> "Since at present red is the dominant colour of light on the rear of automobiles and is often the only bright colour in the field at night, it might be expected that the eye will accommodate so that the best focus is obtained for red light..."

Another possibility here, especially if a partial Purkinje shift occurs, is that focusing on red light may be easier since rods are almost completely insensitive to red. Response would tend to be more localized on the fovea for red and amber which would make central processing and resolution of shape and size easier for red and amber. The blue and green may produce more responses in the concentration of rods off-center from the fovea. This would result in more input in the form of noise in the visual system.

Walsh (1958) states that sensitivity of parafoveal vision is greatest for blue, green, amber and red in that order. In this experiment, with S in almost total darkness and no constant target light on which to fixate, many Ss reported that the target light appeared to go on at different locations. This increases the probability of some parafoveal stimulation which may have produced noise in the visual system especially in the case of blue and green.

Two studies of accuracy in judgements of distance for colour have been carried out. Karwoski and Lloyd (1951) found that a j.n.d. in depth for two lights of the same colour was smallest for yellow followed by red, green and blue in that order. Rockwell and Safford (from A. J. Fisher, 1966) tested three observers in a dynamic driving situation. They judged the distance of red, amber and green tail lights. They were most accurate on red followed by amber and then green.

The origin of red and amber as danger signals may be very primitive. Fire and sun are red and amber whereas most plant life and water are shades of greens and blues. Man's environment may account for the evolution of red and amber as danger and caution signals. Further research on the psychological meanings of colour is needed in order to answer such questions.

3. Additional Records

No significant correlations were found between acuity and accuracy, stereopsis and accuracy, years driving and accuracy, and age and accuracy. This is probably due to the built-in homogeneity of the subjects on these dimensions. All had between 20/20 and 20/40 acuity. Most Ss differed little in stereopsis. The age range of Ss was between 16 and 35 years with most of them between 18 and 24 years. Number of years driving did not vary greatly. Another problem with that measure is to determine what other experience one might have which would improve one's skill at performing the experimental task. For instance, "back seat driving" may be as helpful as actual driving experience.

No correlations were found between colour preference and accuracy or between perceived ease of judgement and accuracy.

Two considerations must be made at this point. First, the amount of uncertainty in the experimental situation was very high. The presentations of the stimuli were very close to threshold in most cases. In order to reach threshold in the forced choice, two alternative situations, S needs 75 per cent correct responses. The mean correct judgements of Ss in the two experiments was 278.82 out of 400 trials which equals 70 per cent correct. The method of constant stimuli is, by design, dependent on the guessing of Ss. Even Ss who were very accurate were not sure of their judgements. In the pilot study, one S who scored better than 90 per cent correct felt that he was guessing on every trial.

Second, the ranking of colours according to ease may have been "forced." With few exceptions S hesitated before ranking them. Many said initially that they saw no differences in ease between the colours and went through the process of ranking only after some encouragement from E.

4. Future Research and Recommendations

There are several basic experiments which should be carried out before serious recommendations can be made concerning rear lighting systems on motor vehicles. Several of them are listed below.

The present study employed the use of only one speed of movement. An attempt should be made to obtain thresholds for different speeds and for a wider range of distances for many different colours. This may be done in a full-scale setting as Parket et al (1964) used to study tail-light assemblies.

Another limitation of the present study was the inability to obtain thresholds for distance. There were probably three reasons for this: (1) not a sufficient number of trials for method of constant stimuli (2) large individual differences in the accuracy of the Ss and (3) the target light moved faster over the latter portions of the cart travel. This meant that for longer distance settings the target light was seen for a proportionately shorter length of time over the latter segments of travel. An apparatus which is able to produce well-controlled speeds and accelerations is most desirable.

An important variable in this situation is the lighting under which judgements are made. Tests should be run in all possible outdoor lighting conditions including cloud cover, dusk, rain and sun as well as simple dark conditions.

The effects of glare must be thoroughly investigated. In a laboratory, tests on minimum visual angle of separation necessary between a glare source and target lights of different colours are important. Detection and identification thresholds should be obtained.

Another crucial test is necessary to determine the minimum distance in depth that a coloured light must be from a glare source before it is detected and identified.

Such thresholds may vary with intensity or colour temperature of the glare source. In France, headlamps are amber. It would be useful to test different coloured glare sources.

For actual road conditions, tests with moving glare sources are important since the most common source of glare is automobile headlamps. The sun, at certain times of the day becomes a veiling glare source. Road tests of coloured lighting systems should be carried out with the sun shining into the driver's eyes and with the sun shining on the tail-light assembly.

More extensive tests are needed for coloured lights in different atmospheric and weather conditions (Connolly 1966). The spectral transmittances of coloured lights in smog, sandstorms and snow must be determined. A related problem is the situation where the winter-time driver often has some dried salt or some ice forming on his windshield.

Human factors research is required. The present study can say nothing about colour-blind persons. The study of individual differences may prove interesting. Why do some persons perform this task better than others? Can persons be trained to use relevant cues and thus improve performance?

The roles of size and shape of tail lights have not been studied extensively. The effects of framing out the tail lights by the windshield and car hood may be important.

Tail light configuration is known to be important. Parker et al (1964) showed that two lights are better than one for depth perception. The possibility of using three running lights spaced across the rear of vehicles has not been investigated.

The presence of apparent movement as a function of colour is still another study. Experiments to determine not only the extent of apparent movement but its direction, including up-down, right-left and toward-away are important.

Connolly (1966) has stated that the driving situation is very complex. Any serious recommendations can be made only after thorough research on vehicle lighting has been carried out. No one factor or single test can be considered sufficient evidence to suggest a specific tail light design or set of colours.

From the findings of the present research, red and amber are the best colours for tail lights. Further research is needed before any specific recommendations can be made.

CHAPTER VII

SUMMARY

It has been suggested that different colours be used in vehicle tail light systems. The effect of colour on depth perception of moving lights has not been examined. In this study, four monochromatic lights (red, amber, green, and blue) were moved toward and away from subjects under simple dark, fog, glare and combinations of fog and glare seeing conditions, S was asked to judge whether these lights moved toward or away from him.

Two experiments were carried out. Experiment I employed lights of equal intensity and Experiment II employed lights of equal brightness as matched on the Standard Observer Luminous Efficiency Curve.

The accuracy of each S on each colour was recorded for all seeing conditions. Overall conditions judgements on red and amber were more accurate than judgements on green and blue (significant at the .05 level). These differences were greatest in the conditions which included fog and glare.

Red and amber most probably penetrated fog better than blue and green due to the differences in wavelength. Other possibilities include differences in "arousal potential" of the colours used. Red and amber have been standard danger signals.

The role of colour adaptation in this experiment may have enhanced the brightness of the red, amber and blue lights since the blue was very

close in wavelength to the complimentaries of the red and amber.

From the results of this research, red and amber appear to be the best colours for rear vehicle lighting systems. Further research is needed on a large scale before serious recommendations for changes in vehicle lighting can be made.

Appendix A

Instructions to S

"Come in and have a seat. Place your head in the chinrest. Is it comfortable? I can adjust the height of the chair.*

This is a 'mic'. It is not too sensitive so you will have to hold it right up to your mouth and speak right into it.

On your left is a set of earphones. You can put them on when we get started. Through them you will be able to hear my voice and an FM radio station.

What type of music do you prefer, that played on CKIW and WKNR or that played on CKWW and WCAR?** We will put that on during the session.

In front of you a light will come on. It will be stationary for a moment and then it will move toward or away from you and go off. You are to report the direction in which the light moved by saying 'toward' if it moved toward you and by saying 'away' if it moved from you. Give an immediate judgement, and if you are not sure, make a guess.

There is one cue I will tell you about. This situation is similar to the case where you are driving and following the tail lights of

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*Instructions for glare conditions were identical to those of the others with the following exception inserted at this point in the instructions. "The light on your left is a glare source. It is best not to look directly into it."

**In cases where reception of S's first choice was unsatisfactory, an alternate station was chosen. A station was selected which played music similar to S's first choice. This was done with S's approval in all cases.

another car at night. You look slightly downward at those lights. You are doing the same thing here. You are looking slightly downward on this light. Any questions?

You will be given three rest periods during the session. If at any other time you feel it necessary to stop for a while, we can do so.

We will wait for a few minutes and let you get used to the dark and then we can begin. I will tell you when. Meanwhile, I will turn the radio on and adjust the volume. The next time you hear my voice will be through those earphones. OK?"

Instructions for Experiment II were the same except that S was told that the light might appear to drop slightly as it moved toward him.

Appendix B

Post Session Interview

1. Do you have a driver's license?

2. How long have you been driving?
   Have you driven much at night?

3. List these colours in order of preference.
   green, red, yellow, blue

4. Did any colour seem easier to make the judgement on in this experiment.
   Please rate the colours according to ease of judgements?

5. Are there any further observations you wish to make?

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VITA AUCTORIS

Born, Paterson, New Jersey, September 24, 1941, to James Joseph and Margaret Mary Sheridan.

Graduated from Mount Carmel Grammar School, Ridgewood, New Jersey, June, 1955.

Graduated from Bergen Catholic High School, Oradell, New Jersey, June, 1959.

B.S. Sociology, College of the Holy Cross, Worcester, Massachusetts, June, 1963.

M.A. Psychology, University of Windsor, Windsor, Ontario, May, 1966.