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Trade-off Between Delineation and Lighting of Freeway Interchanges

Investigation of
Transient Visual Adaptation

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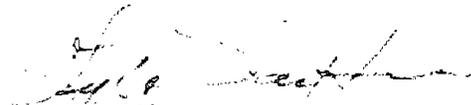
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FOREWORD

This report is a follow-up to Research Report No. FHWA-RD-88-223 titled, "Trade-Off Between Delineation and Lighting on Freeway Interchanges." It documents the methodology used and the results obtained in a study to determine to what extent transient visual adaptation (TVA) affects drivers' visibility. TVA is a temporary reduction in the sensitivity of the eye when a person moves from a bright area into a darker area, i.e., that experienced in entering a movie theater or driving into a tunnel in daytime. The investigation evaluated drivers' ability to recover from TVA when traversing through a partially illuminated interchange consisting of one, two, three, and four luminaries. An attempt was also made to determine the plausible cause of TVA.

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Lyle Saxton

Director, Office of Safety and Traffic
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16. Abstract The objective was to determine the extent that transient visual adaptation (TVA) affects drivers' detection of targets along partially lighted freeway interchanges. The study expanded a preliminary task on TVA described in publication FHWA-RD-88-223. Twenty-five subjects drove 10 trials on an entrance and an exit ramp. Lighting was manipulated to provide trials in darkness, and with one, two, three, and four luminaires lighted along each ramp. The same drivers returned for a second session of 10 trials, when refractors were replaced with sharp cut-off luminaires (low glare). The drivers pressed a button on a hand-held switch when they detected the 7-in by 7-in (17.8-cm by 17.8-cm) gray targets placed on the shoulder at 350 ft (106.75 m) or 475 ft (144.88 m) downstream of the final ramp luminaire. The vehicle computer recorded distances between subjects and targets at the instant of detection. Significantly shorter detection distances were obtained in the lighted conditions than in darkness. Significant differences in mean detection distance as a function of luminaire number were not observed except for four conventional luminaires with the target at 475 ft (144.88 m). A significantly shorter mean detection distance was produced, compared to conditions of one, two, or three luminaires. The results showed no significant differences between conventional and sharp cut-off luminaires.			
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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol	Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH					LENGTH				
in	inches	25.4	millimeters	mm	mm	millimeters	0.039	inches	in
ft	feet	0.305	meters	m	m	meters	3.28	feet	ft
yd	yards	0.914	meters	m	m	meters	1.09	yards	yd
mi	miles	1.61	kilometers	km	km	kilometers	0.621	miles	mi
AREA					AREA				
in ²	square inches	645.2	square millimeters	mm ²	mm ²	square millimeters	0.0016	square inches	in ²
ft ²	square feet	0.093	square meters	m ²	m ²	square meters	10.764	square feet	ft ²
yd ²	square yards	0.836	square meters	m ²	m ²	square meters	1.195	square yards	yd ²
ac	acres	0.405	hectares	ha	ha	hectares	2.47	acres	ac
mi ²	square miles	2.59	square kilometers	km ²	km ²	square kilometers	0.386	square miles	mi ²
VOLUME					VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL	mL	milliliters	0.034	fluid ounces	fl oz
gal	gallons	3.785	liters	L	L	liters	0.264	gallons	gal
ft ³	cubic feet	0.028	cubic meters	m ³	m ³	cubic meters	35.71	cubic feet	ft ³
yd ³	cubic yards	0.765	cubic meters	m ³	m ³	cubic meters	1.307	cubic yards	yd ³
MASS					MASS				
oz	ounces	28.35	grams	g	g	grams	0.035	ounces	oz
lb	pounds	0.454	kilograms	kg	kg	kilograms	2.202	pounds	lb
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")	Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
TEMPERATURE (exact)					TEMPERATURE (exact)				
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C	°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
ILLUMINATION					ILLUMINATION				
fc	foot-candles	10.76	lux	lx	lx	lux	0.0929	foot-candles	fc
fl	foot-Lamberts	3.426	candela/m ²	cd/m ²	cd/m ²	candela/m ²	0.2919	foot-Lamberts	fl
FORCE and PRESSURE or STRESS					FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N	N	newtons	0.225	poundforce	lbf
lbf/in ²	poundforce per square inch	6.89	kilopascals	kPa	kPa	kilopascals	0.145	poundforce per square inch	lbf/in ²

NOTE: Volumes greater than 1000 l shall be shown in m³.

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

Table of Contents

1. Introduction	1
2. Test Interchange Description	3
3. Lighting at the Test	3
4. Test Procedure	11
5. Study Design	12
6. Targets and Target Placement	12
7. Subjects	13
8. Study Results	14
Number of Luminaires	15
Targets Location	18
Type of Luminaire	20
9. Summary and Conclusions	21
10. Recommendations	22
Appendix A. Individual subject data	23
References	24
Bibliography	24

List of Figures

<u>Figure</u>	<u>Page</u>
1. Typical light distributions from refractor and sharp cut-off luminaires.	2
2. Southbound entrance ramp.....	4
3. Northbound exit ramp.	4
4. Plan view of luminaire and target locations.....	5
5. Refractor luminaire—illuminance values-right edgeline.	7
6. Refractor luminaire—illuminance values-centerline.	7
7. Refractor luminaire—illuminance values-left edgeline.	7
8. Sharp cut-off luminaire—illuminance values-right edgeline.....	9
9. Sharp cut-off luminaire—illuminance values-centerline.	9
10. Sharp cut-off luminaire—illuminance values-left edgeline.	9
11. Number of luminaires for refractor and sharp cut-off luminaires - near targets.	16
12. Number of luminaires for refractor and sharp cut-off luminaires - far targets.	16
13. Near and far targets and number of luminaires - refractor luminaires.	19
14. Near and far targets and number of luminaires - sharp cut-off luminaires.	19

List of Tables

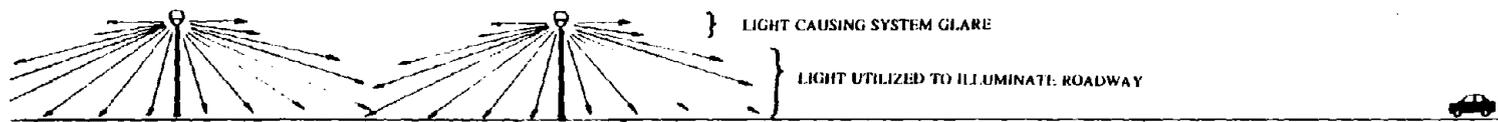
<u>Table</u>	<u>Page</u>
1. Summary of installation characteristics.	10
2. Summary of lighting characteristics.	11
3. Subjects by age and sex.	13
4. Analysis of variance for detection distance.	14
5. Summary statistics.	15

1. Introduction

The underlying rationale for the conduct of the study was that the basic vision literature has shown that transient visual adaptation (TVA) occurs when different luminance levels are encountered (see references 1 through 6). That is, the eye moves from one luminance level to another and is continuously adapting to higher and lower levels, thereby temporarily reducing contrast sensitivity. The reduction of contrast sensitivity in turn can reduce the probability of detecting a target on the road or roadside. An earlier pilot study of TVA was conducted in the context of a larger study of a tradeoff between delineation and lighting . This study was performed in 1987 and described in FHWA-RD-88-223 .(1)

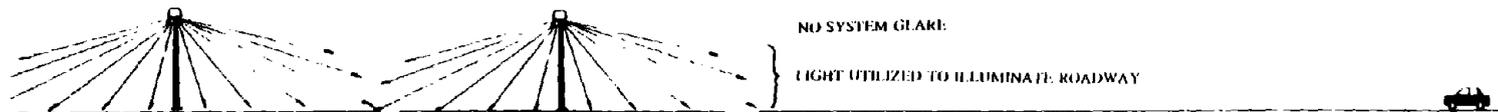
The pilot TVA study was conducted to determinewhether the phenomenon, previously established in laboratory studies, was evident in the field. The pilot study showed a statistically significant reduction in target detection performance when driving through a partially lighted interchange that was illuminated with four refractor type luminaires. The purpose of the current study was to make an empirical determination of the extent to which transient visual adaptation (TVA) occurs when drivers traverse partially illuminated interchanges outfitted with various numbers of luminaires and types of luminaires. Specifically, the conditions tested were no lights versus one, two, three and four luminaires. These conditions were tested using refractor type luminaires and sharp cut-off type luminaires; the latter type designed to reduce glare.

The purpose of using the two types of luminaires was to determine, if possible, the cause (or causes) of TVA in the field. That is, it is not yet known whether the TVA effect observed in the pilot study may have been caused by the light emitted from overhead luminaires and directed into the drivers' eyes, or caused by the luminance of the pavement. If the TVA effect is caused by the light emitted from the overhead luminaires, while drivers are at some distance from the luminaires, the refractor type luminaire would show some disabling effect, while the sharp cut-off luminaires would not. This disability would be manifested in shorter observed target detection distances with the refractor luminaires than with the sharp cut-off luminaires. On the other hand, if TVA is caused by the luminance of the pavement, the findings of the present study would be expected to show no difference between the refractor type and the sharp cut-off type luminaires. Figure 1 illustrates the typical light distributions from both types of luminaires.



TYPICAL LIGHT DISTRIBUTION FROM REFRACTOR TYPE LUMINAIRE

2



TYPICAL LIGHT DISTRIBUTION FROM SHARP CUT-OFF TYPE LUMINAIRE

Figure 1. Typical light distributions from refractor and sharp cut-off luminaires.

In addition to the specific purpose noted, an additional goal was to obtain results which could help to explain and support the results of the main field study of lighting and delineation as reported in FHWA Report No. FHWA-RD-88-223. (1)

2. Test Interchange Description

The interchange used for the testing was partially illuminated with four luminaires at the exit ramp. Since the driving circuit used for the study required that the opposite (southbound) entrance of the interchange be used to return to the (northbound) test exit and since the lighting configuration was also partial for the entrance, it was decided to gain additional trials by obtaining detection data on the entrance. The only restriction was that the entrance ramp permitted targets on the right side only because of the two-lane mainline following the entrance luminaires.

The four luminaires at the exit ramp were located over an area of approximately 650 ft (198.1 m), with each luminaire support being separated by approximately 200 ft (61 m). The four luminaires at the entrance ramp were spaced at approximately 230 ft (70.1 m), and were located over an area of approximately 690 ft (210.3 m).

Figures 2 and 3 show photographs of both the entrance and exit ramps. Figure 4 shows a plan view of the site along with the target locations discussed in section 6.

3. Lighting at the Test Interchange

The first half of the field data for the current study were collected under the same lighting setup as used for the pilot study performed in 1986 and described in FHWA-RD-88-223. The lighting measurements made in conjunction with the pilot study showed that the average illuminance, determined from measurements on both the exit and entrance portion of the interchange, was 18 lux, with a minimum of 2.4 lux and a maximum of 60 lux. The average pavement luminance was 1.6 cd/m^2 with a minimum of 0.4 cd/m^2 and a maximum of 3.4 cd/m^2 . The veiling luminance was calculated at 0.7 cd/m^2 .

Prior to the conduct of the current study, the luminaires were cleaned, checked for proper level and adjusted, as necessary, and relamped. Also, two broken refractors were replaced. So that the number of luminaires could be easily varied over the course of a subject driving session, each luminaire was equipped with a switch to allow field personnel to activate or deactivate the luminaires individually.



Figure 2. Southbound entrance ramp.



Figure 3. Northbound exit ramp.

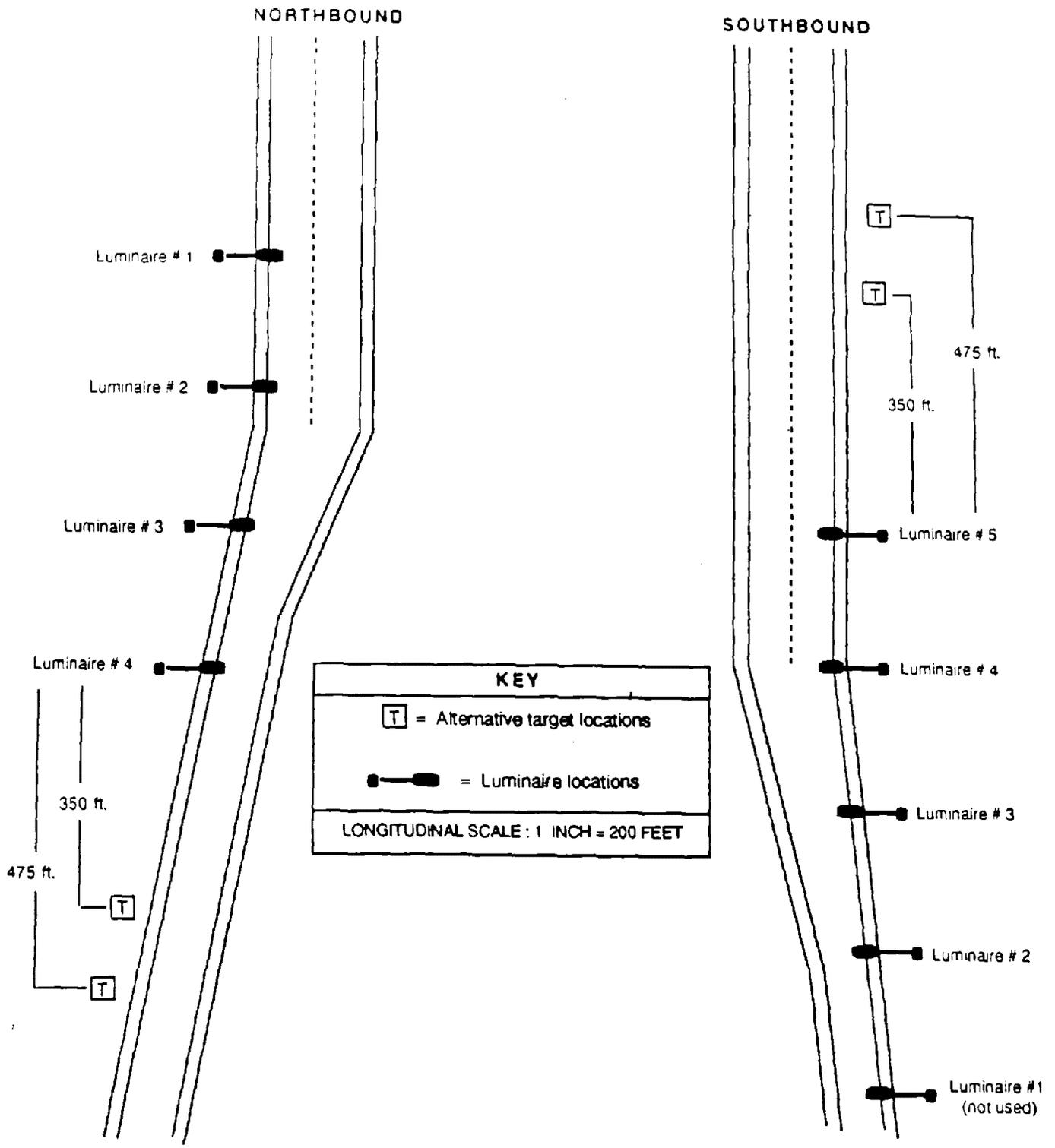


Figure 4. Plan view of luminaire and target locations.

For the purposes of the current study, detailed field measurements were taken over a 700-ft (213.3-m) section at the southbound entrance ramp between the first luminaire encountered by the approaching driver and the fourth luminaire (see figure 4 for luminaire numbers). This area was selected since it contained a gore between the on-ramp and two through-lanes and represented a more severe geometry than the exit ramp, which consisted of a single lane. In addition, luminaire spacings at the on-ramp exceeded those on the exit ramp. The entrance ramp contained five 310-watt, high pressure sodium (HPS) luminaires, however only four luminaires were used during the study. The exit ramp contained three 310-watt and one 200-watt unit. Reading locations were established every 20 ft (6.1 m) along the right edgeline of the ramp as well as along the center line and the left edgeline of the highway.

Figures 5, 6 and 7 show the illuminance readings obtained for the refractor luminaires for the right and left edgelines and the centerline.

After data collection using the refractor type luminaires was completed, these luminaires were replaced with sharp cut-off (SCO) types for the second half of the study. Sharp cut-off type luminaires normally have no light emitting glassware projecting below the main body of the luminaire (as is the case with a conventional refractor type) and therefore emit considerably less or no light at high vertical angles where glare might have deleterious effects on a driver's visibility. It was hypothesized that this would help to determine how glare, emitted by the refractor, and seen for a considerable time while approaching the lighting installation, influences transient visual adaptation. Prior to replacing the existing system, a computer analysis was made to select sharp cut-off luminaires which would perform as closely as possible to the luminaires they would replace. Nothing other than the luminaires was replaced. The HPS lamps remained at the same luminaire locations, and the poles, bracket arms, luminaire mounting height, power supply characteristics, and pavement were the same. The intent was to keep the horizontal pavement illuminance as close as possible between the two systems. With point-by-point illuminance, and therefore pavement luminance, constant between the two systems, the only variable that could influence detection distance was increased glare associated with the refractor type luminaires.

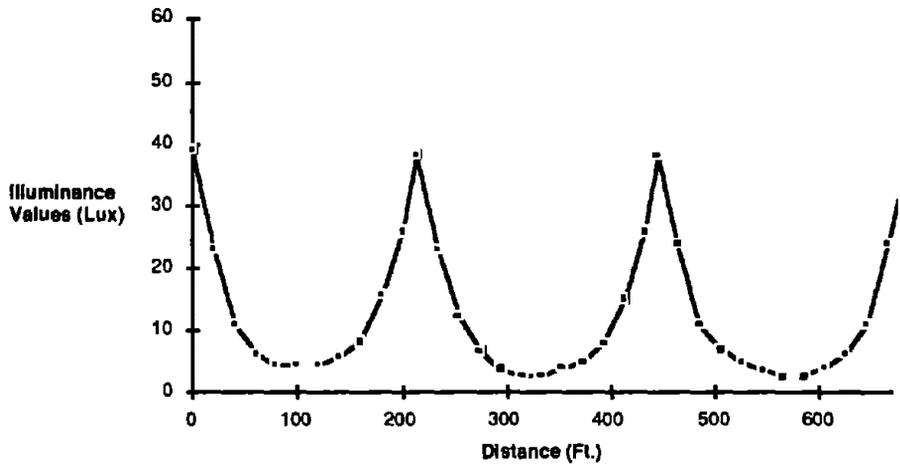


Figure 5. Refractor luminaire—illuminance values-right edgeline.

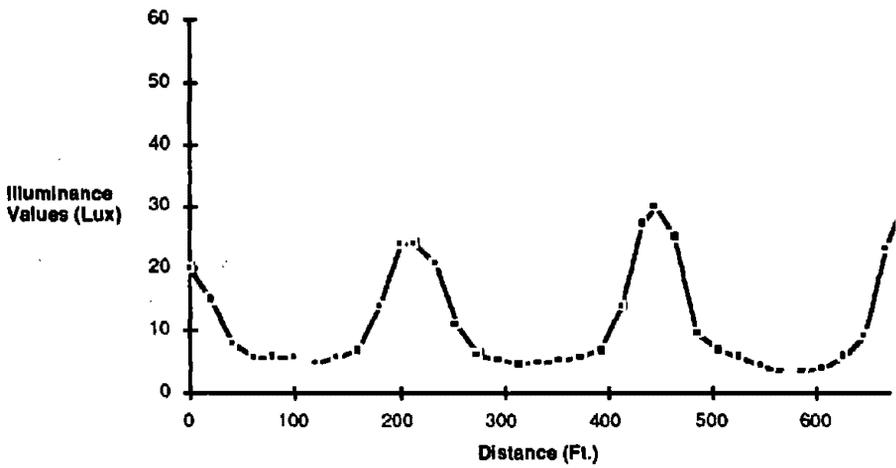


Figure 6. Refractor luminaire—illuminance values-centerline.

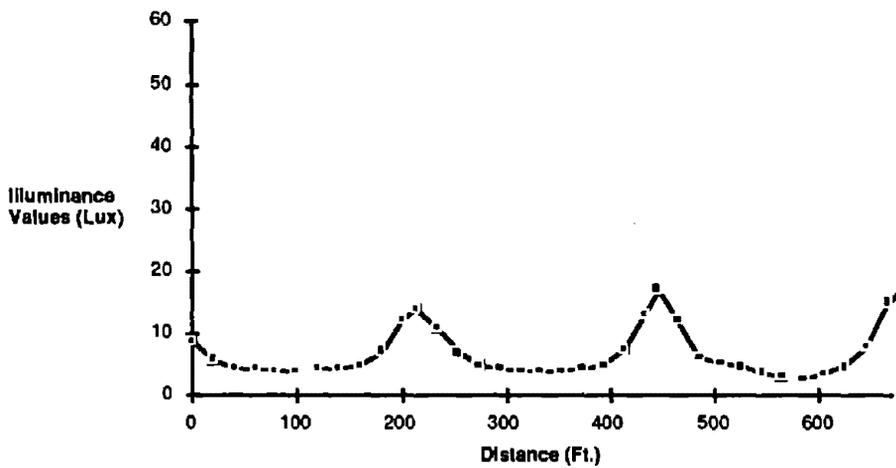


Figure 7. Refractor luminaire—illuminance values-left edgeline.

To obtain average and minimum illuminance values, the central 466-ft (142-m) section of the 700-ft (213.4-m) test site was evaluated. This included luminaire locations #2 and 3, and the area from halfway between luminaires #1 and 2 through halfway between luminaires #3 and 4 (110 ft through 576 ft [33.5 m through 175.6 m]). The number references for the luminaires are given in figure 4. The original refractor type installation (cleaned and relamped) provided an average horizontal illuminance of 10.32 lux, maximum of 39 lux, and minimum of 2.4 lux. The average to minimum ratio of this system was 4.3 to 1. These parameters were used in the computer analysis of a series of sharp cut-off luminaires to find a type which would match. The unit most closely meeting this requirement had a IES Type III, Medium, Cut-Off distribution with a predicted performance of 10.33 lux average, a maximum of 52.1 lux, a minimum of 3.3 lux, and an average to minimum ratio of 3.5 to 1. The calculations were based on a 35-ft (10.7-m) mounting height and an average 220-ft (67.1-m) luminaire spacing.

After removal of the refractor type luminaires and installation of the sharp cut-off system, the field measurements were repeated to verify the computer predictions. Unfortunately, the actual performance was considerably different from what was expected. Although the average was close (12.5 lux measured vs. 10.33 calculated), the minimum was very low (0.4 lux measured vs. 3.3 calculated) resulting in an extremely poor average to minimum ratio of 31 to 1. A field investigation was performed to determine the cause of this discrepancy and to find a remedy. During this investigation, the luminaire mounting heights were found to be 2 to 3 ft (.6 to .9 m) lower than the 35 ft (10.7 m) we had been told they were. This was primarily responsible for the very low illuminance values found between luminaires. Another factor contributing to the low minimum level was the longer than 220-ft (67.1-m) spacing between several luminaires. Since there was no possibility of increasing the mounting height or changing the luminaire spacings, the lamp positions were manually adjusted to improve the minimum illuminance levels and thereby improve the average to minimum uniformity ratio. This adjustment consisted of physically pulling the lamp downward as far as possible (about 1/4 in [.64 cm] at the light center.) The adjustment was the only way to improve the illuminance uniformity on the roadway enough to meet the study objective as well as American Association of State Highway and Transportation Officials (AASHTO)/ Federal Highway Administration (FHWA) requirements.

Field measurements were taken after this modification. The average illuminance was 10.33 lux, the maximum was 54.3 lux, and the minimum 1.4 lux, resulting in an average to minimum illuminance uniformity ratio of 7.4 to 1. The illuminance values associated with sharp cut-off luminaires are shown in figures 8, 9 and 10.

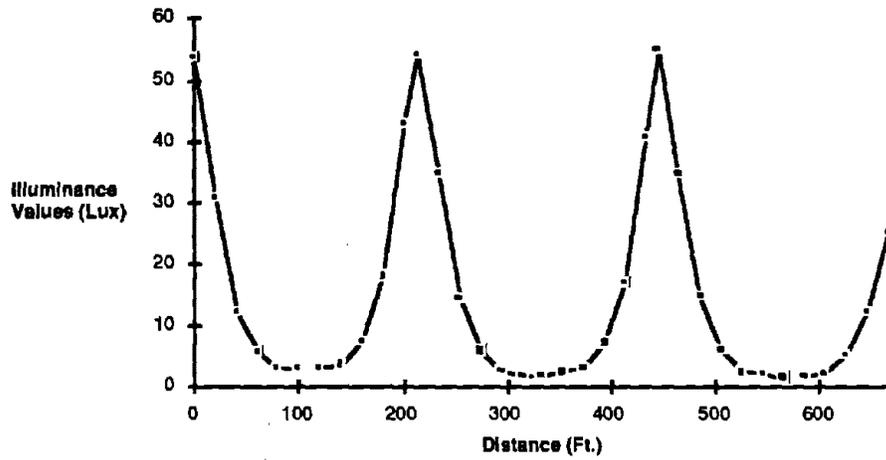


Figure 8. Sharp cut-off luminaire—illuminance values-right edgeline.

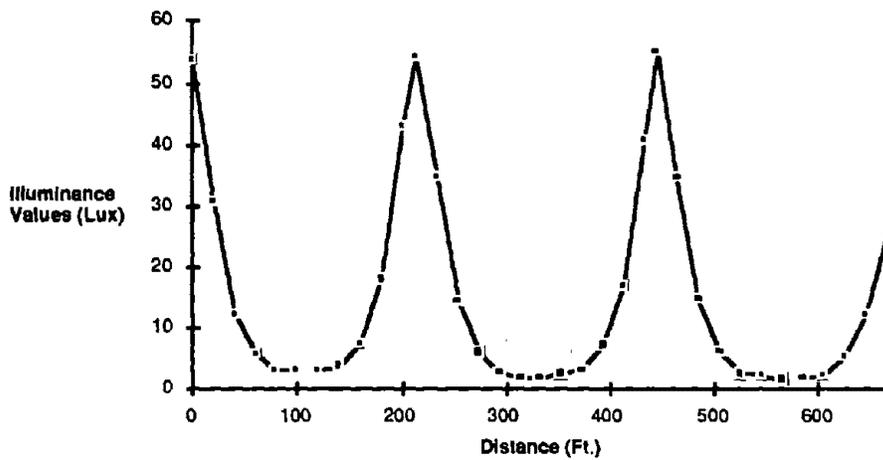


Figure 9. Sharp cut-off luminaire—illuminance values-centerline.

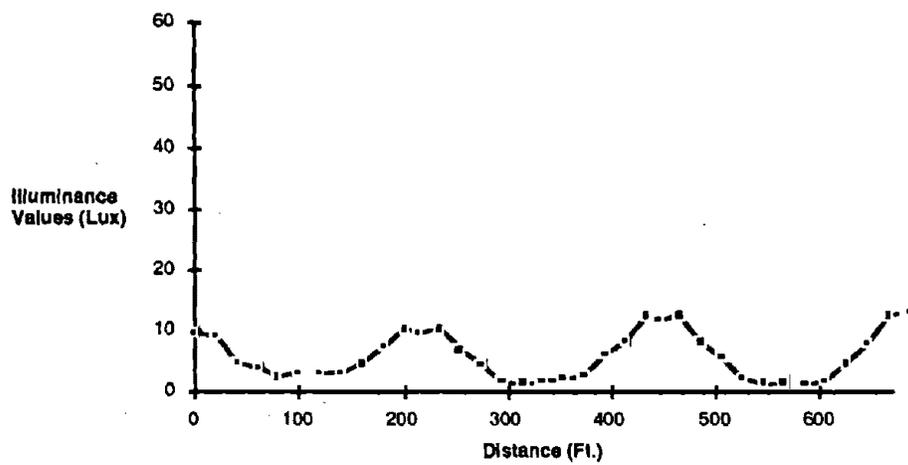


Figure 10. Sharp cut-off luminaire—illuminance values-left edgeline.

Lighting of the exit ramp was not investigated in as great detail since the spacing of the luminaires was slightly closer, and the total road width was only 16 ft (4.9 m) and was bordered on the left edge by a Jersey barrier, which would have made extensive collection of the lighting data quite hazardous.

The lighting characteristics are summarized in tabular form in tables 1 and 2.

Table 1. Summary of installation characteristics.

Luminaires No.	Size	Ent. Ramp (South)		Size	Exit Ramp (North)	
		Mount. Ht.	Spacing		Mounting Height	Spacing
1	310 W HPS	32'8"	214'	310 W HPS	32'5"	214'
2	310 W HPS	33'6"	232'	310 W HPS	33'4"	180'
3	310 W HPS	32'0"	244'	310 W HPS	32'0"	218'
4	310 W HPS	33'7"	250'	200 W HPS	29'8"	-----
5	310 W HPS	33'3"	-----	-----	-----	-----

Note: Luminaire No.1 is the first luminaire encountered when entering the ramp. Spacings are between adjacent luminaires (i.e. 214-ft (65.2-m) between No. 1 and 2) - see figure 4 for luminaire locations.

Table 2. Summary of lighting characteristics.

	Ent. Ramp (South)		Exit Ramp (North)	
	Refr. Lum.	SCO Lum.	Refr. Lum.	SCO Lum.
Average Illuminance	10.3 lux	10.3 lux	14.1 lux	14.7 lux
Minimum Illuminance	2.4 lux	1.4 lux	5.1 lux	2.2 lux
Maximum Illuminance	39 lux	54 lux	38 lux	58 lux
Illum. Uniformity Ratio (Avg. to Min.)	4.3:1	7.4:1	2.8:1	6.7:1
Pavement Luminance ¹	1.8-2.6 cd/m ²	1.4:2.6 cd/m ²	3.8-4.0 cd/m ²	1.3-1.6 cd/m ²
Veiling Glare ¹	0.3 cd/m ²	0.1-0.2cd/m ²	0.4-0.5 cd/m ²	0.1-0.2 cd/m ²
Glare Contrast Factor ¹	0.92	.95-1.00	.86-.93	.95-1.0

¹Note: Pavement luminance was measured with two different meters (Minolta 1° Spot Luminance Meter and A.R.T. Model 2000 Glare Meter). Veiling Glare and Glare Contrast were measured with an A.R.T. Model 2000 Glare Meter.

4. Test Procedure

The procedure employed 25 subjects driving an instrumented vehicle through the interchange under various partially illuminated and nonilluminated conditions. A target detection task was used to assess the existence (and extent) of transient adaptation. The subjects were instructed to press a hand-held button when a target was detected. They were also asked to verbally identify whether the target was on the left or right side of the ramp. The indication of detection was automatically entered into the on-board computer. Prior to a point at which it was possible to detect the target, the experimenter entered several location reference codes via the computer keyboard. The instrumentation also included a distance measuring instrument (DMI), which was sampled every half second by the computer. Thus for each trial, the location reference entered by the experimenter along with the target detection point entered by the subject, provided the target

detection distance measure. The experimenter used a tape recorder to note field events that may have influenced detection on a given trial.

Subject drivers were instructed to maintain a 45-mi/h (72.4- km/h) approach speed and, if the speed was over or under 45 mi/h (72.4 km/h), they were reminded of the speed required as the illuminated section of the interchange was approached. On the approach subjects were also instructed to maintain enough distance from any lead vehicles to preclude lead vehicle headlights from illuminating targets or to allow closely following vehicles to pass. Any trial on which the experimenter judged that a following vehicle may have produced glare in the rear view mirror or that the headlights of a lead vehicle may have illuminated the target, the trial was repeated. Each experimental session provided 10 trials on each of the ramps and required approximately 2 hours of driving.

5. Study Design

The study was designed as a fully crossed factorial, repeated measures design. In other words each subject was exposed to all illumination conditions. To control for fatigue effects or effects associated with order of presentation of the various conditions, four different blocks of trials were designed. The blocks varied with respect to the order of: the number of luminaires; longitudinal target location (350 ft or 475 ft [106.8 m or 144.9 m]); and lateral target location (left or right).

Subjects were assigned to one of the blocks and first exposed to the refractor type luminaires which were in place at the time the study started. Following the completion of data collection for all subjects under these conditions, the luminaires were replaced with the sharp cut-off luminaires and each subject completed the same "order" block that had been assigned previously.

6. Targets and Target Placement

The detection targets were 7 in by 7 in (18 cm) with a reflectance value of approximately 20 percent; the target characteristics being those adopted by the Roadway Lighting Committee of the Illuminating Engineering Society (IES) for visibility measurements. While all of the data shown is for targets placed on the right side of the roadway, targets were placed on the left side of the exit ramp for 50 percent of the trials. While this created additional uncertainty and task

variation, the primary purpose of the lateral variation was to induce scanning behavior on the part of the subject drivers. This was desired because it has been shown that if the eye is not fixed on an object but is scanning a large field, transient adaptation will have the maximum effect on contrast sensitivity in a nonuniform luminance field. The different target placements created the need for drivers to scan the maximally relevant field rather than fixating on one side of the roadway. Targets were always placed such that no target luminance was provided by the fixed lighting.

The measurable light from the luminaires terminated at 200 ft (61 m) downstream from the base of the last luminaire. The "near" target placement for both entrance and exit ramps was 350 ft (106.8 m) downstream of the last luminaire. This value, which represented a distance of 150 ft (45.8 m) past the influence of the luminaire, was chosen because it approximated the design of partial lighting on some sharply curved ramps that had been cataloged for another part of the project. The "far" targets were located 475 ft (144.9 m) from the last luminaire. The lateral location of the targets (measured to the left side of the targets) was 2 ft (.61 m) from the outside edge of the edgeline.

7. Subjects

All subjects were tested for contrast sensitivity using the Vistech VCTS 6000 system (Vistech Consultants, Inc., Dayton, OH). All of the subjects accepted had normal contrast sensitivity. Subjects wore corrective lenses for their driving trials if their licenses so indicated or if they habitually wore glasses while driving. The subject age and sex breakdown is shown in table 3:

Table 3. Subjects by age and sex.

AGE GROUP	MALE	FEMALE
18—39	5	8
40—59	1	4
> 59	6	1

8. Study Results

The analysis of variance (ANOVA) showed that the main effects for both number of luminaires (0 through 4) and target location (350 ft and 475 ft [106.8 m and 144.9 m]) are highly statistically significant ($p < .001$). The effect of subjects is also highly significant. However, the effect of type of luminaire (refractor and sharp cut-off) was not significant. In addition to the main effects, the interactions of type of luminaire and target location with number of luminaires is significant, with p -values of $p < .05$ and $p < .01$ respectively. The analysis of variance table is shown below (table 4), followed by a table of the summary statistics for all experimental conditions (table 5). This is followed by the discussion of the effects of the individual independent variables and interactions. The data for individual subjects is in appendix 1.

Table 4. Analysis of variance for detection distance.

	Degrees of Freedom	Sum of Squares	Mean Square	F-ratio	Prob.
Subjects	24	865503	36062.6	23.47	0.000
No. Luminaires	4	318744	79686.0	18.50	0.000
Type Luminaire	1	57	57.1	0.01	0.942
Tgt. Location	1	98926	98926.2	59.39	0.000
Subj. x No. Lum.	96	413524	4307.5	2.80	0.000
Subj. x Type Lum.	24	252705	10529.4	6.85	0.000
Subj. x Tgt. Loc.	24	39979	1665.8	1.08	0.376
No. Lum. x Type Lum.	4	25394	6348.5	3.12	0.018
No. Lum. x Tgt. Loc.	4	27086	6771.6	4.01	0.005
Type Lum. x Tgt. Loc.	1	71	71.4	0.03	0.872
Error	96	147526	1536.7		
Total	499	2620550	5251.6		

Table 5. Summary statistics.

Experimental Condition			Statistical Measures				
No. Lights	Luminaire Type	Tgt. Loc.	Means	Medians	Std. Devs	Range	85th %ile
0	REFRACTOR	NEAR	452	446	62	286	518
0	SHARP CUT-OFF	NEAR	445	426	89	353	533
0	REFRACTOR	FAR	462	457	79	329	560
0	SHARP CUT-OFF	FAR	439	433	91	351	564
1	REFRACTOR	NEAR	382	383	56	205	456
1	SHARP CUT-OFF	NEAR	374	364	77	348	437
1	REFRACTOR	FAR	409	408	44	177	466
1	SHARP CUT-OFF	FAR	401	390	66	324	457
2	REFRACTOR	NEAR	370	365	61	202	447
2	SHARP CUT-OFF	NEAR	367	354	55	208	427
2	REFRACTOR	FAR	420	427	42	157	468
2	SHARP CUT-OFF	FAR	405	399	64	276	456
3	REFRACTOR	NEAR	368	361	72	250	457
3	SHARP CUT-OFF	NEAR	376	370	68	336	457
3	REFRACTOR	FAR	414	408	43	150	466
3	SHARP CUT-OFF	FAR	412	410	69	348	470
4	REFRACTOR	NEAR	359	359	63	231	435
4	SHARP CUT-OFF	NEAR	369	357	71	247	465
4	REFRACTOR	FAR	370	378	80	292	451
4	SHARP CUT-OFF	FAR	411	394	58	230	464

Number of Luminaires

It should be noted that in the graphics showing the effect of number of luminaires, the data for the dark conditions represent the combined data from both refractor and sharp cut-off luminaires,

since type of luminaire cannot influence detection distance under unlighted conditions. However, the separate detection distance data for each type of luminaire are retained in the summary of descriptive statistics (table 5) presented above. The comparisons of mean detection distances for various numbers of luminaires with dark conditions are shown graphically in figures 11 and 12. Because of the significant interaction of number of luminaires with type of luminaire, the graphics show the means for each type.

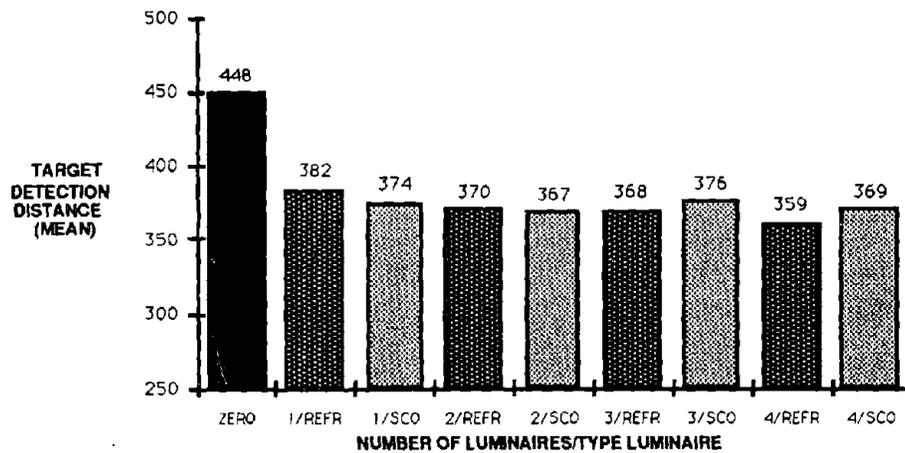


Figure 11. Number of luminaires for refractor and sharp cut-off luminaires - near targets.

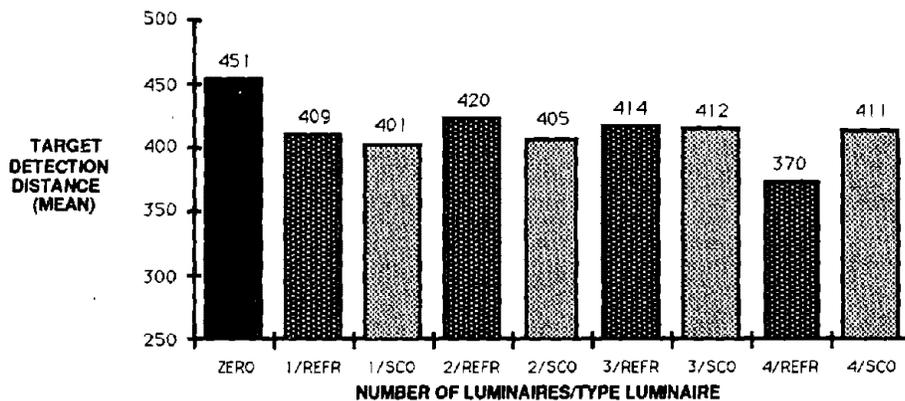


Figure 12. Number of luminaires for refractor and sharp cut-off luminaires - far targets.

Given the highly significant overall effect of number of luminaires, it is also important to know how many luminaires act to produce the transient effect. This information will allow specification of the maximum number of luminaires that should be used in a partial lighting installation to avoid a transient effect. For the statistical comparisons of individual experimental conditions, it should be noted that all of the data obtained under dark conditions (zero luminaires) was collapsed into a single value. The individual treatment comparisons showed that for near targets the results are clear for both the refractor and sharp cut-off luminaires. In all cases, the differences between dark conditions (zero luminaires) and any number of luminaires was significant at the $p=.01$ level. All other comparisons were nonsignificant. Thus, for the near targets, where the transient effect would be expected to be strongest, the effect is observed with any number of luminaires.

The statistical comparisons for the far target location are somewhat different for the refractor type luminaires versus the sharp cut-off luminaires. For the refractor type luminaires, the differences in mean detection distance between dark conditions and any number of luminaires are all significant at the $p=.01$ level. In other words, as with near targets, any number of luminaires produces a transient effect, as reflected in the shorter distances associated with lighting. In addition to the significant light/dark effects, there were significant differences between four luminaires and one, two and three luminaires. As shown on figure 12, the 370-ft (112.8-m) mean detection distance associated with four luminaires of the refractor type is substantially shorter than any of the other far target detection distances.

For the sharp cut-off luminaires, the observed differences between dark conditions and lighted conditions are significant for one and two luminaires ($p=.01$), but not for three or four luminaires. The differences between dark conditions and three or four luminaires approached statistical significance, both resulting in t -values with $p=.07$. The mean detection distances for three and four luminaires of the sharp cut-off type are slightly longer than those for one and two luminaires (see figure 11). But the differences are sufficiently small that they would not be expected to impact on a decision as to how many luminaires should be used for a partially lighted interchange; the maximum difference (between one luminaire and three luminaires) being 11 ft (3.4 m). Further, comparisons between the various numbers of sharp cut-off luminaires (via paired sample t -tests) show that none of the other differences are statistically significant.

In terms of the actual magnitude of the differences in detection distance associated with various numbers of luminaires, a review shows that for the near targets (figure 11) the differences among number of luminaires is relatively small. The maximum difference for the near targets when

refractor type luminaires were used is 23 ft (7.0 m). For the sharp cut-off luminaires, the maximum difference is 9 ft (2.7 m). In other words, for the near targets there is little practical difference between one and four luminaires, with either type of luminaire. The differences between any number of luminaires and no illumination is much more substantial. For the refractor type luminaires, the minimum difference in mean detection distance is 66 ft (20.1 m) and the maximum difference is 89 ft (27.1 m). For the sharp cut-off luminaires, the minimum and maximum differences are 72 ft (21.9 m) and 81 ft (24.7 m) respectively. In terms of time for a driver to detect a 20-percent reflectance object on the roadside, the differences in detection distance, on the average, translate to a disadvantage of 1.0 to 1.3 seconds associated with the lighting. The time "disadvantage" is based on the 45-mi/h (72.4-km/h) speed at which the subjects were required to drive during the detection trials.

For the sharp cut-off luminaires and far targets there is very little difference between the means for one through four luminaires (see figure 12). As noted above, the maximum mean difference is 11 ft (3.4 m). The comparison of the various light conditions with the dark condition shows that the maximum detection distance difference is 50 ft (15.2 m) and the minimum is 39 ft (11.9 m). In terms of time, these distance differences represent 0.76 and 0.59 seconds respectively, at the 45-mi/h (72.4-km/h) ramp speed.

For the refractor-type luminaires, the detection distances associated with far targets show slightly greater variation between various numbers of luminaires than do the other data sets. Of note is the comparatively short 370-ft (112.8-m) detection distance associated with the four-luminaire condition.

The four-luminaire condition produced the only far-target detection distance, including those associated with the sharp cut-off luminaires, that is in the range of the near-target detection distances. The maximum and minimum differences in detection distances between any of the lighting conditions and the dark condition are 81 and 31 ft (24.7 m and 9.4 m) respectively. The related time values are 1.23 and 0.47 seconds.

Target Location

The effects of target location are consistent for both the refractor and the sharp cut-off type luminaires. In all cases, the far target location (475 ft [144.8 m] from the last luminaire) resulted in longer detection distances than those for the near targets (350 ft [106.5 m] from the last

luminaire), regardless of the number of luminaires. Figures 13 and 14 show the mean detection distances for near and far targets under the various illumination conditions as compared to the mean detection distance under dark conditions.

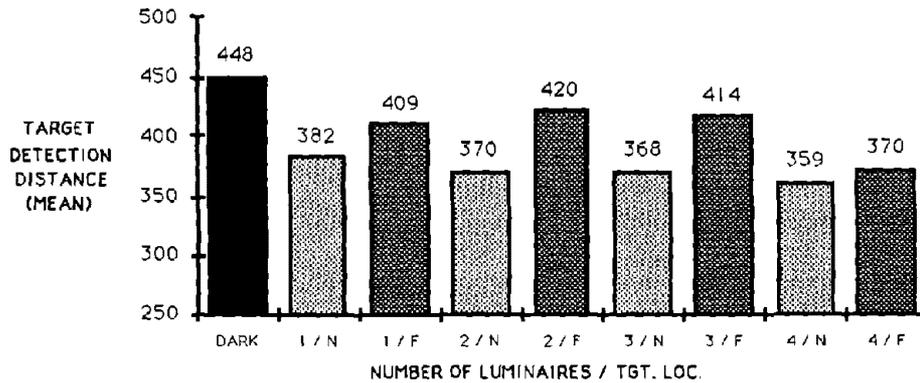


Figure 13. Near and far targets and number of luminaires - refractor luminaires.

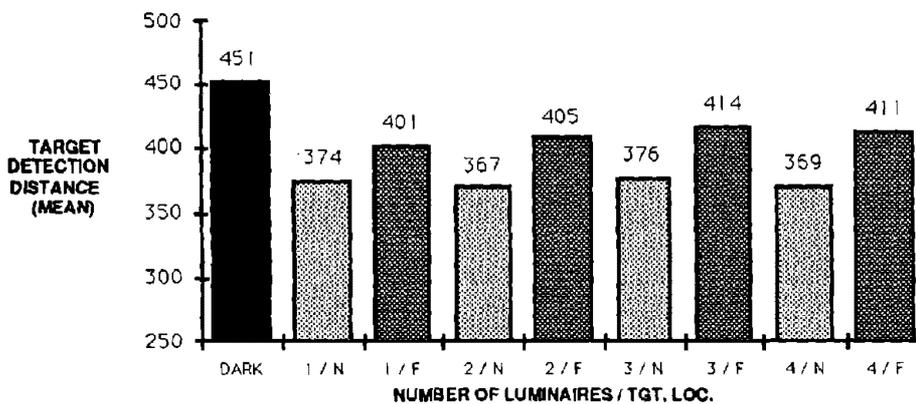


Figure 14. Near and far targets and number of luminaires - sharp cut-off luminaires.

The fact that the detection distances associated with the far targets are closer to the detection distance observed under nonilluminated conditions shows that the transient visual adaptation effect is partially dissipated as the driver approaches the target located 475 ft (144.8 m) from the last luminaire. Given that the difference between the near and far targets is 125 ft (38.1 m), and that the

subjects were driving at approximately 45 mi/h (72.4 km/h), this means that the transient adaptation effect begins to dissipate in less than 2 seconds.

To confirm that the observed effects were statistically reliable, further analyses of the differences between near and far targets were done using paired sample t-tests to assess each near-far difference. With the exception of one experimental condition, the near-far differences in mean detection distance were statistically significant ($p < .01$). The exception was the difference between near and far targets under the four-luminaire condition when the refractor-type luminaires were used. As can be seen in figure 13, the near-far difference in mean detection distance is only 11 ft (3.4 m) for this condition. This exception indicates that with the longer exposure to light (four luminaires) and the higher levels of glare associated with the refractor-type luminaires, the TVA dissipation effect noted for most conditions does not occur. It should be noted that the pilot study conducted on this interchange showed that the TVA effect associated with four luminaires of the refractor type was totally eliminated by the time a driver approached a point 600 ft (182.9 m), approximately 9 seconds, past the last luminaire.

Type of Luminaire

While the ANOVA showed that there was no statistically significant difference between the refractor and sharp cut-off luminaire types, this finding should be viewed with some caution. As pointed out previously, the erroneous information in mounting height obtained from the lighting contractor resulted in the need to manually adjust the sharp cut-off luminaires to bring the illuminance performance closer to the legal requirements set up by Pennsylvania Department of Transportation and AASHTO/FHWA. Because of the adjustment glare from the sharp cut-off luminaires was somewhat higher than would normally be the case. However, veiling glare from the sharp cut-off installation was considerably lower than that found with the refractor type luminaires; and system glare (light emitted at high angles) is practically nonexistent with the sharp cut-off units.

The above caution is given only because the sharp cut-off luminaires may have produced less favorable results than might be expected from an installation for which the design of the luminaires was matched to the appropriate mounting heights and spacing of the poles.

It should be noted that a number of the test subjects provided unsolicited comments regarding the improved visibility and comfort they felt to be associated with the sharp cut-off installation.

9. Summary and Conclusions

The results of the study confirm the results of a pilot study which showed that transient visual adaptation (TVA) occurs under field conditions. The effect is manifested in the shorter mean target detection distances under overhead lighting conditions as compared with those observed under unlighted conditions (see figures 11 through 14).

The results also showed that under all but one condition tested, the transient effect is of approximately the same magnitude regardless of the number of luminaires, i.e., significant differences in mean detection distance as a function of number of luminaires were not observed. The differences in mean detection distance between dark conditions and the various lighting conditions ranged from 39 to 89 ft (11.9 to 27.1 m); the lighted conditions always resulting in the lower values. Based on the 45-mi/h (72.4-km/h) speed at which the detection trials were conducted, this means that drivers traversing a partially lighted section can, on the average, be expected to detect a roadside target 0.6 to 1.3 seconds later than would be the case without lighting.

The only condition under which significant differences between number of luminaires was observed was when refractor luminaires were used and the target was at 475 ft (144.8 m). Under these conditions the use of four luminaires produced a significantly lower mean detection distance as compared with one, two, or three luminaires. The difference in mean detection distance between the dark and four-light conditions was 81 ft (24.7 m). The differences for the other three lighting conditions ranged from 31 to 42 ft (9.4 to 12.8 m). On the basis of this finding it is recommended that if refractor luminaires are to be used in a partial lighting installation, the maximum number of luminaires that should be used is three.

Another finding of the study is that the observed transient effect begins to dissipate rather rapidly. The dissipation is demonstrated by the differences in mean detection distance between targets located at 350 and 475 ft (106.7 to 144.8 m) from the last luminaire. For all except one condition tested, the detection distances observed for targets further away from the last luminaire were significantly longer than those for the closer targets. The only condition which did not result in a statistically significant difference between near and far targets is, again, the four-luminaire, refractor lighting configuration. Given the difference of 125 ft (38.1 m) between the near and far targets, the finding indicates that, for the 45-mi/h (72.4-km/h) speed used, the effect begins to dissipate in less than 2 seconds. Further, the previous pilot study showed that the effect is

eliminated by the time a driver reaches a point 600 ft (182.9 m), or 9 seconds, downstream of the last luminaire.

The objective of determining whether the transient effect is caused by the light emitted from overhead luminaires and directed into the drivers' eyes, or caused by the luminance of the pavement was not met. The results showed that there was no significant difference between the refractor and sharp cut-off type luminaires. However the finding is suspect because of the possibility that the manual adjustments required to compensate for erroneous mounting height information, may have introduced higher levels of glare than is typical of this type of luminaire. It is therefore recommended that a study similar to the current one be conducted to more accurately determine the source of the glare that produces the transient visual adaptation effect.

10. Recommendations

With regard to the use of partial lighting on interchanges, the decision must be left to engineering personnel. The current study has provided information on the magnitude of the transient visual adaptation effect under various lighting conditions and has provided some information on the dissipation of the effect. The decision to use or not to use partial lighting rests on a site-specific analysis of the driver detection task, i.e. what must be detected and where critical detection must take place relative to the location of the luminaire(s). For most freeway ramps with relatively little ramp curvature, the effects of transient adaptation are probably not critical. However, for severe geometrics, such as sharply curved ramps associated with cloverleaf interchanges, partial lighting is not recommended because the effects of transient adaptation could interfere with the ability of the driver to adequately detect the degree of curvature.

Based on the results obtained it is recommended that, to minimize the effects of transient adaptation, the number of refractor type luminaires used for partial lighting be kept to a maximum of three . If it is necessary to use a greater number of luminaires to meet the visibility needs at a particular installation, it is suggested that the luminaires be of the sharp cut-off type since this type of luminaire seemed to produce a less severe transient effect.

LIGHTING	DA RK				ONE LUMIN.				TWO LUMIN.				THREE LUMIN.				FOUR LUMIN.			
TARGET	NEAR TGT		FAR TGT		NEAR TGT		FAR TGT		NEAR TGT		FAR TGT		NEAR TGT		FAR TGT		NEAR TGT		FAR TGT	
GLARE	HI	LO	HI	LO	HI	LO	HI	LO	HI	LO	HI	LO	HI	LO	HI	LO	HI	LO	HI	LO
SS's																				
1	371	364	328	403	401	303	420	340	358	328	444	351	438	334	375	379	331	336	233	353
2	406	373	449	424	333	350	351	371	325	324	342	371	321	370	359	375	231	316	370	365
3	542	342	376	312	322	308	384	370	349	283	348	309	361	342	368	383	350	269	262	387
4	402	514	409	451	474	422	429	431	374	334	412	376	397	405	403	445	292	394	257	411
5	477	527	510	564	399	440	471	470	377	392	434	425	456	467	406	420	288	357	274	410
6	460	383	468	419	454	311	473	455	409	348	473	416	473	429	447	490	375	375	321	438
7	416	404	465	457	383	372	391	390	266	354	428	399	398	385	424	419	289	318	258	417
8	456	369	457	398	354	323	346	423	296	357	397	377	313	336	364	378	263	257	238	378
9	444	465	460	413	353	383	418	373	430	431	401	465	263	332	398	408	386	459	370	394
10	490	420	590	448	388	282	344	392	459	425	477	408	247	335	375	368	437	470	416	396
11	510	516	462	566	421	364	413	414	365	422	457	562	438	367	414	449	345	421	428	583
12	434	470	520	319	383	391	392	372	400	367	453	405	276	376	434	275	416	303	370	411
13	610	623	626	653	410	526	520	533	468	491	499	585	396	456	449	482	452	464	525	518
14	396	480	449	375	347	370	392	293	342	313	393	334	314	404	389	311	383	304	391	413
15	515	370	547	335	327	381	428	345	410	382	423	385	281	221	368	410	369	344	408	386
16	440	383	413	421	389	345	465	394	460	419	467	455	405	353	418	446	462	440	449	535
17	397	374	417	457	339	349	376	396	294	329	371	393	357	379	410	439	343	312	378	379
18	324	471	297	439	318	395	366	375	292	329	350	408	291	422	381	421	359	402	370	391
19	395	591	398	331	312	307	343	361	275	321	387	314	361	466	382	469	256	257	349	365
20	547	309	558	433	517	437	428	398	436	327	456	393	497	348	497	371	435	504	483	359
21	475	662	520	663	493	630	434	617	337	473	429	439	470	557	463	623	413	479	420	458
22	453	442	573	439	395	389	408	421	324	426	406	421	340	388	509	464	342	378	389	359
23	446	446	409	357	341	284	382	331	399	298	427	357	322	292	497	367	413	356	418	358
24	427	426	422	436	373	335	433	385	446	332	431	384	442	313	418	313	401	376	471	423
25	458	397	438	466	330	356	407	369	351	378	390	399	348	313	408	395	343	340	405	384
MEAN	452	445	462	439	382	374	409	401	370	367	420	405	368	376	414	412	359	369	370	411
SD	62	89	79	91	56	77	44	66	61	55	42	64	72	68	43	69	63	71	80	58

Appendix A - Individual subject data

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