THE MEASUREMENT OF DARK ADAPTATION LEVEL IN THE PRESENCE OF GLARE

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16. Abstract
An investigation was carried out to measure the effect of glare on driver dark adaptation. The procedure used was to measure the time after the glare was extinguished until the subject could detect a target light source. The procedure was calibrated in a laboratory by adapting the subject to a large surface of known luminance, reducing its luminance to that associated with low beams on a dark road, and measuring the time until the target source could be detected. The test was run facing standard, US-type low and high beams at a distance of about 150 feet. The level of dark adaptation was found to be about 5 ft-L with low beams and about 20 ft-L with high beams.

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INTRODUCTION

The human visual system adapts to different levels of lighting, making it possible for individuals to gain at least some visual information over a span of about eleven log units of illumination. Most of this adjustment takes place at the retinal level. At higher levels of illumination (photopic levels) photoreceptors known as cones are active. At low levels of illumination (scotopic levels) the cones no longer function, but receptors known as rods are active. At middle levels of illumination (mesopic levels) both the rods and cones function. Figure 1, taken from Grether and Baker (1972), shows the luminance levels (in foot-Lamberts [ft-L]) encompassing the functional range of vision.

While operating a motor vehicle at night, a driver is adapted to some level that is clearly below that normally associated with daytime conditions, but probably higher than that normally associated with night conditions, due to his/her own headlamps, those of other cars, streetlights, advertising signs, etc. There is no information on driver dark adaptation level in the literature. Indeed, there has been no real need for such information in the past. In recent years more and more work has been carried out on motor vehicle headlighting through the use of computer models. These models rely on laboratory studies of target detection in which level of dark adaptation is a significant parameter. Now, the lack of such information is a handicap.

Given the need for data on driver dark adaptation, a project was initiated to collect these data under certain representative conditions. The effort started as part of an ongoing project on headlighting systems under NHTSA sponsorship (Olson, et al., in process). In that study measures of dark adaptation were made in a dark rural road setting without lights, and with low and high beams. The levels of dark adaptation were found to be 0.005, 0.3, and 1.7 ft-L respectively. Referring to Figure 1, it will be noted that these values range from nearly the bottom to the top of the rod and cone vision (mesopic) zone.

None of the conditions examined in the original dark adaptation study included glare sources, because the threshold target detection task employed was sensitive to both changes in dark adaptation and the disabling effects of glare. Since there was an interest in measuring the effect of glare on dark adaptation, another procedure had to be devised. The procedure, and the results of the subsequent investigation, are described in this report.

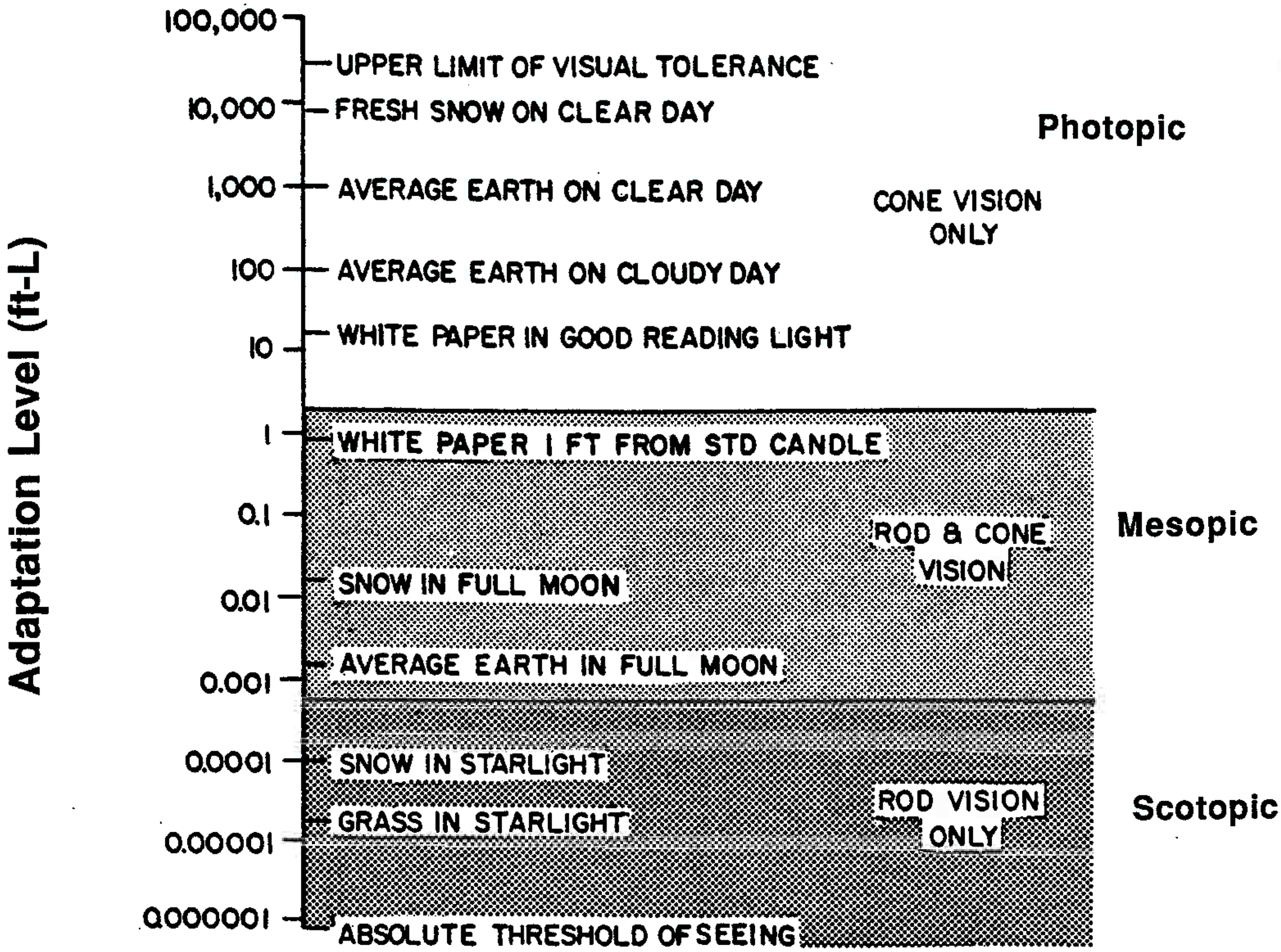

FIGURE 1. Vision at various luminance levels. (From: Grether and Baker, 1972.)

METHOD

Dark adaptation was measured using the same threshold target detection device that was employed in the original, no-glare adaptation study. Instead of direct measurements of threshold visibility, as in the first study, readaptation time was measured. Readaptation times from a number of levels were measured in a laboratory before measures were taken in the field.

Equipment

The threshold-measuring device was a metal enclosure housing a four-inch-diameter, sealed-beam, 12-volt spot lamp. Two milk-white pieces of translucent plastic were placed in front of it to act as dispersion filters. The front of the unit was closed off except for an opening the size of a 35 mm slide, which constituted the "target" for the subject. Neutral-density filters in 35 mm slide mounts could be used to adjust the luminance of the detection task. A single filter that provided 100% probability of detection at a dark adaptation level of 0.3 ft-L (appropriate for low beams without glare on a dark road) was used in this test. The whole unit was painted flat black. A shield about two feet long was provided around the device, to prevent illumination from car headlamps, etc. impinging directly on its face.

Procedure

The threshold task was used with a single subject (one of the experimenters). The first step was to give that subject sufficient practice time with the instrument to reduce error variance to the lowest level possible. This was done in the NHTSA adaptation study while selecting the set of neutral density slides.

The next step was to develop a set of calibration times. To do this the subject was seated 20 feet from a flat white screen 12 feet wide by 8 feet high. The threshold device was placed in front of the screen, about one foot below the subject's eye height, with its face shielded from direct illumination by the light source. At that distance the source subtended 0.24° vertically and 0.33° horizontally. The bulb was driven at 12.8 volts by a regulated power supply. The screen was illuminated by two sources. One maintained screen luminance at 0.3 ft-L. The second provided, together with the first lamp, the higher luminance levels of interest.

To obtain the desired calibration data both lamps were switched on to obtain one of four luminance levels, i.e., 5, 10, 20, or 30 ft-L. The lamps were left on for several seconds to permit the subject to adapt to the higher level, then the second lamp was turned off, returning the screen luminance to 0.3 ft-L. At the same time that the lamp was extinguished the subject started a timer, turning it off when the target could be detected.

Twenty such calibration trials were run at each of the four levels of adaptation luminance listed. The resulting times are given in Table 1. These data are presented in graphic form in Figure 2. The diagonal line is a visual best fit to the individual data points and defines the relationship between initial adaptation luminance and readaptation time for this subject.

To take data in the field the subject sat in a car with the threshold device approximately 20 feet in front of him. The height of the instrument was such that it was nearly on line with the horizon. The subject's cars headlamps were on low beam. A second vehicle, provided with precision voltage control equipment, was used to drive the bulb at 12.8 volts. This car was placed off the road to the subject's right. A third vehicle was used to provide glare. This car was placed to the subject's left, approximating a meet on a two-lane road, at a distance of about 150 feet. The glare car was equipped with halogen lamps meeting SAE specifications. The test was carried out in an area having no significant sources of artificial illumination.

Field data were taken in much the same way as in the laboratory. The lamps of the glare car were turned on for several seconds until the subject felt a stable level of adaptation had been reached. The lamps were then extinguished. At the same time the lamps were turned off the subject started a timer, which he stopped when the threshold task became visible. This process was repeated 15 times with low beam and 14 times with high beam. These data are presented in Table 2.

TABLE 1. Readaptation Times From Indicated Luminance Levels

	Luminance 5 17	 10 34	 20 68	 30 103	 (Ft-L) (nit)
1	3.17	4.08	4.88	5.86	
2	3.85	4.62	4.86	5.10	
3	4.28	4.26	6.19	5.26	
4	3.25	4.06	4.34	5.43	
5	4.49	4.91	4.71	8.11	
6	3.62	4.96	4.65	5.26	
7	3.32	4.33	4.83	5.09	
8	3.80	4.42	5.66	5.83	
9	3.77	6.27	5.14	5.43	
10	3.98	3.14	5.21	5.69	
11	4.07	4.34	5.03	6.33	
12	3.51	4.08	5.55	4.93	
13	3.99	4.25	4.89	5.24	
14	3.29	4.89	4.25	5.82	
15	3.81	4.89	4.91	6.26	
16	3.63	4.48	5.43	6.13	
17	3.80	4.54	5.84	5.77	
18	3.97	4.81	4.98	6.09	
19	3.93	4.66	5.05	5.82	
20	3.98	5.57	5.25	6.27	
Mean	3.78	4.58	5.08	5.79	
S.D.	0.34	0.63	0.48	0.70	

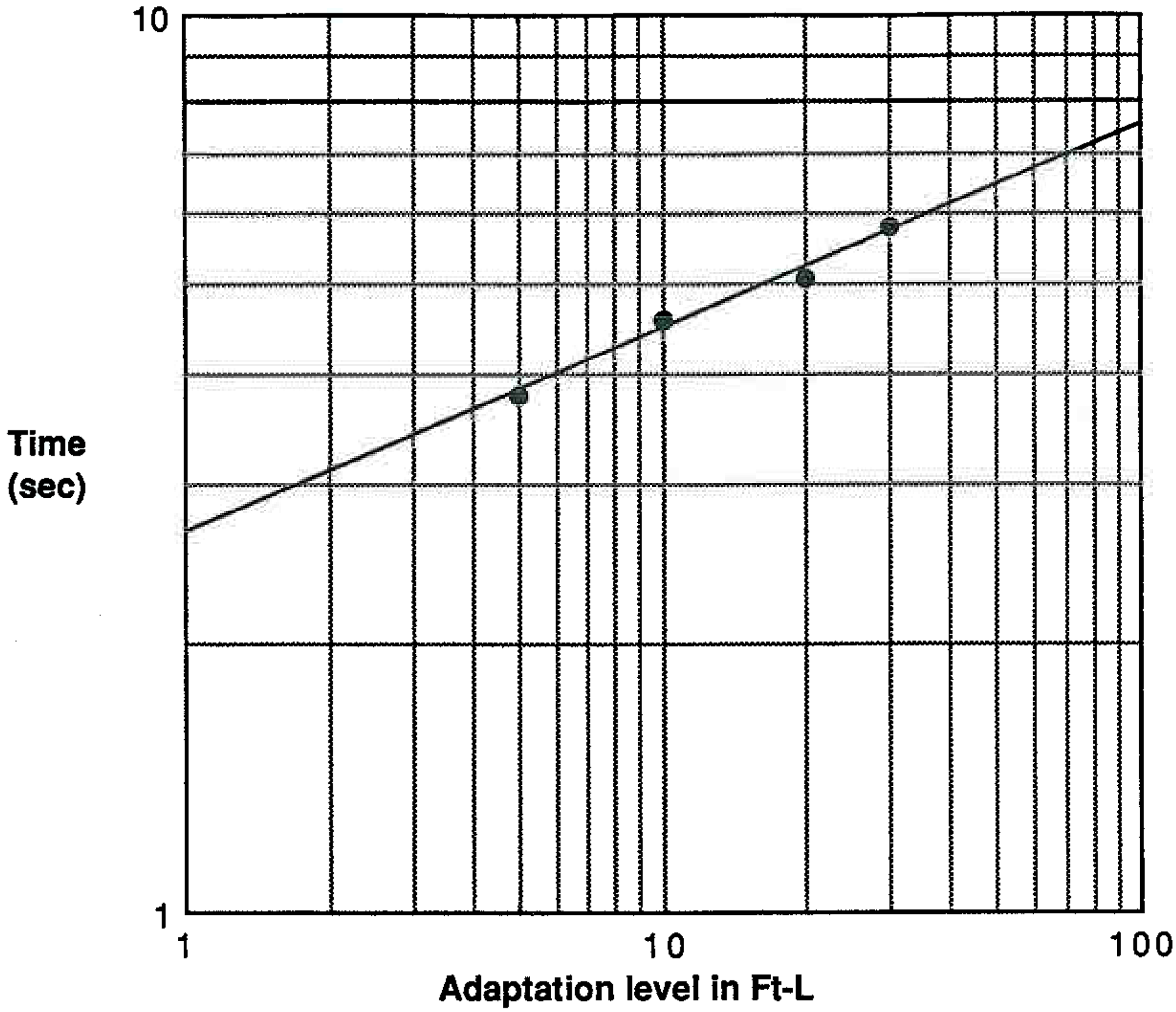

FIGURE 2. Readaptation times at various luminance levels.

TABLE 2. Readaptation Times From Low and High Beam Glare

	Low Beam	High Beam
1	3.56	7.56
2	3.97	4.56
3	3.92	4.60
4	4.15	6.39
5	4.74	4.44
6	3.74	4.55
7	3.27	4.71
8	2.73	5.55
9	4.16	4.07
10	2.84	4.63
11	4.09	4.52
12	3.96	5.25
13	2.74	5.62
14	3.52	5.51
15	3.12	
Mean	3.63	5.14
S.D.	0.59	0.94

RESULTS

Comparing the field-measured mean readaptation times of 3.63 and 5.14 seconds for low and high beams respectively given in Table 2 with the data in Figure 2 indicates that the respective adaptations levels are about 5 and 20 ft-L. Referring to Figure 1, both of these levels are in the cone vision (photopic) zone.

DISCUSSION

Coupled with the results of the initial study without glare, the data from this investigation provide a more complete understanding of the range of luminance values to which drivers eyes must adjust. Clearly, it is a very broad range. At the test site used, a pedestrian would have a dark adaptation level of about 0.005 ft-L. If that pedestrian becomes a motorist at the same site, and switches on his/her low beams, the adaptation level would increase almost two log units, to about 0.3 ft-L. If high beams are selected instead, the adaptation level would be almost another log unit higher, i.e., about 1.7 ft-L.

All of the above is without glare. If the driver is on low beams and meets another car on low beams, the adaptation level will increase to a peak of about 5 ft-L, a full three log units above that of the pedestrian standing on an unlighted road. If the oncoming car is on high beams, the adaptation level will increase fourfold to a peak of about 20 ft-L.

One of the interesting things is that the pedestrian, without special illumination, can see some things better than the driver can with the illumination of the vehicle's headlamps, simply because of the difference in adaptation level. This is not to suggest that headlights are more of a hindrance than a help, but undoubtedly some things out of the range of the headlamps can be seen by the pedestrian, but not the driver. This may be a factor that contributes to the apparent overconfidence many pedestrians seem to have regarding their own visibility on the road at night (e.g., Allen, et al., 1970).

The data also give some indication of how long it takes drivers to recover full visual capability after exposure to various levels of glare. The time may be less than some people thought, but still represents a significant period. For example, recovery from high beam glare requires a little over five seconds, during which time the vehicle will travel almost 500 feet at 65 mph. Recovery from low beam glare is not much better. At 65 mph, the vehicle will travel about 350 feet before visual capability returns to maximum. When meeting a fairly steady flow of oncoming traffic, this means that a driver's vision is seldom as good as it could be in the absence of such traffic, due to a combination of disability glare and upward adjustments in dark adaptation.

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