

# Recovery of Foveal Dark Adaptation

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•A continuing problem in night driving is the effect of glare sources, as oncoming headlights, on the visual sensitivity of the driver. The literature contains considerable information on the effect of brief, bright lights on peripheral, scotopic vision, and the amount of time necessary to recover sensitivity after such exposures can be estimated from these data (4, 5, 8, 11).

Although good scotopic vision is undoubtedly of use to the night driver, its importance should not be overemphasized. Peripheral acuity, even at best, is not adequate for most seeing tasks; in the purely scotopic range of illumination levels, where the fovea is blind, acuity is exceedingly poor. At these levels targets must be 10 to 25 times as big as a foveal target at a normal light level to be seen. Furthermore, in the mesopic range of illumination levels, where most night driving situations fall, foveal vision can be used and foveal or central acuity is better than peripheral (9). These facts, coupled with the normal tendency to direct one's gaze at an object that one wishes to see, make foveal vision of major importance in night driving situations.

The literature on the effect of brief glare sources on foveal sensitivity in this range is rather sparse. There are, of course, numerous studies on foveal dark adaptation (6, 7) and a few on the effects of brief exposures on recovery of this dark adapted foveal sensitivity (3, 10). From these studies we know that foveal sensitivity to dim lights improves with dark adaptation, that this increased sensitivity takes place very rapidly (the major portion in the first 30 sec or 1 min), and that there is no further increase after about 5 min in the dark. The recovery of foveal dark adaptation after exposures to light depends on the intensity and duration of the adapting source, the longer or brighter the source the more recovery time needed.

Investigations have also been made of visual acuity during dark adaptation (1, 2). After complete light adaptation to a given level, the luminance required for resolution of a target decreases with time in the dark. The curves are very similar to those of simple foveal dark adaptation except that the final acuity threshold is higher than the light threshold and depends on the size of the target to be resolved.

There are, to our knowledge, no data specifically concerning an important night driving question: What is the effect on dark adapted foveal acuity of brief, bright sources of light? This study was undertaken to answer the question.

The sources investigated varied between 0.3 and 3,000 ft-L, a range which includes most of the brightnesses of oncoming headlights. Durations between 1 and 45 seconds were studied. Since the amount of light required for an acuity threshold varies with the size of the target to be resolved, an acuity target was chosen of a size which gave a final threshold in the low photopic range of illumination and within the range of intensity levels typical of the night driving situation.

All measures were made with a Hecht-Shlaer adaptometer. The glare stimuli were produced by the mechanism for an adaptation source provided in the Hecht-Shlaer; this source subtended  $35^\circ$  in diameter and was set at six different luminance levels between 0.36 and 3,000 ft-L. A source subtending  $4^\circ$  was also investigated to be sure that size was not a variable in this study. The test stimulus was an acuity grid,  $1^\circ$  in diameter, whose luminance could be varied by a neutral density wedge and neutral filters. The bars of the grid, alternately opaque and transparent, subtended 6 min of visual angle. Two fixation points were provided, one on either side of the acuity grid, and the subject was instructed to look in the middle of them.

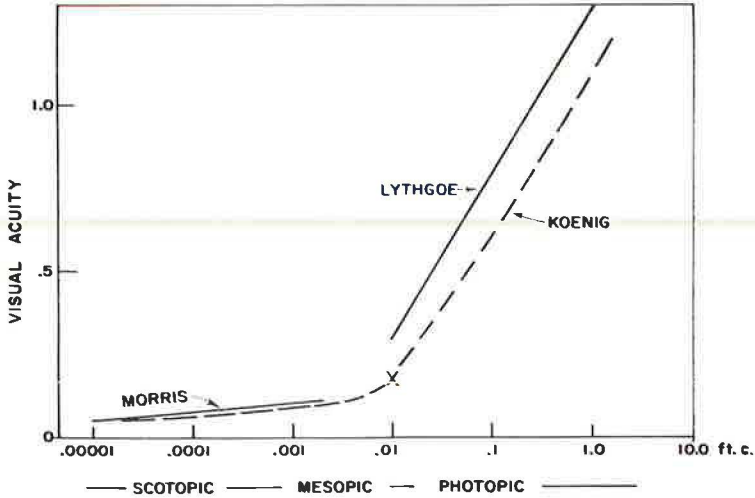


Figure 1.

The subject first dark adapted for 5 minutes; then measures were made of his acuity threshold by a method of constant stimuli. The adaptation source was then presented for a given interval and the course of readaptation to the previously determined threshold was measured. Since foveal adaptation often proceeds very quickly, a single curve could not be determined all at once; therefore the following procedure was adopted. The acuity grid was set at a predetermined level of luminance above threshold and was presented repeatedly for 1 sec at 5-sec intervals until the subject reported seeing it. If the first level was considerably above threshold, a second lower luminance level was then set and the procedure repeated. In order to fill in other points in the curve, the adaptation source was presented again and the test stimulus set at different lu-

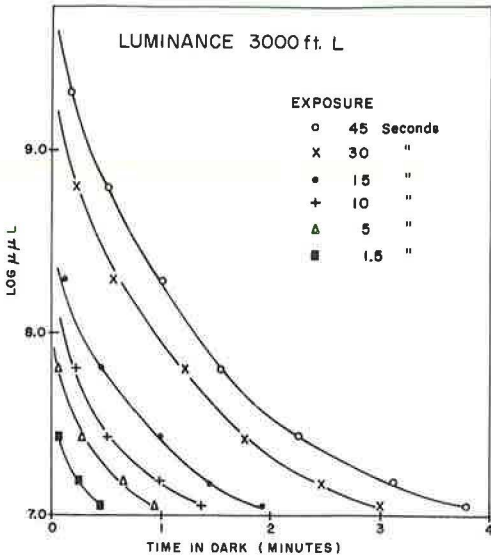


Figure 2.

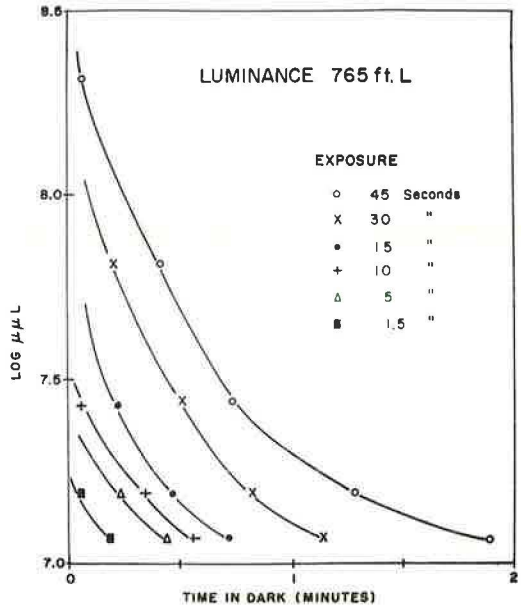


Figure 3.

minance values. All the durations for a given adapting luminance were measured in one session with the order of presentation of both durations and repetitions of the same duration randomized within the session. At least three sessions were run for each adaptation level.

Figure 1 gives the position of our acuity measures in the total picture of acuity and illumination. General levels are given at the bottom of the graph: peripheral scotopic vision at the left below  $1/1,000$  ft-L; foveal, photopic at the right, above  $1/100$  ft-L; with the mesopic range in the middle. Luminance levels for night driving, reported to this group in the past, almost all lie in the mesopic and low photopic range (12).

At the right (Fig. 1), the straight lines show the typical relation of increased acuity with increased illumination for foveal vision. The comparable function found for scotopic, peripheral vision is at the left. The target yields a visual acuity value of about 0.2; this is the reciprocal of the detail size in minutes. After complete foveal dark adaptation, the threshold in ft-L for this target is 0.01 ft-L (indicated by large X). The conditions of this study thus lie close to the limit of foveal vision and are typical of the range of values found in night driving.

The main results of the experiment are shown as a series of dark adaptation curves. Figure 2 shows the data given for the 3,000 ft-L source. On the ordinate are the luminances required for the target to be seen; on the abscissa the time in the dark. Thus, after 45 sec of 3,000 ft-L, the initial threshold is considerably above  $9.0 \log \mu\mu\text{L}$  or above 1 ft-L, and it required about 4 min in the dark for the final threshold value of 0.01 ft-L to be regained. After 5 sec of the same source, the initial threshold is about 0.1 ft-L, and 1 min in the dark is required for the acuity grid to be seen at threshold. After only 1.5 sec, it still takes about 30 sec to regain the original acuity level. Similar families of curves are found for each adaptation source. Figure 3 shows the curves for the 765 ft-L source, and Figure 4 shows the data for the 450 ft-L and the 36 ft-L sources. The obvious differences between these families of curves are that the initial threshold is lower and the total time to readapt is less for the dimmer sources.

This point can be made more explicit by plotting the same data with intensity the parameter rather than time. Figure 5 is an example of this treatment, showing the effects of different luminances at a constant exposure time. With an exposure of 15 sec,

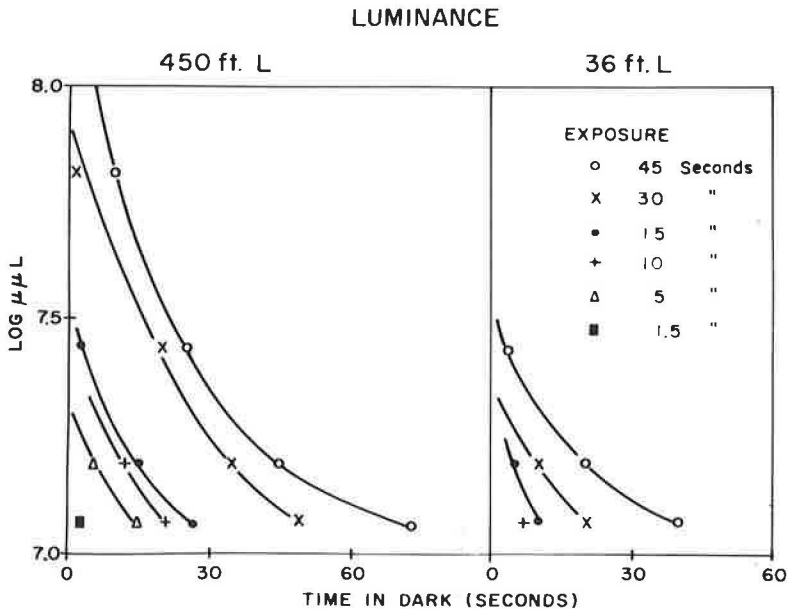


Figure 4.

for example, the total time to readapt varies from 2 min for the 3,000 ft-L source to 10 sec for the 36 ft-L source. With lower luminances of these exposure times, there was no measurable effect on the acuity threshold.

The data presented thus far have been the averages of the three subjects and there are, of course, individual differences. However, regular families of curves were

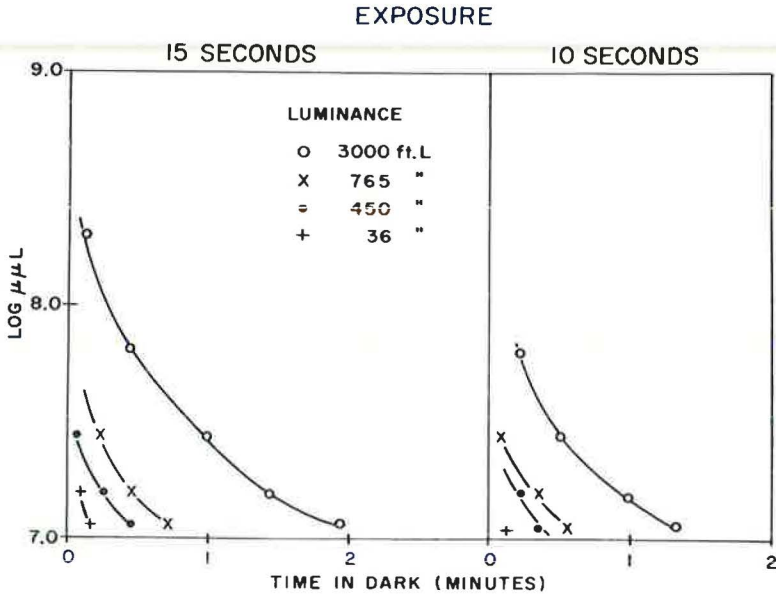


Figure 5.

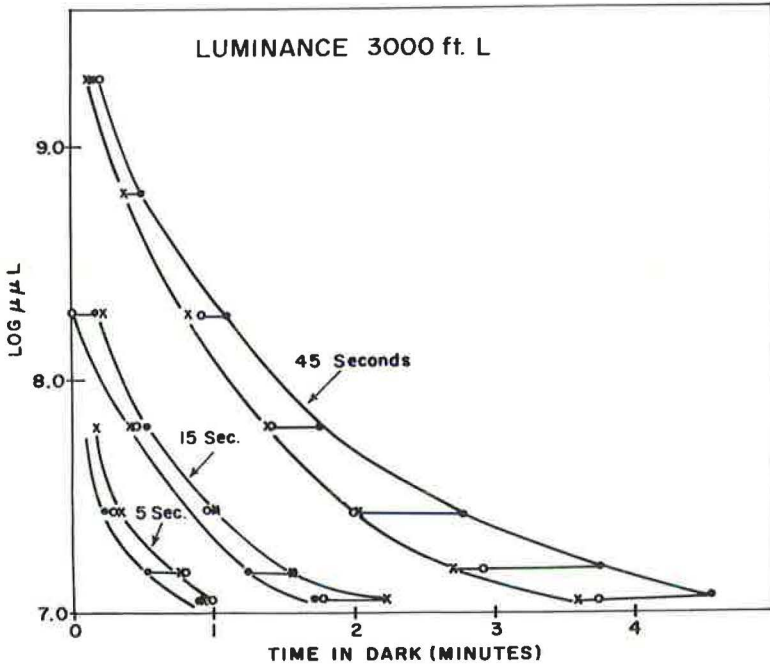


Figure 6.

found for each subject; the initial threshold and the total time to readapt varied systematically with the intensity and duration of the adaptation source in the same way as was shown in the average curves.

Figure 6 is an example of the individual variations. The luminance of the adaptation source is 3,000 ft-L and the exposure times of 45, 15 and 5 sec are given. The horizontal lines indicate the range of individual differences. Thus after 45 sec the extreme values for the final threshold were 3.5 to 4.5 min and after 5 sec exposure, 50 to 60 sec. Individual differences thus are minor compared to the effects of the glare sources.

There are two other questions that were investigated during the course of the experiment. First is the size of the adapting field. Since this field stimulates the fovea and we are measuring foveal readaptation, there is no theoretical reason why its size should be a factor. Nevertheless, an empirical check was made on this and sample readaptation curves following stimulation by a  $4^\circ$  glare source produced the same curves as did the larger field.

Second, we determined for each subject the length of exposure time beyond which no further effects were found; or in other words, the exposure time which completely light adapted the fovea at each level. For one subject, the curves for 30 sec and 45 sec were very similar; for the other two subjects, a time of 1 min produced the same curves as 45 sec. Thus with exposures beyond approximately 45 sec any further increases in dark adaptation times are not expected.

Considering some of the relationships between these data and the night driving situation, the effects of glare sources are many. There is, of course, the discomfort and even pain when the intensity of the glare is well above the adaptation level. There may be losses of visual sensitivity even if the source is located on a different retinal area than that being tested; such losses are usually attributed to reduced contrast and to stray light within the eye itself (13). These effects were not the subject of this study; instead, what is the effect when the glare source is directed at the retinal area to be subsequently used? This effect may be considerable or it may be so small as to be unmeasurable, depending on the intensity and the duration of the source.

To summarize the data, various products of intensity and time of the glare sources

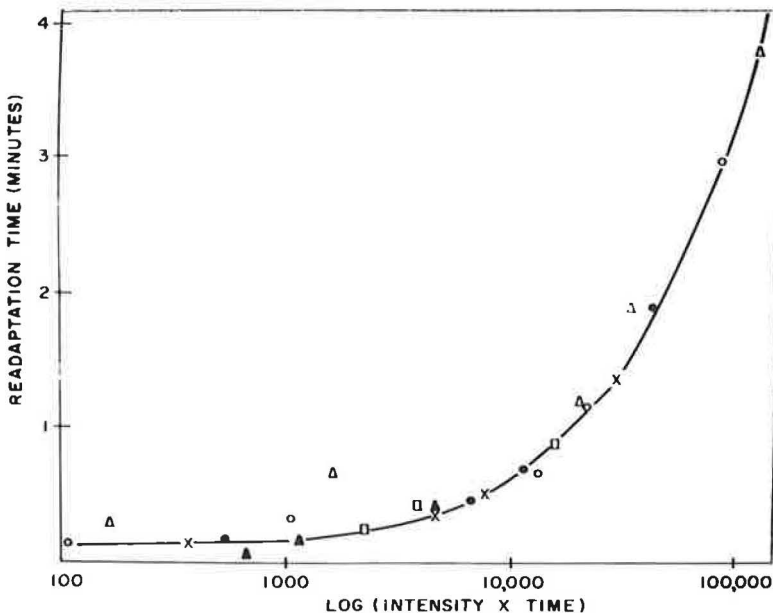


Figure 7.

have been compared. Figure 7 shows the results of this comparison. The total time necessary for the fovea to readapt to threshold is plotted as a function of the log of the product of intensity and duration of the source, and a single line has been drawn through the data points. Thus 3 sec of 3,000 ft-L is plotted at the same point as 30 sec of 300 ft-L; both require about 40 sec of readaptation time. The curve starts at a level of very little effect, 10 sec or less of readaptation time, and rises sharply to an asymptote of 4 to 5 min with large values of intensity  $\times$  time.

There is an obvious temporal limit beyond which the function will not apply. Since the fovea is completely light adapted within, say a minute, longer intervals will produce no additional effect and longer temporal values cannot reasonably be used in the calculations. It does not matter whether the eye is exposed to a given level for 1 min or 5 min; the subsequent dark adaptation curve will be the same. One other precaution—not all the data points fit perfectly; there seem to be, for example, a few systematic differences but these are more interesting from a theoretical than a practical point of view. In general, however, the curve holds very well and it holds over a remarkable range of values, in time from 1 to 30 sec, and in luminance for 4 log units. Thus, certainly, to a first approximation, the effect of any combination of intensity and time of glare source can be predicted.

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