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# NIGHTTIME LEGIBILITY OF TRAFFIC SIGNS: CONDITIONS ELIMINATING THE EFFECTS OF DRIVER AGE AND DISABILITY GLARE

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**Abstract**—The effects of observer age and environmental glare on nighttime legibility of traffic signs were investigated in two field experiments with the subjects driving or riding in a car towards a sign. Experiment 1 showed that equating older and younger subjects in terms of their low luminance/high contrast visual acuity resulted in elimination of any age effects on legibility. Furthermore, the presence of a glare source with an illuminance of 0.17 or 0.017 lux offset 2° from the sign legend improved legibility distance significantly. The results of Experiment 2 indicated that a glare source with an illuminance of 0.0098 lux had no effect on legibility when presented at an offset angle of 1.5° or 0.6°, but it had a significant detrimental effect at an offset angle of 0.2°. The present findings suggest that (1) the usually observed age-related performance decrement on nighttime legibility tasks is the result of visual-acuity deficits, and not shortcomings in information-processing ability; (2) legibility is relatively unaffected by glare, unless the glare angle is very small or glare level very high; and (3) glare sources positioned outside of the fovea might improve nighttime legibility performance under certain conditions.

## INTRODUCTION

The nighttime legibility of signs with alphanumeric material depends on a variety of factors. The most critical sign factors include the size of the legend, contrast between the legend and its background, and luminance of the background [Olson and Bernstein, 1979], as well as stroke-width and the direction of the luminance contrast [Hind, Tritt, and Hoffmann, 1977]. Among the environmental factors, the effects of glare are of interest, because of known glare effects on detectability and contrast sensitivity [Schober, 1967]. Among observer characteristics, the effects of age are of concern because of known age effects on visual acuity [Burg, 1966].

In a previous nighttime field investigation [Sivak, Olson, and Pastalan, 1981], the effect of observer's age on the legibility of traffic signs was of interest. In that study two age groups (under 25 and over 61 years), were matched in terms of high-luminance (daytime) visual acuity. (The mean visual acuity for each of the two groups was 20/19.) The subjects drove or were driven towards a sign. The results indicated that the legibility distances for the older subjects were 65–75% of those for the younger subjects. This finding implies that the older drivers are likely to have less distance (and thus less time) in which to act on the information displayed by traffic signs. Furthermore, a visual acuity of 20/19 is substantially better than the population average for the older age group, but representative of the younger age group [Burg, 1966]. Thus, a representative sample of older subjects would be expected to perform even worse than did the older subjects in that study.

The present study was designed to investigate (1) whether the age effect in nighttime legibility of traffic signs persists after older and younger subjects are matched not only in terms of high-luminance (daytime) but also low-luminance (nighttime) visual acuity, and (2) the effects of glare on the nighttime legibility of traffic signs.

## EXPERIMENT 1

### *Method*

This was a nighttime investigation in which subjects either drove or rode in an automobile and at the same time watched for a retroreflective sign. The sign had been erected along the right side of the road, showing a left- or right-facing letter E. The measure of performance was the distance at which the subject could identify the orientation of the letter (E or Ǝ).

*Test Signs.* The backgrounds of the test sign were 90 cm high and 90 cm wide. They were constructed by attaching retroreflective or non-retroreflective sheeting to aluminum panels. A ledge was fixed to each sign to support a 20-cm tall letter in the center of the background. The entire sign was placed on a flat-black supporting stand. With this arrangement, the center of the letter E was about 1.3 m above the pavement.

The background material was green (except for the non-reflective material which appeared black at night), while the letter was white. Five combinations of the letter and background were used (see Table 1).

*Glare sources.* Glare was provided by one of two 12 V, 10 cm (in diameter) spotlamps (No. 4416). Using a 6 V battery and neutral density filters, the lamps were calibrated to emit a maximum of either 140 cd or 1400 cd. The glare sources were mounted on tripods at the same height as the letter E, but displaced 3.2 m laterally. The lamps were aimed so that the maximum output reached the driver's eyes at a predicted no-glare legibility distance of 122 m (400 ft). At the actual mean no-glare legibility distance (which proved to be 88.3 m), the glare angle was 2°, and the glare illuminances provided by the two glare sources were 0.017 and 0.17 lux.

*Subjects.* Subjects of two age levels participated. The younger subjects were between 20 and 30 years of age and the older subjects were between 63 and 75 years of age. Fifty potential subjects were screened with visual acuity and color vision tests. Six younger and six older subjects whose visual acuity scores could be most closely matched were selected to participate. Their characteristics are described in Table 2. As is evident from Table 2, the two groups had comparable visual-acuity scores under three sets of conditions: high luminance/high contrast, high luminance/low contrast, and low luminance/high contrast. (The low-luminance acuity scores were obtained after 10 min of dark adaptation.) From each age group two subjects participated as drivers and four as passengers.

*Test vehicle.* The test vehicle was a standard full-size station wagon. The vehicle has a distance-measuring system with a digital readout.

*Facility.* The test was conducted on a recently finished, but still unopened, limited-access highway with two lanes in each direction. The utilized section is dark, flat and straight, and about 1.6-km long. Two signs were erected opposite each other at the right edges of the two right-hand lanes in both directions.

Table 1. Photometric properties of the letter/background combinations. Experiment 1

| COMBINATION (Letter Material on Background Material) | SPECIFIC LUMINANCE ($cd/lux/m^2$) | | CONTRAST RATIO |
|---|---|---|---|
| | LETTER | BACKGROUND | |
| Enclosed Lens on Encapsulated Lens | 115 | 36 | 3:1 |
| Encapsulated Lens on Encapsulated Lens | 325 | 36 | 9:1 |
| Prismatic on Encapsulated Lens | 1200 | 36 | 33:1 |
| Prismatic on Enclosed Lens | 1200 | 15 | 80:1 |
| Enclosed Lens on Non-Reflective | 115 | 0.06 | 1916:1 |

Table 2. Subject characteristics. Experiment 1

| SUBJECT | AGE | SEX | VISUAL ACUITY | | | | COLOR VISION |
|---|---|---|---|---|---|---|---|
| | | | HL HC | HL LC | LL HC | LL LC | |
| 1 | 21 | M | 20/22 | 20/35 | 20/60 | 20/100 | Normal |
| 2 | 30 | F | 20/22 | 20/50 | 20/50 | 20/150 | Normal |
| 3 | 21 | M | 20/25 | 20/35 | 20/35 | 20/100 | Normal |
| 4 | 20 | M | 20/18 | 20/20 | 20/25 | 20/60 | Normal |
| 5 | 27 | M | 20/14 | 20/25 | 20/22 | 20/60 | Normal |
| 6 | 21 | F | 20/18 | 20/25 | 20/27 | 20/60 | Normal |
| 7 | 66 | M | 20/22 | 20/40 | 20/35 | 20/60 | Normal |
| 8 | 75 | M | 20/20 | 20/35 | 20/40 | 20/150 | Normal |
| 9 | 59 | F | 20/22 | 20/35 | 20/40 | 20/80 | Normal |
| 10 | 70 | M | 20/20 | 20/35 | 20/40 | 20/150 | Normal |
| 11 | 63 | M | 20/18 | 20/40 | 20/40 | 20/60 | Normal |
| 12 | 72 | M | 20/18 | 20/40 | 20/40 | 20/100 | Normal |
| Mean (younger group): | | | 20/20 | 20/32 | 20/36 | 20/88 | |
| Mean (older group): | | | 20/20 | 20/37 | 20/39 | 20/100 | |

Note: HL - High Luminance (161 $cd/m^2$)
LL - Low Luminance (.2 $cd/m^2$)
HC - High Contrast (22.5:1)
LC - Low Contrast (1.3:1)

*Procedure.* Each run began with the test vehicle proceeding in the right lane (at a speed of approximately 72 km/h), passing the sign placed on the right, and continued until the vehicle reached a median crossing that was used as a crossover to the opposite direction of the highway. The data were collected from three subjects concurrently (a driver and two passengers). The three were seated in the front seat of the car. Each subject held a push-button switch. When depressed, each switch turned on a small light bulb in the rear compartment of the vehicle. The switches operated silently, so subjects were unaware of the timing of each other's responses. The experimenter, who sat in the rear seat behind the subjects, also had a switch which turned on a fourth bulb. The experimenter pressed his switch when he was passing the sign. This array of lights was viewed by a camera and videotaped along with the distance readout. For each run, then, three lights indicated when each subject had identified the orientation of the letter and the last light indicated the position of the sign. By subtracting the first three distance readings (corresponding to the onset of the lights) from the last, legibility distances were determined.

The instructions specified that the subjects were to press the button once for a right orientation of the letter and twice for a left orientation. After the instructions had been read, all questions were answered and four practice runs given. The 45 experimental trials (three replications, three glare levels, five signs) took about 1.5 hours to complete. Two short breaks were permitted during the session. Any required make-up trials were added at the end of the regular sequence. The orientation of the letter E was varied randomly. The order in which the letter/background combinations and glare levels were presented was varied systematically.

*Results*

The mean legibility distances for the various letter/background combinations, glare levels, and age groups are presented in Table 3.

Analysis of variance revealed the following:

(1) Effect of age was statistically not significant; the mean legibility distances for the younger and older groups were identical (93.9 m).

(2) Effect of seat position (driver, middle, and right passenger) was statistically not significant ($F < 1$).

(3) Effect of letter/background combination was statistically significant ($F[4, 24] = 5.07, p < 0.005$). *Post hoc* pairwise comparisons, using Newman–Keuls range test [Hicks, 1973], showed that both the 1200/36(33:1) and 325/36(9:1) combinations yielded significantly longer legibility distances than either the 1200/15(80:1) or 115/0.06(1916:1) combinations. Also, the 1200/36(33:1) combination yielded significantly longer distances than the 115/35(3:1) combination

(4) Effect of glare level was statistically significant ($F[2, 12] = 12.49, p < 0.005$). The mean legibility distances were 88.3, 95.3, and 98.1 m for the no-glare, 0.017 lux, and 0.17 lux conditions, respectively. *Post hoc* pairwise comparisons using Newman–Keuls range test showed that the legibility distances were shorter under the no-glare condition than under either of the conditions with glare present.

Table 3. Mean legibility distances (in meters) for the two age groups, Experiment 1

| LETTER/BACKGROUND SPECIFIC LUMINANCE (CONTRAST RATIO) | GLARE ILLUMINANCE (lux) | | | | | | MEAN BY AGE | | MEAN |
|---|---|---|---|---|---|---|---|---|---|
| | 0 | | .017 | | .17 | | | | |
| | YOUNG | OLD | YOUNG | OLD | YOUNG | OLD | YOUNG | OLD | |
| 115/36 (3:1) | 94.6 | 82.3 | 92.9 | 89.2 | 99.8 | 81.6 | 95.8 | 84.3 | 90.1 |
| 325/36 (9:1) | 98.3 | 92.2 | 105.8 | 101.9 | 105.0 | 109.2 | 103.0 | 101.1 | 102.1 |
| 1200/36 (33:1) | 95.3 | 93.3 | 99.2 | 96.3 | 107.5 | 123.5 | 100.7 | 104.4 | 102.5 |
| 1200/15 (80:1) | 78.5 | 82.7 | 91.6 | 101.5 | 82.9 | 86.4 | 84.3 | 90.2 | 87.3 |
| 115/.06 (1916:1) | 77.9 | 87.9 | 87.2 | 87.2 | 91.9 | 93.4 | 85.6 | 89.5 | 87.6 |
| MEAN BY AGE | 88.9 | 87.7 | 95.3 | 95.2 | 97.4 | 98.8 | 93.9 | 93.9 | |
| MEAN | 88.3 | | 95.3 | | 98.1 | | | | 93.9 |

(5) Effect of age × glare level interaction was statistically not significant ($F < 1$).

(6) No other main effects or interactions were statistically significant (except some involving subjects as a factor).

*Discussion*

One of the most interesting findings of this study was the absence of an age effect. In a previous study [Sivak *et al.*, 1981], matching older and younger subjects on high luminance/high contrast acuity did not prevent younger subjects from enjoying a 30–54% advantage in legibility distances. In the present study, on the other hand, the two age groups were also matched on low luminance/high contrast acuity. The implication of the results is that good low luminance/high contrast acuity assured good performance under the test conditions. Furthermore, this finding implies that the usually-observed age-related decrement in nighttime legibility performance is due exclusively to visual deficits (deterioration of visual acuity with age) and not to any information-processing deficits.

The older subjects had poorer low luminance/low contrast visual acuity than did the younger subjects (see Table 2). Therefore, it is not surprising that there was a tendency toward poorer performance for the older subjects on the letter/background combinations providing the least contrast (see Table 3). On the other hand, the older subjects showed a tendency to perform better than the younger subjects on the letter/background combinations providing the three highest contrast ratios. However, these differences were statistically not significant.

The longest legibility distances were provided by the letter/background combinations yielding contrast ratios of 9:1 and 33:1. Further increase in the contrast ratio (to 80:1) or a decrease (to 3:1) was accompanied by a performance decrement. This finding of an essentially inverted U-shaped function of the legibility vs contrast ratio is in general agreement with previous data [e.g. Sivak *et al.*, 1981; Hind *et al.*, 1977]. However, contrast levels remained partially confounded with background luminance levels.

Probably the most surprising result is an apparent "glare enhancement" effect: the presence of a glare source resulted in longer legibility distances in comparison to the no-glare control condition. This effect was not the result of averaging across subjects and/or across legend/background combinations. The longest legibility distances were obtained from either of the two conditions with glare present (as opposed to the no-glare condition) for both age groups, 11 out of 12 subjects, and all five legend/background combinations. One can only speculate about the reasons for this effect. A possible explanation is as follows: In the present situation (dark rural road), the pupil size is close to maximum as a result of the pupil-light reflex [Crawford, 1936]. However, it is known that at low levels of background luminance, reducing the pupil size (while keeping the retinal illuminance constant) results in better visual acuity [Leibowitz, 1952]. The presence of a glare source would, in the present situation, lead to a decrease in the pupil size. Therefore, it is possible that, at the glare angle of 2°, the beneficial effect of the reduced pupil size (i.e. a reduction in the dioptric aberrations) more than compensated for the detrimental effect of the reduced pupil size (i.e. a reduction in the amount of light reaching the retina), and for the veiling luminance because of the glare source. Potentially beneficial effects of a low-level glare have been noted by other researchers [e.g. Fischer and Christie, 1965; Schober, 1967].

## EXPERIMENT 2

The primary purpose of this experiment was to investigate angular separations between the sign and the glare source that were smaller than the one tested in the first study. As in Experiment 1, the subjects drove or rode toward a sign and indicated as soon as they could whether the sign contained a left- or right-facing E. A different facility was used in this experiment, because the new highway used in Experiment 1 had been opened to traffic. The trials were run at lower speeds than in Experiment 1; also, only younger subjects were tested.

*Method*

*Test sign.* The background material was made of retroreflective sheeting (encapsulated-lens type) having a specific luminance of 36 cd/lux/m$^2$ (at 0.2° and −4°). The letter E appeared white and was made of retroreflective sheeting (encapsulated-lens type) with a specific luminance of

325 cd/lux/m$^2$. Thus, the contrast ratio between the letter and the background was approximately 9:1. Otherwise, the sign was identical to those used in Experiment 1.

*Glare sources.* Glare was provided by the same lamps as in Experiment 1. The lamps were calibrated to each deliver a maximum of 140 cd. The lamps were aimed so that the maximum output reached the driver's eyes at a distance of 122 m.

*Glare angles.* Three glare angles were investigated (in addition to the no-glare control). At the mean no-glare legibility distance (which proved to be 119.3 m) the three glare angles were as follows: 0.2°, 0.6°, 1.5°, and the glare illuminance was 0.0098 lux. The lamps at the two smaller glare angles were mounted on the sign-support panel, 0.43 and 1.14 m below the center of the letter E. The lamp at 1.5° was mounted on a tripod at the same height as the letter E but was displaced 3.2 m laterally. (The glare separation of 3.2 m was identical to the one used in Experiment 1. However, the no-glare legibility distance was different in the two experiments [88.3 m in Experiment 1; 119.3 m in Experiment 2], possibly because of the difference in the facilities and approach speeds. Consequently, the effective glare angle for the 3.2 m glare separation was different in the two experiments [2° in Experiment 1; 1.5° in Experiment 2].)

*Subjects.* Three subjects participated. Some of their characteristics are listed in Table 4.

*Test vehicle.* The same vehicle was used as in Experiment 1.

*Facility.* The test was conducted on a dark, private-access road. The road has two asphalt lanes, is 800 m long, and is flat and straight. Two signs were erected at the edge of the paved surface, facing in opposite directions, 400 m away from the ends of the road.

*Procedure.* Each run was started with the test vehicle at one end of the road. The driver proceeded in the right lane (at a speed of approximately 24 km/h), passed the sign placed on the right, then continued to the end of the road, turned around, and started the next run. The 40 experimental trials (10 replications per each glare angle and the no-glare condition) took about 1.25 hr to complete. In all other respects the procedure was identical to that in Experiment 1.

### *Results*

The mean legibility distances for the various glare conditions are presented in Table 5.

Analysis of variance revealed that the effect of glare angle (treating the no-glare condition as a glare angle of infinity) was statistically significant, $F(3,6) = 8.42, p < 0.05$. *Post hoc* Newman–Keuls range test showed that the legibility distance for the smallest glare angle (0.2°) was significantly different from each of the other glare conditions ($p < 0.05$). However, no other pairwise differences were statistically significant. (The other main effect and interaction in the analysis involved subjects as a factor.)

Table 4. Subject characteristics, Experiment 2

| SUBJECT | AGE | SEX | VISUAL ACUITY | | | | COLOR VISION |
|---|---|---|---|---|---|---|---|
| | | | HL HC | HL LC | LL HC | LL LC | |
| 1 | 19 | F | 20/10 | 20/16 | 20/22 | 20/40 | Normal |
| 2 | 21 | M | 20/10 | 20/20 | 20/25 | 20/50 | Normal |
| 3 | 27 | M | 20/14 | 20/25 | 20/22 | 20/60 | Normal |

Note: HL - High Luminance (161 cd/m$^2$)
LL - Low Luminance (.2 cd/m$^2$)
HC - High Contrast (22.5:1)
LC - Low Contrast (1.3:1)

Table 5. Mean legibility distances as a function of glare angle, Experiment 2

| GLARE ANGLE | LEGIBILITY DISTANCE (m) |
|---|---|
| .2° | 96.1 |
| .6° | 122.9 |
| 1.5° | 117.9 |
| (No Glare) | 119.3 |

*Discussion*

The main finding of this experiment is that the detrimental effects of a 0.0098 lux glare are present only at very small angular separations between the legibility target and the glare source. The glare-angle conditions of 0.6° and 1.5° did not yield different legibility distances than the no-glare condition. Only at the glare-angle of 0.2° there was a statistically significant reduction in legibility distance.

The conditions in this experiment did not result in the glare enhancement evident in the findings of Experiment 1. While one can only speculate about the reasons for this difference, the following is a possible explanation: The effect of a given glare source on a dark-adapted observer is influenced by the angular separation of the glare source from the legend. At very small glare angles (0.2° under the conditions of Experiment 2), the effect is negative, yielding the traditional disability-glare findings. At larger glare angles (0.6 and 1.5° under the conditions of Experiment 2), the negative consequences (light scatter and veiling luminance) and positive consequences (reduced pupil size) balance out. At even larger glare angles (2° under the conditions of Experiment 1), the positive consequences might more than compensate for the negative consequences, resulting in the "glare-enhancement" effect.

## SUMMARY, CONCLUSIONS AND IMPLICATIONS

The present experiments investigated under dynamic conditions the nighttime legibility of traffic signs as a function of the age of the observer, various combinations of sign legend and background, and glare parameters.

The results of Experiment 1 indicate the following: First, equating older and younger subjects in terms of their low-luminance/high-contrast visual acuity resulted in elimination of the age effect on the legibility distances. Second, intermediate luminance contrast between the legend and its background (9:1 to 33:1) yielded optimal performance, and a further increase in contrast ratio (to 80:1) or a decrease (to 3:1) resulted in performance decrement. (However, the contrast levels in the present study were confounded with background luminance, and therefore this effect cannot be conclusively attributed to contrast alone.) Third, glare sources delivering peak outputs of 0.17 and 0.017 lux at 2° away from the legend improved performance significantly.

The results of Experiment 2 indicate that a glare source producing glare illuminance of 0.0098 lux has no effect on legibility distances if the peak illuminance is achieved at 1.5° or 0.6° away from the legend. However, a significant disability-glare effect was obtained if this glare source was positioned at 0.2°.

There are several practical ramifications of the present findings. First, nighttime legibility performance of older drivers can be comparable to that of the younger drivers if the two age groups are matched on low-luminance (nighttime) visual acuity. If confirmed by other studies, this conclusion suggests that driver licensing (currently relying primarily on high-luminance visual-acuity screening) might be more relevant to nighttime driving if it included low-luminance visual acuity evaluation. Furthermore, when correcting older vision, ophthalmologists and optometrists should pay attention to visual acuity under both high-luminance and low-luminance conditions. This procedure might lead to two different corrections: one optimal for the daytime and one for the nighttime [see, e.g. Leibowitz and Owens, 1977].

Second, the optimal legibility performance is likely to be achieved by contrast ratios (between legend and background) in the intermediate range. (The exact optimum will depend on other parameters, including the background luminance.)

Third, legibility performance appears to be a robust process, rather unaffected by glare unless the glare angle is extremely small or glare level very high. (The robustness of the legibility performance should be contrasted with the susceptibility to glare of detection performance [e.g. Schober, 1967].) Furthermore, glare sources positioned outside of the fovea (at 2° under the conditions of Experiment 1) might even lead to improved legibility of the legend. Confirmation of the present findings, as well as delineation of the conditions leading to improvement of performance with glare present, is required to establish glare enhancement as a reliable phenomenon.

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