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James R. Sayer
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The University of Michigan
Transportation Research Institute
Ann Arbor, MI 48109-2150
U.S.A.

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James R. Sayer, Michael J. Flannagan, Michael Sivak, Shinichi Kojima, and Carol C. Flannagan

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16. Abstract

A recent study by Huey, Dekker, and Lyons (1994) concluded that a difference between two signal lamp intensities of less than 25% cannot be detected reliably by most drivers. Consequently, Huey et al. recommended that an intensity difference of 25% be used as a criterion for inconsequential noncompliance with federal regulations for signal lamps. The present study was designed to evaluate just noticeable differences for glare intensities of oncoming low-beam headlamps. The results of this study indicate that, under controlled conditions, just noticeable differences in the low-beam headlighting context are between 11% and 19%. In real-world conditions, just noticeable differences would probably be somewhat larger. Therefore, the recommendation by Huey et al. of using 25% as a criterion for inconsequential noncompliance of signal lamps is also about right for low-beam headlamps, at least with respect to how headlamps themselves are perceived by other drivers (such as discomfort glare). The 25% value may also apply with respect to how headlamps affect the ability of drivers to see illuminated objects, but further research on that issue would be desirable.

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just noticeable difference, JND, headlamp, low beam, intensity, FMVSS 108

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INTRODUCTION

A recent NHTSA-sponsored study on automotive signal lamps concluded that differences between two signal lamp intensities of less than 25% cannot be reliably distinguished by most drivers (Huey, Dekker, and Lyons, 1994). The 25% criterion was derived from testing to determine the just noticeable difference (JND) for eleven combinations of signal-lamp intensity and ambient illumination. The actual range of JNDs reported by Huey et al. was 14% to 35%, with a mean of approximately 25%. Based upon these results, Huey et al. suggested that intensity differences of 25% from Federal Motor Vehicle Safety Standard (FMVSS) 108 performance specifications could be considered inconsequential noncompliance. That previous study was performed to determine the JND for the range of intensities relevant to motor vehicle signaling; it did not address the higher intensities applicable to low-beam headlighting. The question to be investigated in this study is whether a JND of 25% holds for the range of intensities relevant to low-beam headlamps, and is therefore appropriate for use in evaluating inconsequential noncompliance for headlamp regulations.

The task that participants were asked to perform in this study, and the definition of the JND used, were both somewhat different from those used by Huey et al. In both studies, the stimuli on each of a series of trials, consisted of a pair of lamps, presented simultaneously. In the Huey et al. study, the two lamps had the same intensity on 19% of the trials. On the remaining 81% of the trials, a variable comparison stimulus was either more or less intense than a fixed standard lamp, by varying amounts ranging from 10% to 50%. Over a number of sets of trials, the comparison lamp was sometimes more intense than the standard and sometimes less intense, but never both within any one set of trials. Nor were the participants ever given the option, on a single trial, of choosing either of the lamps as brighter. On every trial, the participants had to choose between two possible responses. In some sets of trials they could say that the lamps were equal or that the comparison lamp was brighter, and in other sets of trials they could say that the lamps were equal or that the standard was brighter.

Because even identical stimuli may not be perceived as equal, performance on such a task can be affected by the participants' criteria for deciding that a difference exists, as well as by their actual abilities to discriminate between stimuli. One indication of this is that Huey et al. obtained "different" response rates for those trials on which the lamps were nominally equal (i.e., false positive rates) that varied between 10.0% and 48.7% over the various lamp conditions that they presented. Huey et al. dealt with this by defining the JND as the difference in intensity needed to increase the proportion of "different" responses from each of those false positive rates to a level halfway between the false positive rate and 100%.

In order to avoid the issue of participants' criteria for detecting differences, we gave participants a different task, which could be considered simpler than that used by Huey et al. As in the Huey et al. study, on each trial in our procedure the participants saw a fixed-intensity standard lamp and a variable-intensity comparison lamp. However, the variable lamp ranged from clearly brighter than the standard to clearly dimmer, and the participants' task was always to indicate which appeared to be brighter. They could always pick either lamp as brighter, and they were never allowed to say that the lamps were equal (i.e., it was a "two-alternative, forced-choice" task). The results from such a task can be used to plot a participant's tendency to indicate that the comparison lamp is brighter than the standard as a function of the intensity of the comparison lamp.

Such a function is often referred to as a psychometric function (or, in some contexts, as a dose-response curve). The tendency to say that the comparison is more intense than the standard normally increases monotonically with the intensity of the comparison, and the shape is usually reasonably well represented by a cumulative normal distribution function. The point of subjective equality (PSE) is defined as the value of comparison-stimulus intensity at which the standard and comparison stimuli are chosen equally often (each 50% of the time). When that point is different from the point of objective equality (POE) the difference is described as a constant error. Any constant errors would be of secondary interest in the present study, which is concerned primarily with the JND. Various measures of how steeply a psychometric function rises could be used to define the JND. Because a cumulative normal function usually provides a good description of the data, the JND is often defined as the standard deviation of the best-fitting normal function. We used probit analysis (Finney, 1971) to derive means and standard deviations for the psychometric functions measured in this study, but—for partial compatibility with Huey et al.—we then used those parameters to calculate the JND as the difference in comparison-lamp intensity between the 50% and 75% points on the cumulative normal function.

METHOD

Participants

Ten individuals participated in the study. Five participants were between the ages of 20 and 30 (mean = 24.5 years), and five were between the ages of 60 and 70 (mean = 68.2 years).

Apparatus

Participants viewed two 2A1 low-beam headlamps from a distance of 50 m across an asphalt-paved parking lot. One was used as a fixed standard lamp and the other as a variable comparison lamp. These lamps were separated by a distance of 6.1 m (see Figure 1). The intensity of the comparison lamp could be varied to be either more intense or less intense than the standard lamp. The headlamps were "seasoned" 10 hours each prior to use in the study. Each headlamp was attached to a stand, which in turn was bolted to the pavement. The headlamps were energized by voltage-regulated power supplies set at 12.8 V.

Three levels of luminous intensity of the standard lamp were examined: 475 cd (upper end of ECE glare values), 850 cd (a typical glare value for U.S. lamps), and 2000 cd (a typical glare value in a curve). The illuminance levels at the participant's eyes (50 m from the lamp) corresponding to the three standard luminous intensity levels were 0.19, 0.34, and 0.80 lux, respectively. Neutral density filters were used to lower the luminous intensity of both headlamps to get them within the range of interest (for the 475 cd and 850 cd conditions). Once within the desired range of intensity, only the comparison lamp was adjusted and these finer adjustments were made with an episcotister.

An episcotister is a device that permits the variation of luminous intensity without introducing secondary variations. Secondary variations, such as variation in color, can be introduced when using filters, even certain neutral density filters. The episcotister consisted of a rotating disk with multiple sectors that were either transparent or opaque. As the disk rotated in front of the comparison lamp, light was allowed to pass through the transparent sectors, but was prevented from passing through the opaque areas. The ratio of transparent area to opaque area determined the amount of light reaching the participant's eyes. That ratio was varied in step sizes of roughly 5% over a series of disks that permitted light transmittance ranging from approximately 10% to almost 100%.

The rotating disks of the episcotister were constructed of clear acrylic (2 mm in thickness), and the opaque areas consisted of foil-backed poster board cemented to the disks. In order to prevent the detection of flicker from the rotating disks, the number of sectors (six) and speed of rotation (900 RPM) were designed to produce a flash rate of 90 Hz (well above the detectable

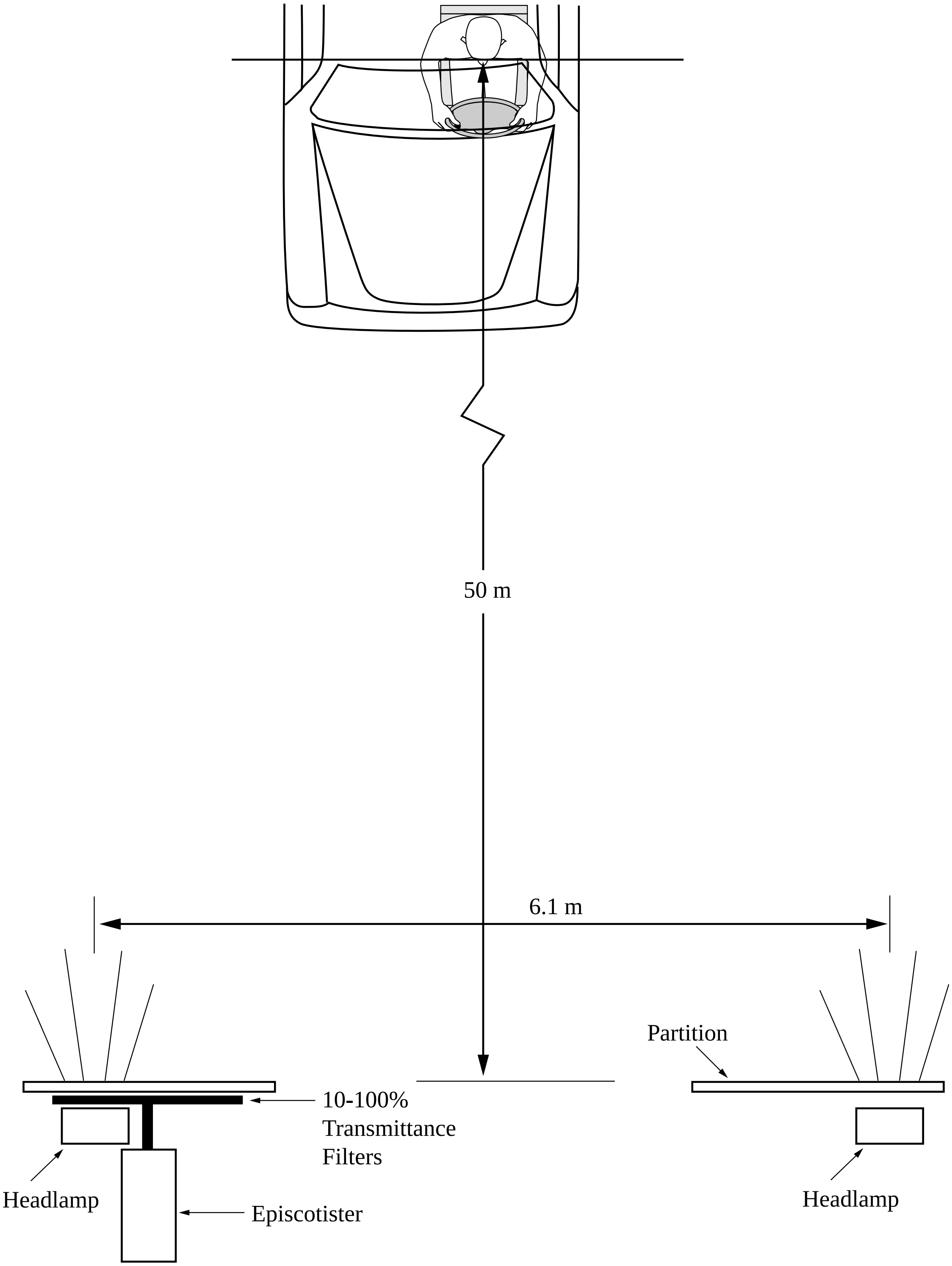

Figure 1. Overhead diagram of the experimental setup. The lamp on the participant's right (shown with the episcotister) was always the variable comparison lamp, and the lamp on the left was always the fixed standard lamp.

range of flicker). Individual disks of varying transmittance were changed between trials by an experimenter. The presence of the episcotister was masked by a partition (see Figure 1), while openings in the partitions were large enough to permit full view of the headlamps. The comparison lamp was always located on the right side (as viewed by the participant).

Procedure

The participants' task was to identify the brighter of two lamps when viewing them simultaneously. All testing was performed out-of-doors under partly cloudy nighttime conditions with no precipitation. On each of a series of trials participants were instructed to examine the two headlamps, and to rapidly report which headlamp appeared to be brighter. Participants used the left and right turn signals of the vehicle in which they were seated to indicate their responses. Participants lowered their heads between trials, and were instructed by an experimenter when to look up in order to make each comparison. Only after the rotating disk of the episcotister had reached full speed were participants instructed to raise their heads and perform the comparison. Participants were further instructed that they could not report a tie. The specific instructions to participants were as follows:

> In this study you will be asked to compare two lights directly in front of you at the other end of the parking lot. Before every trial you will be asked to lower your head and look at your lap. You will then be instructed to look up at the two lights, comparing them, and report either the left or right lamp to be brighter. You must rapidly compare the two lamps and report your findings to the experimenter (using your turn signal). There can be no ties. In other words, you must report one lamp as being brighter than the other regardless of how similar they may look to you.

Each participant saw a total of 120 trials, divided into 3 blocks of 40. For every trial in a block, the standard lamp was presented at the same intensity (475, 850, or 2000 cd). Only the comparison lamp varied in intensity from trial to trial within a block. The intensity of the standard was changed after each block, so that, over the course of three blocks, each participant saw all three standard-lamp intensities. The order of standard-lamp intensities was varied between participants.

The intensity of the comparison stimulus on each trial was determined by a variant of the general "staircase" or "up and down" method (Levitt, 1970). In general, staircase methods involve increasing the level of the comparison stimulus when the participant judges the comparison to be below the standard stimulus, and decreasing the level of the comparison stimulus when the participant judges it to be higher than the standard. Often, staircases are designed to converge on the level of the comparison stimulus that is subjectively equal to the standard (the point of subjective equality, or PSE). At the PSE, the participant is equally likely to choose the comparison or the standard stimulus as being greater, meaning that the comparison is chosen 50% of the time.

Because we were interested in the JND, or range of uncertainty, rather than the PSE, we used staircases designed to converge on values of the comparison stimulus at which the rates of choosing the comparison as greater than the standard were 29% and 71% (for details see Levitt, 1970). In each block of 40 trials, 20 trials were run in each of these two staircases, interleaved randomly. Using staircases such as these that concentrate trials on either side of the PSE, but not directly on it, tends to reduce the precision with which the PSE can be estimated, but increases the precision for measuring the interval of uncertainty around the PSE (i.e., the JND).

RESULTS

For each standard-lamp intensity, data from the 29% and 71% staircases were combined. Probit analysis (Finney, 1971) was used to fit a normal cumulative curve for the probability of calling the comparison lamp brighter as a function of the log of the comparison lamp intensity. These fits were performed individually for each of the 30 combinations of participants and standard-lamp intensities. The points of subjective equality (PSE), where participants report the standard and comparison stimuli to be equal (50%), and the 75% points on the normal cumulative curves were then determined and converted to candela values by inverting the log transformation used in the fitting process. The JND was defined as the difference in stimulus intensity between the 50% (PSE) and 75% points, and was determined independently for each standard lamp intensity for each participant. Table 1 shows the calculated values of JND expressed as percentages of the PSEs.

Table 1. Just noticeable differences (JND) expressed in percentage, and averaged across participants.

Intensity of the standard	Participant		
(cd)	20 - 30 years	60 - 70 years	Mean of both age groups
475	18.8%	19.4%	19.1%
850	9.4%	12.2%	10.8%
2000	13.3%	17.7%	15.1%

An analysis of variance was performed using participant age and intensity of the standard as the independent variables, and the JND values (in percentages) as the dependent measure. The analysis showed no significant differences in the size of the JNDs between the young and old participants, $F(1,8) = 1.85$, $p = 0.186$, or among the three levels of intensity for the standard lamp $F(2,24) = 3.029$, $p = 0.067$. Furthermore, the analysis of variance did not show an interaction effect between participant age and intensity of the standard, $F(2,24) = 0.633$, $p = 0.540$.

Constant error is defined as the difference between the standard stimulus and the point where the comparison stimulus is determined to be subjectively equal to the standard (PSE). In most instances, the PSE does not correspond exactly to the standard stimulus (Gescheider, 1985). Analyses of the constant error in the present results revealed no pattern that was consistent over participants. Measures of constant error ranged from -21% to 16%, with an approximately equal number of participants having positive and negative constant errors at all three levels of intensity.

CONCLUSIONS

This study obtained just noticeable differences for low-beam intensities between 11% and 19%. These values are somewhat lower than the value of 25% recommended by Huey et al. for signal-lamp intensities. However, there are many methodological and practical considerations that influence the determination of a JND that is applicable to the real world. Observers are likely to detect smaller differences in the rather simple and uncluttered environment of a controlled study than in complex and dynamic real-world environments. Consequently, the values of JND determined from controlled studies are likely to be too conservative for direct application to real-world conditions. Therefore, we believe that the present results are in reasonable agreement with the recommendation by Huey et al. to use 25% as a criterion for inconsequential noncompliance.

The present results also can be used to extend that recommendation from signal lamps to at least certain aspects of low-beam headlamps. In both the present study and the Huey at al. study, participants were asked to make judgments about the subjective brightnesses of lamps while those lamps were viewed directly, and JNDs were derived in order to provide some indication of how small a difference in lamp intensity would have to be in order to be considered inconsequential for driver vision. Such use of JND values always involves an assumption that the JND for subjective brightness is a fairly general indicator of how sensitive the visual system is to intensity. Performance on the task of comparing subjective brightness does not necessarily predict performance on the real-world visual tasks that are affected by lamp intensity, such as reaction time to a brake lamp or the distance at which a pedestrian illuminated by a headlamp at night can be seen. Furthermore, it is clear that performance on all such tasks is a continuous function of lamp intensity. While JNDs can serve as useful benchmarks, they are based more on convention than on fundamental thresholds.

Nevertheless, the application of JNDs derived from judgments about the subjective brightnesses of lamps viewed directly seems less of a leap in the case of signal lamp functions, and of those aspects of headlamps that involve direct viewing (primarily discomfort glare), than in the case of headlamp functions that involve the illumination of objects. The primary reason for caution in extending the current results to illuminated objects is that the range of luminances of such objects (e.g., a pedestrian at 100 m illuminated by headlamps at night) will be much lower than the luminances of the headlamps themselves. The present results can therefore be used more confidently to justify applying the 25% limit for inconsequential noncompliance to a photometric test point that specifies a maximum for glare protection than to one that specifies a minimum for seeing light. Further work on the effects of changes in lamp intensity on the visibility of illuminated objects is desirable to clarify more completely the issue of inconsequential noncompliance for headlamps.

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