VISUAL AIMING OF LOW-BEAM HEADLAMPS: EFFECTS OF EXPERIENCE AND AMBIENT LIGHT

Michael J. Flannagan
Michael Sivak
Eric C. Traube

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

Report No. UMTRI-97-03
February 1997

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Visual Aiming of Low-Beam Headlamps: Effects of Experience and Ambient Light		5. Report Date February 1997 6. Performing Organization Code 364992
7. Author(s) Michael J. Flannagan, Michael Sivak, and Eric C. Traube		8. Performing Organization Report No. UMTRI-97-03
9. Performing Organization Name and Address The University of Michigan Transportation Research Institute Ann Arbor, Michigan 48109-2150 U.S.A		10. Work Unit no. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address American Automobile Manufacturers Association 7430 Second Avenue Detroit, Michigan 48202		13. Type of Report and Period Covered 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

Recently there has been a considerable amount of interest in formally adopting visual aiming for headlamps in the United States. Because of this interest, several studies have been made of how the sharpness of the cutoff affects the accuracy with which a low-beam headlamp can be vertically aimed. However, a number of issues have not been resolved. The present study was undertaken to address two of these issues: (1) how background light on the aiming screen affects visual aiming, and (2) whether the training and experience of the person doing the aiming affect aiming performance.

Two experiments on visual aiming were conducted. The results demonstrate clear effects of ambient illumination of the aiming screen on the mean position set by visual aiming, but provide no evidence for an effect on variability of visual aiming up to the maximum level examined, 108 lux. The effects on mean aim, although highly significant statistically, are not large relative to estimates of the current variability of headlamp vertical aim in the United States.

The present results therefore suggest that, at least up to 108 lux, ambient illumination of the aiming screen will not have significant detrimental effects on visual aiming of low-beam headlamps. The present results also indicate that special training, at least at the level of professional mechanics, does not affect aiming ability. This suggests that the average vehicle owner would have adequate success in aiming headlamps visually.

17. Key Words	18. Distribution Statement
Headlamps, low-beam headlamps, aiming methods, visual aiming, vertical gradient, cutoff	

19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. of Pages	22. Price
None	None	19	

Contents

Introduction

Currently, all headlamps in the United States are required to have aiming pads that serve as reference points for mechanical aiming devices. By aligning the aiming devices with the pads, it is possible to set both the vertical and horizontal aim of the headlamps with acceptable accuracy. However, a different form of aiming, visual aiming, is commonly used in the United States. In visual aiming, the light from the headlamp is projected onto a vertical surface in front of the vehicle, and the lamp is adjusted until certain landmarks in the light distribution from the lamp appear to be aligned with reference markings on the vertical surface. The judgment of when the landmarks are aligned is based simply on the visual impressions of the person doing the aiming.

Visual aiming has been the accepted form of headlamp aiming in Europe for many years. It is possible to achieve acceptable accuracy with visual aiming, at least for certain lamps. The low-beam pattern of European lamps traditionally has been designed to have a sharp cutoff, that is, a spatially abrupt transition between the bright lower portion of the beam pattern (which allows the driver to see the road ahead) and the dark upper portion (which protects oncoming drivers from glare). When a European headlamp is projected on a vertical surface, this transition appears as a clearly defined boundary between a bright lower area and a darker upper area. Setting the vertical aim of the lamp by aligning this boundary to a horizontal reference line on an aiming screen is relatively easy. In contrast, U.S. low-beam patterns have traditionally had much gentler cutoffs. When U.S. lamps are projected onto vertical aiming screens, the light/dark boundary that must be aligned to the horizontal reference line is less well defined.

Recently there has been a considerable amount of interest in formally adopting visual aiming in the United States. The Society of Automotive Engineers included procedures for visual aiming, along with procedures for several other headlamp aiming methods, in Recommended Practice J1735 (SAE, 1995). Because of this interest, several studies have been made of how the sharpness of the cutoff affects the accuracy with which a low-beam headlamp can be vertically aimed (e.g., Poynter, Plummer, & Donohue, 1992; Sivak, Flannagan, Chandra, & Gellatly, 1992). (Horizontal aim is generally considered less critical than vertical aim. For a discussion of this issue, see Sivak, Flannagan, & Sato, 1994.)

Although previous studies provided considerable information about the relationship between the sharpness of the cutoff and the resulting consistency of vertical aiming, several issues have not been resolved. The present study was undertaken to address two of these issues.

First, it is not known how background light on the aiming screen affects visual aiming. It seems likely that background light, at least at some level, would make it difficult to see the beam pattern clearly, and thus affect visual aiming. However, it is not clear at what level such an effect would be large enough to be a practical problem. Furthermore, it is not easy to eliminate light completely from many of the environments, such as garages and maintenance buildings, in which visual aiming is now conducted, or is likely to be conducted in the future. In standard practice, the aiming screen is 25 feet (7.6 m) from the headlamps (SAE, 1981). A visual aiming facility must therefore be reasonably large, and there may be many cases in which providing a facility of the needed size with complete light control (e.g., a windowless room) would be burdensome. It is therefore important to quantify in some detail how background illumination affects visual aiming, in order to identify a practical level of light control that allows accurate aiming but is not unduly burdensome to achieve.

Second, it is not known how the training and experience of the person doing the aiming affect aiming performance. Previous studies of visual aiming have used subjects who had no special training in either headlighting or vehicle maintenance. If visual aiming of headlamps is formally adopted in the United States, it is likely that most aiming will be done by professional mechanics. It seems unlikely that people with special training and experience in vehicle maintenance would be any less capable at visual aiming than nonmechanics, but it is possible that they are more capable. If so, previous studies might have underestimated the level of performance that could be expected in actual practice.

The following two experiments were conducted to address those issues. Much of the equipment, and many of the procedures, were the same as used in one of the previous studies of visual aiming (Sivak, et al., 1992). Aiming was conducted in a laboratory, where illumination of the aiming screen could be easily controlled. For subjects we used both lay people from the general population of drivers and professional mechanics from a local garage. Each subject repeatedly adjusted the vertical aim of each of a number of low-beam headlamps. (Horizontal aim was always fixed at the correct position.)

Experiment 1: Effects of Ambient Lighting and Experience

In this experiment, we measured visual aiming performance while varying the ambient illumination of the aiming screen. We used both mechanics and nonmechanics as subjects; we used three levels of aiming screen illumination; and we used six different low-beam lamps, representing a wide range of sharpness of the cutoff.

Method

Subjects. There were 17 subjects in all, 9 experienced mechanics and 8 nonmechanics. The mechanics were all male, and ranged in age from 17 to 49 with a mean age of 30.0. The nonmechanics consisted of 3 males (ranging in age from 20 to 30 with a mean age of 25.3), and 5 females (ranging in age from 18 to 31 with a mean age of 25.0) Each subject was given a brief visual acuity test. Subjects who normally wore corrective lenses while driving wore them during the acuity test, and during the experiment itself. The acuities were all 20/35 or better. All subjects were paid for their participation.

The mechanics were all employed at a local garage. By self-report, they had an average of 13.2 years of experience working on vehicles. The nonmechanics were selected in such a way that we could expect them to be reasonably representative of the driving public in general. They were selected randomly from a subject pool that is used for a variety of human-performance studies at UMTRI. The people in that pool had been contacted originally in a variety of ways, including advertisements in local papers and referrals from previous subjects.

Laboratory setup. The laboratory setup is shown in Figure 1. Ambient lighting of the aiming screen was provided by incandescent light bulbs, using no reflectors or other optics so that illumination of the screen would be relatively even. They were positioned, as shown in Figure 1, as far from the aiming screen as practical given other constraints on the setup. A baffle was placed between them and the subject's position so that the subject was shielded from direct light. The highest ambient level was provided by three 100-W bulbs, and a medium level was provided by a single 75-W bulb. In the lowest of three ambient light conditions, the only light on the screen was that from the headlamp itself. The walls and the floor of the room were covered with black cloth to reduce the amount of indirect light from the headlamp that reached the aiming screen.

A goniometer was placed 25 ft (7.6 m) from the aiming screen. Hand cranks on the goniometer could be used to adjust both horizontal and vertical orientation of the lamps (although the subjects controlled only the vertical adjustment). Vertical angle could be read in 0.01-degree increments.

Figure 2 shows the subjects' view of the aiming screen. It was white and diffusely reflecting, with a reflectance (for light from the tungsten-halogen lamps used in the study) of 88 percent. The screen was marked with horizontal and vertical aiming reference lines as shown in Figure 2. The lines were black, and had a width of 0.125 in (3.18 mm). The intersection of the aiming reference lines was positioned so that a line from that point, normal to the aiming screen surface, would pass through the center of rotation of the goniometer.

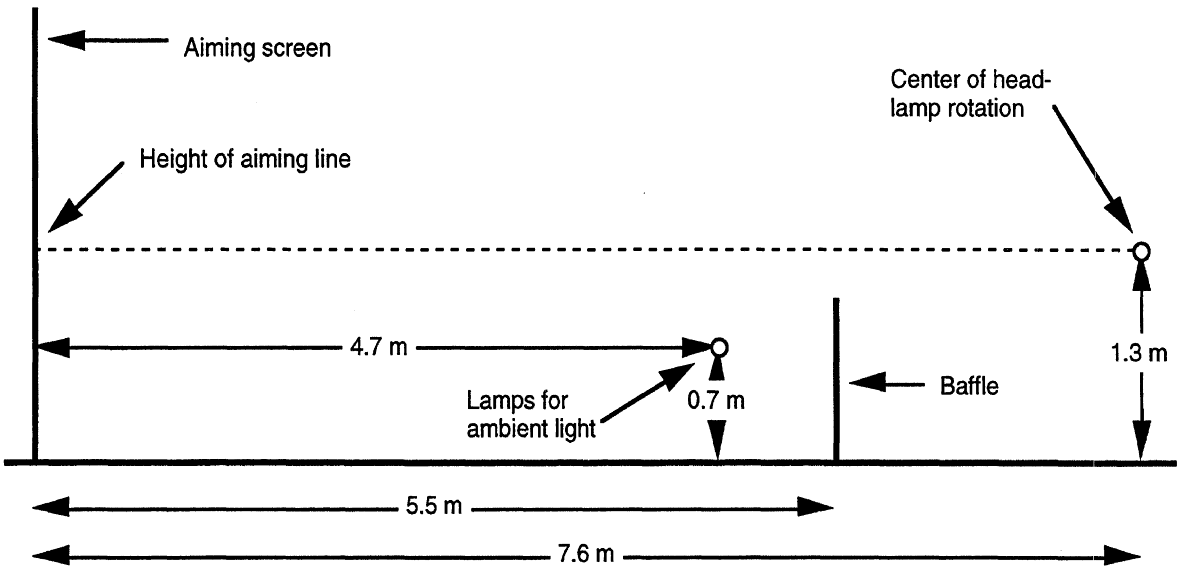


Figure 1. A side view of the laboratory setup. The aiming line was at the same height as the center of rotation of the headlamp. The baffle shielded the subject's position from direct light from the lamps that provided the ambient light.

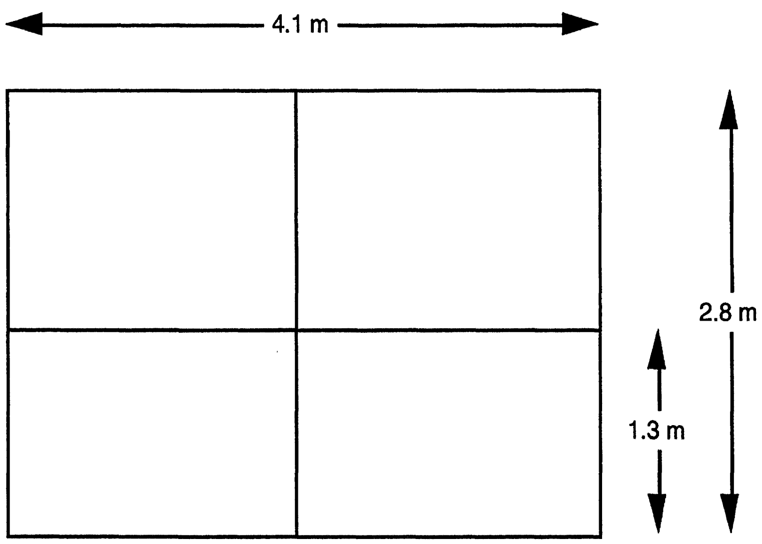


Figure 2. The subject's view of the aiming screen. The horizontal and vertical aiming reference lines were black, with a width of 0.125 in (3.18 mm).

Headlamps. Six lamps were selected from among the ten that had been used in a previous study of visual aiming (Sivak et al., 1992). They were selected to span a range of sharpness of the vertical gradient. Three were lamps manufactured for sale in the United States (referred to in the documentation of the previous study, and in this report, as A3, A5, and A7), and the other three were manufactured for sale in Europe (referred to as E1, E2, and E3). All the lamps were large, rectangular lamps (2B1) with both high-beam and low-beam filaments. Only the low beams were used. All lamps were photometered at a matrix of points between 10 degrees left and 5 degrees right (in 0.2-degree steps) and between 1.5 degrees down and 1.5 degrees up (in 0.1-degree steps).

An index of the sharpness of the vertical gradients for the six lamps is provided in Table 1. This is the index used by Sivak, et al. (1992). It is computed by taking the difference of the natural logarithms of beam-intensity values at vertically adjacent points, using a vertical spacing of 0.1 degrees. For the European beams, the values shown in Table 1 are the maximum such values anywhere in the left half of the beam (the part relevant for aiming the European lamps). For the U.S. beams, the values shown in Table 1 are the maximum values in the right half of the beam (the part relevant for aiming the U.S. lamps), and within 0.2 degrees of the part of the beam that is typically aimed to horizontal. (Because the European lamps did not have aiming pads, the candela matrices that had been measured for them during preliminary photometry could not be definitively calibrated to the alignment of the lamps during subject testing. Therefore the additional constraint of selecting maximum contrast values within 0.2 degrees of a typical aim point could not be used for those lamps.)

Table 1.
Contrast measures of the vertical gradients of the six lamps used in this study, from Sivak, et al. (1992).

Lamp	Contrast $\ln I_1 - \ln I_2$ (0.1-degree intervals)
A3	0.348
A5	0.539
A7	0.248
E1	0.625
E2	0.585
E3	0.843

Aiming screen photometry. There were three levels of ambient light on the aiming screen: 0.0, 7.0, and 28.4 lux. These values are the averages of measurements made in a five-by-five grid of points on the aiming screen, centered on the intersection of the horizontal and vertical aiming reference lines, and spaced at 1-degree intervals. The photometered points thus ranged from 2 degrees below to 2 degrees above the point aligned with the center of rotation of the goniometer, and from 2 degrees left of to 2 degrees right of that point. The illumination over this portion of the aiming screen was approximately even. For the middle level of ambient light, the range of lux values at the 25 points in the photometered grid was 7.00 to 7.07 lux. For the high level, the range was 27.8 to 28.6 lux. (For the lowest level of screen illumination, which was nominally 0.0 lux and was produced by having the room completely dark except for the headlamp itself, no actual measurements were taken.)

Procedure. Each subject participated in a single, individual session that took about one hour. The only task was to set the vertical aim of the six lamps. The subjects were instructed to attend to the right half of the screen while aiming the U.S. lamps, and to the left half while aiming the European lamps. (The complete text of the instructions that were read to the subjects is given in the Appendix.) The experimenter misaimed the lamps either four degrees up or four degrees down at the beginning of each of a series of trials. (Horizontal aim was always fixed at the correct position.) The subjects then adjusted the vertical aim themselves, using a hand crank, and they were allowed to move the aim up and down if they wished before declaring that they were satisfied with it.

Each subject made 6 settings (3 starting from 4 degrees down, and 3 starting from 4 degrees up) for each of the 18 combinations of 6 lamps and 3 lighting conditions (108 settings in all). The trials for each of the 6 lamps were run in blocks, so that the lamp was changed every 18 trials. The 3 lighting conditions were also blocked within lamp conditions, so that lighting was changed every 6 trials. Starting misaim was alternated after each trial. The orders of lamps, ambient brightnesses within lamp type, and starting aim positions were randomized across subjects. After each of the subject's settings, the experimenter recorded the vertical aim to the nearest 0.01 degree.

Results and Discussion

Effects on consistency of aiming.

As expected from previous results (Sivak, et al., 1992), the vertical gradients of the headlamps affected the consistency with which they were aimed. Table 2 shows the overall standard deviations of aim for each of the six headlamps. These results include all possible sources of variability that were represented in the experiment, including differences among subjects, differences among repeated aims by the same subjects, and differences among ambient lighting conditions. As shown in Figure 3, the differences in overall standard deviation among headlamps were systematically related to the sharpness of the vertical cutoffs of the lamps, r = .86, $p < .05$.

The experience and training of the aimers did not affect the consistency with which they aimed the lamps. Mean aims by the mechanics were somewhat more variable than those by the nonmechanics, opposite what might be expected from a higher level of training, but the difference did not approach statistical significance. Ambient light level also had little if any effect on the variability of aiming. Figure 4 shows the overall standard deviation of aims for each ambient light condition. There is a slight tendency for standard deviation to be lower (indicating more consistent aiming) for higher ambient light levels.

Table 2.
Overall standard deviation of vertical aim for each of the six lamps. These results include variability due to differences among subjects, differences among repeated aims by the same subjects, and differences among ambient lighting conditions.

Lamp	Standard Deviation of Vertical Aim
A3	0.176
A5	0.132
A7	0.300
E1	0.162
E2	0.126
E3	0.093

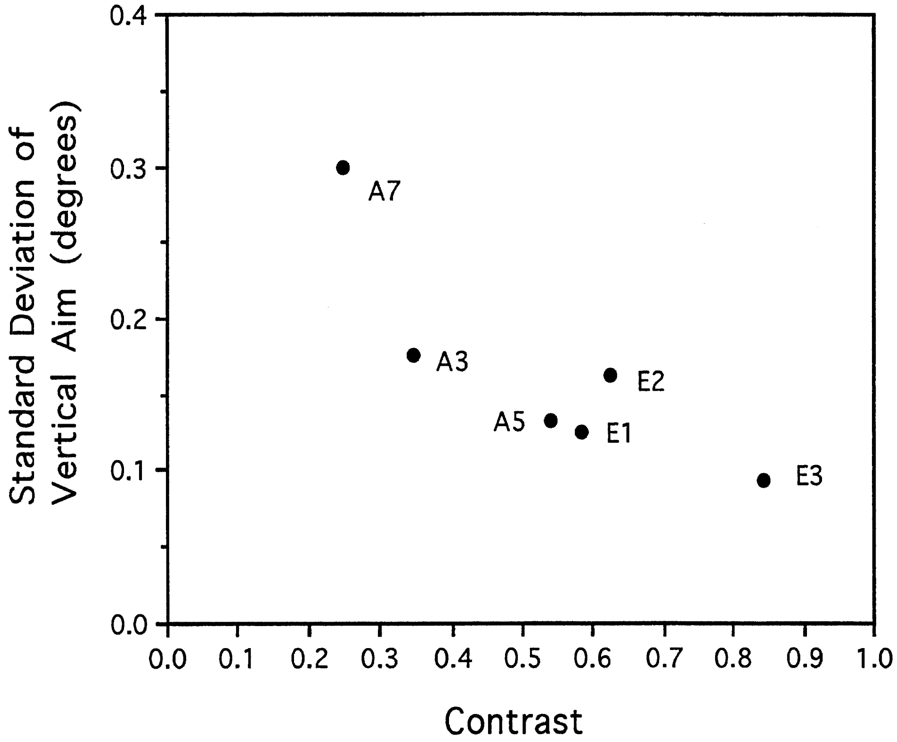


Figure 3. The relationship between overall standard deviation of vertical aim and the contrast measure shown in Table 1.

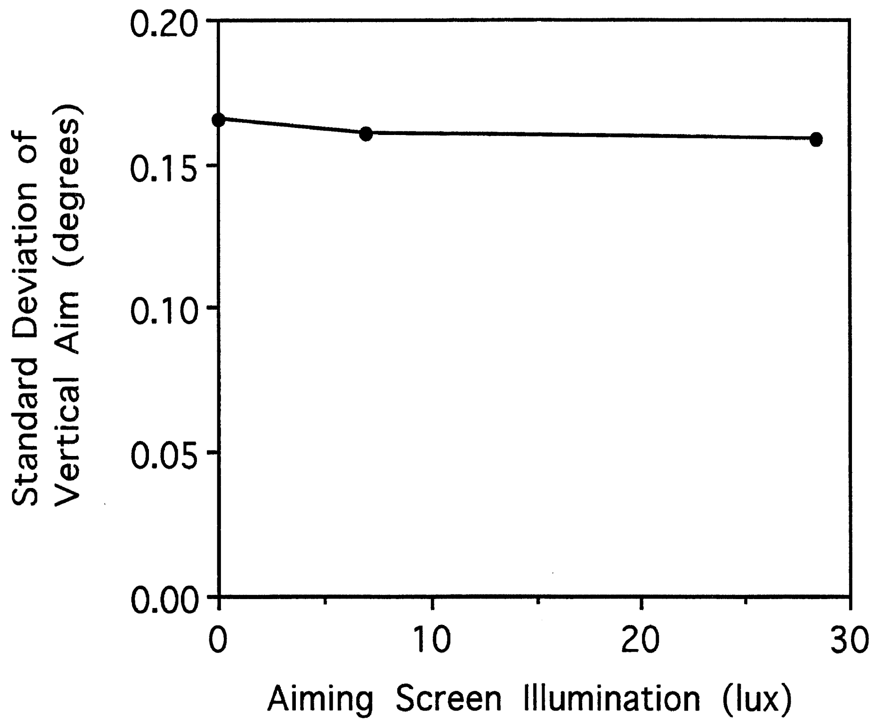


Figure 4. Overall standard deviation of vertical aiming as a function of aiming screen illumination. There is a slight tendency for standard deviation to be lower (meaning that aiming is more consistent) at higher ambient levels.

Effects on mean aim.

The subject's aiming performance was compared to that of an expert aimer, a lighting engineer with eight years experience in headlamp design. In agreement with the results of two previous studies (Poynter, et al., 1992; Sivak, et al., 1992), there was a slight tendency for the mean aim points of the mechanic and nonmechanic subjects to be higher than those of the expert aimer. Combining data over all lamps and ambient lighting conditions, the mechanics aimed 0.10 degrees higher than the expert, and the nonmechanics aimed 0.05 degrees higher. However, in neither case was the difference significant, $t(8) = 2.13$, $p > .05$, and $t(7) = 1.38$, $p > .10$, respectively. The difference of 0.05 degrees between the mean aim points of the mechanics and of the nonmechanics was also not statistically significant, $t(15) = 0.94$, $p > .10$.

The effect of ambient light on the mean aim of all six lamps, shown in Figure 5, was highly significant, $F(2,30) = 65.9$, $p < .0001$. The effect of ambient light was larger for some lamps than others, as show in Figure 6. The interaction of ambient light and lamp was also highly significant, $F(10,150) = 7.19$, $p < .0001$. The data in Figure 6 suggest that the extent to which a lamp's mean aim was affected by ambient light is related to the sharpness of the cutoff, as represented by the values in Table 1. Lamps with sharper cutoffs appear to be less affected by the changes in ambient light. Figure 7 shows the relationship between the size of the effect of ambient light (mean aim at 28.4 lux minus mean aim at 0.0 lux), and the sharpness of the cutoff. The correlation is high, $r = -.80$, but does not quite reach statistical significance, $p = .055$.

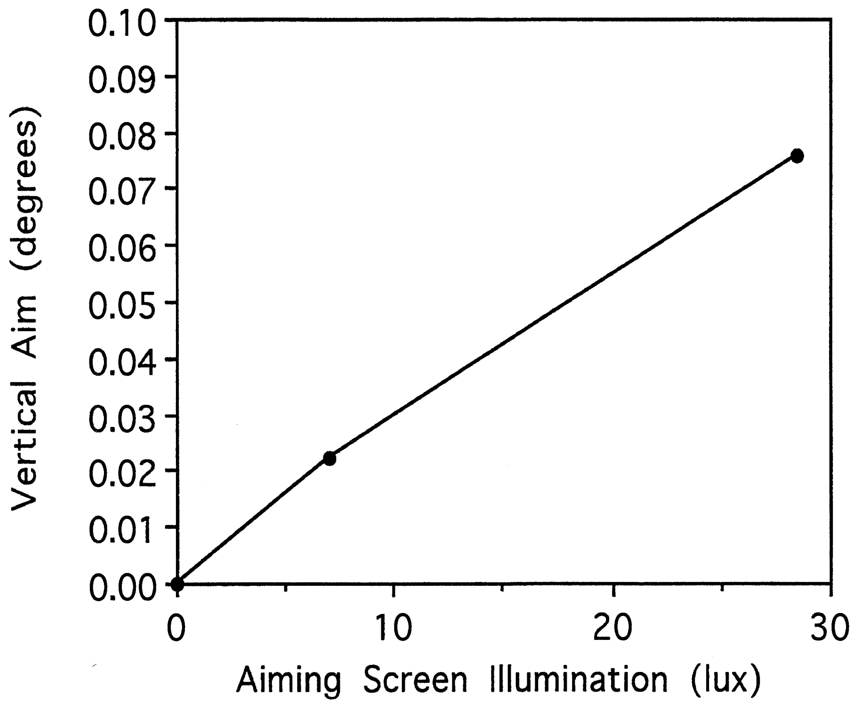


Figure 5. Vertical aim relative to the dark condition (0 lux), averaged over all lamps and subjects, as a function of aiming screen illumination.

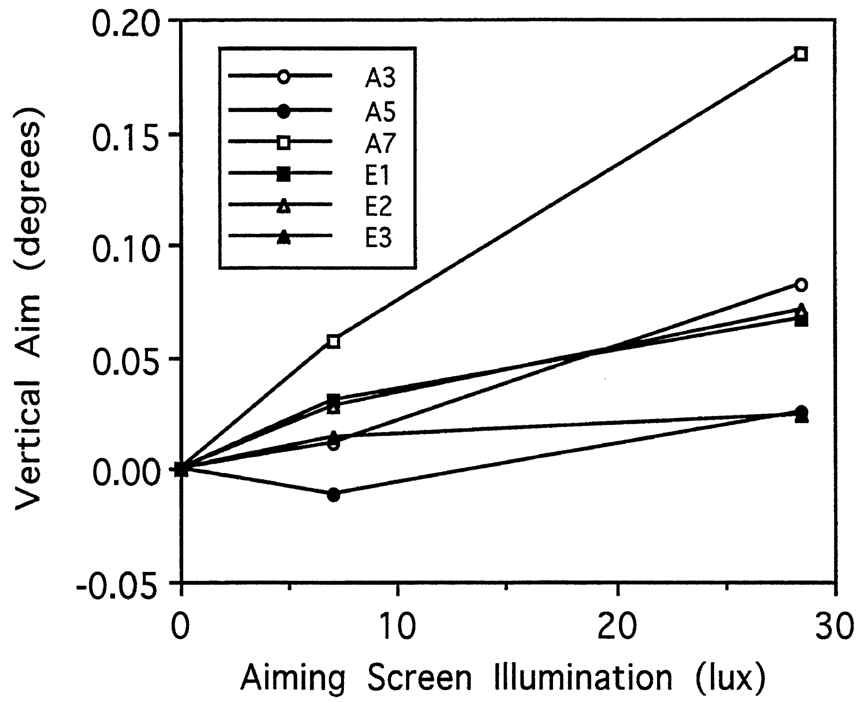


Figure 6. Vertical aim relative to the dark condition (0 lux) as a function of aiming screen illumination for the six lamps individually.

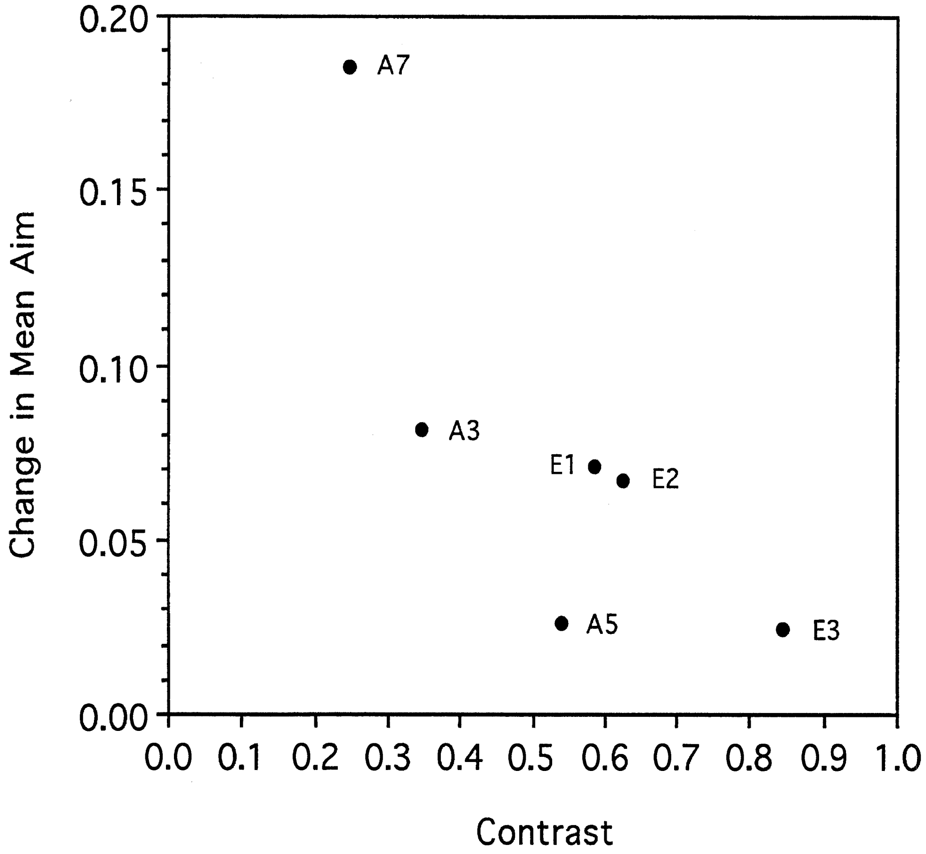


Figure 7. The relationship between the change in mean aim between the lowest and highest aiming screen illumination, and the contrast measure of the vertical gradient from Table 1, for the six individual lamps.

Experiment 2: Effect of Extended Ambient Light Levels

Within the range of ambient light used in Experiment 1, there was a clear effect of ambient light on mean aim, but no discernible effect on the variability of aim. In Experiment 2 the range of ambient lighting was increased to see if changes in variability would appear at higher ambient levels. Because no significant differences in aiming performance between mechanics and nonmechanics were detected in Experiment 1, only nonmechanics were used in Experiment 2. In other respects the method was the same as in Experiment 1.

Method

Subjects. There were 12 subjects in all: 7 males ranging in age from 19 to 33 with a mean age of 26.4, and 5 females ranging in age from 24 to 31 with a mean age of 27.4. Each subject was given a brief visual acuity test. Subjects who normally wore corrective lenses while driving wore them during the acuity test and during the experiment itself. The acuities were all 20/25 or better. All subjects were paid for their participation.

Aiming screen photometry. As in Experiment 1, there were three levels of ambient light on the aiming screen, but in this experiment the range was extended: 0.0, 36.0, and 108 lux. These values are the averages of the same 25 points on the aiming screen described in the Method for Experiment 1. As in that experiment, the illumination over the photometered portion of the aiming screen was approximately even. For the middle level of ambient light, the range of lux values at the 25 points in the photometered grid was 35.6 to 36.7 lux. For the high level, the range was 106 to 111 lux. (As in the first experiment, no actual measurements were taken for the nominally 0.0 level.)

Results and Discussion

As shown in Figure 8, ambient light still has no discernible effect on variability of aiming, even at 108 lux. Figure 8 also shows the variability results from Experiment 1, indicating reasonably good agreement in the overall magnitude of variability.

The effect of ambient light on mean aim that we found in the first experiment was replicated. Figure 9 shows mean aims for all subjects and all lamps as a function of ambient illumination, along with the corresponding data from Experiment 1. There is good agreement within the overlapping range of illumination. The magnitude of the effect appears to diminish at the higher illumination levels used in the new experiment. Figure 10 shows the Experiment 2 data from Figure 9 broken down by lamp. As in the first experiment, the lamps vary in how much they are affected by changes in ambient illumination.

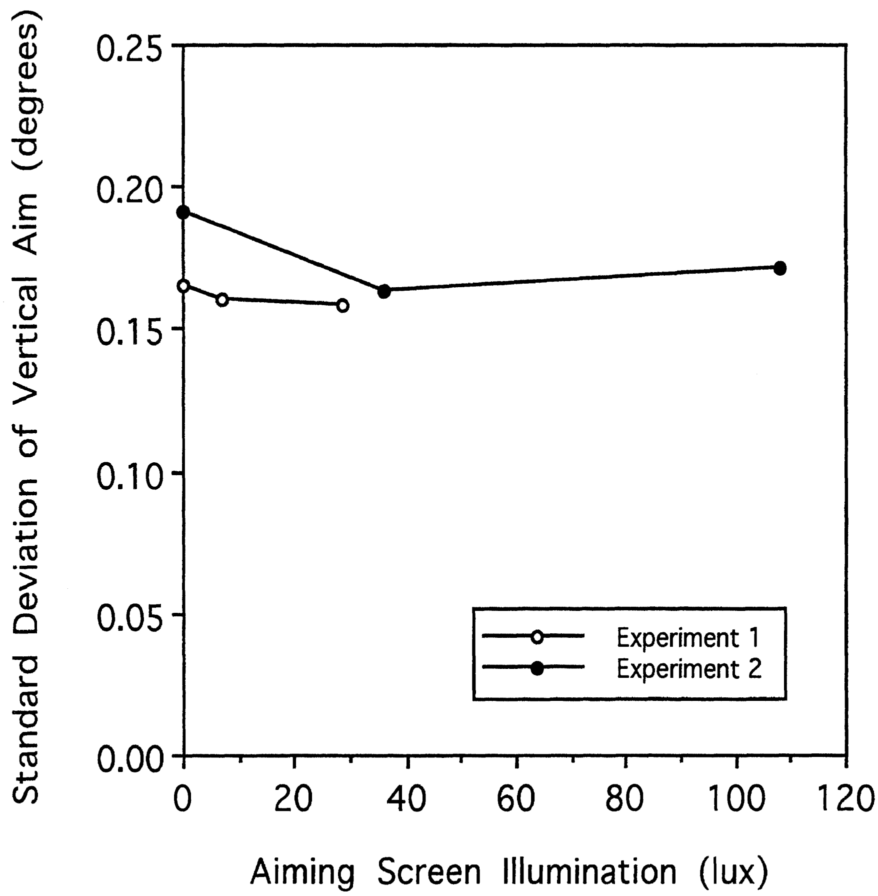


Figure 8. Standard deviation of vertical aim as a function of aiming screen illumination. The new data, from Experiment 2, are represented by the filled symbols. For comparison, the corresponding results from Experiment 1 (shown earlier in Figure 4) are replotted here using the open symbols.

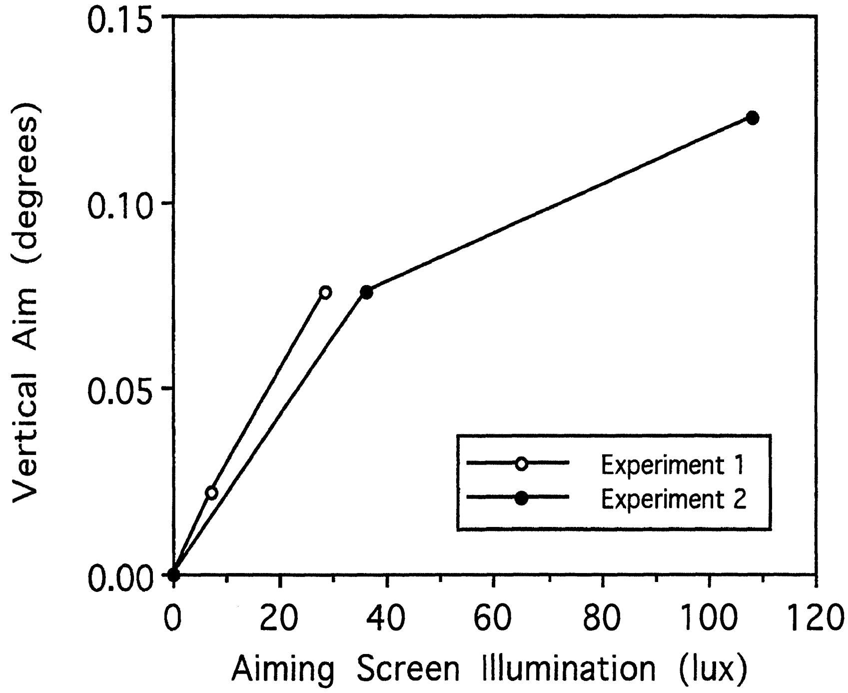


Figure 9. Vertical aim relative to the dark condition (0 lux), averaged over all lamps and subjects, as a function of aiming screen illumination. The new data, from Experiment 2, are represented by the filled symbols. For comparison, the corresponding results from Experiment 1 (shown earlier in Figure 5) are replotted here using the open symbols.

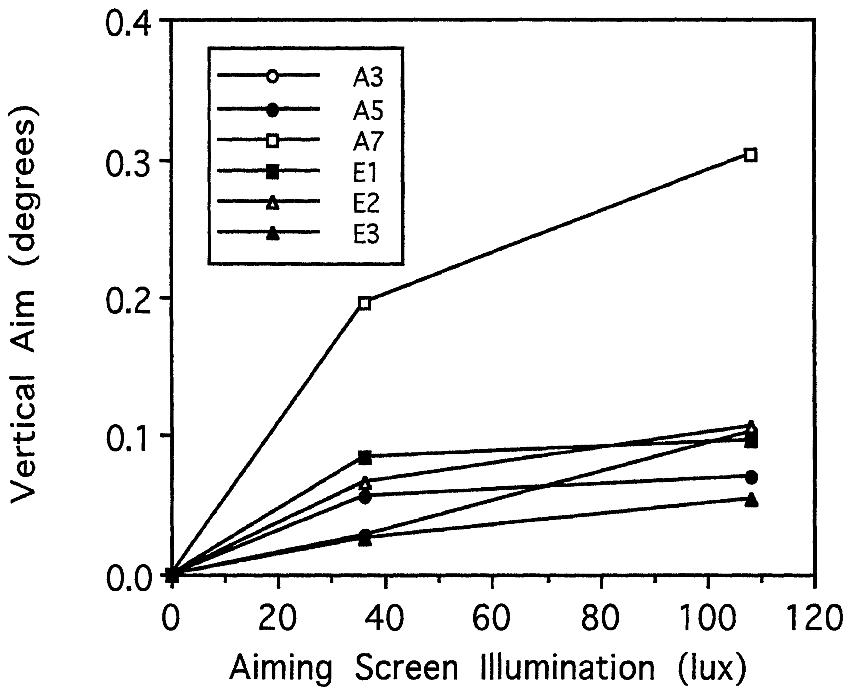


Figure 10. Vertical aim relative to the dark condition (0 lux) as a function of aiming screen illumination for the six lamps individually. All data in this figure are from Experiment 2. These results correspond to the results from Experiment 1 shown in Figure 6.

General Discussion and Conclusions

These two experiments demonstrate clear effects of ambient illumination of the aiming screen on the mean of visual aiming, but there is virtually no evidence for an effect on variability of visual aiming up to the maximum level examined, 108 lux. The effects on mean aim, although highly significant statistically, are not large relative to the current estimated variability of headlamp vertical aim in the United States. Olson (1985) conducted a field study in which the standard deviation of vertical aim of cars on the road in the United States was measured at 0.9 degrees. In comparison, the largest change in mean aim observed in these experiments, for headlamp A7 over the a range of 0.0 to 108 lux, was 0.30 degrees. The second largest change, for headlamp A3 over the same range, was only 0.10 degrees.

The present results therefore suggest that, up to 108 lux, ambient illumination of the aiming screen will not have significant detrimental effects on visual aiming of low-beam headlamps. The present results also indicate that special training, at least at the level of professional mechanics, does not affect aiming ability. This suggests that the average vehicle owner would have adequate success in aiming headlamps visually.

Appendix

The following instructions were read to the subjects:

The purpose of this study is to examine how people visually aim automobile headlamps. This device *(point to goniometer)* holds the headlamps so that they shine on the screen in front. Your task will be to align headlamps to the horizontal line on the screen by turning this crank *(point to crank)*. Every time you see a lamp, it will be way off from the horizontal line (either too high, or too low), so you will always have to make some correction. When you turn the crank, please do not lean on the table.

I will present several different lamps to you, one at a time. You will be asked to aim each of the lamps several times. There will be breaks in the experiment in between lamps, while I place a different lamp in the goniometer.

The lamps that you observe will have one of two distinctly different patterns. Some will have a pattern of light that looks like Figure A, others will look like Figure B. The shaded area of the figure represents the brightest portion of light. When the lamp is correctly aimed, the top edge of the brightest portion is aligned with the horizontal line. In both of the figures, the pattern is aligned properly to the horizontal line. The beams that you actually see will look like one of these two general types, but there will be some variation. When you see a pattern that looks like Figure A, you should pay attention to the portion of light that is to the left of the vertical line; when you see a pattern like Figure B, you should pay attention to the portion of light that is to the right of the vertical line. Each time a new lamp is shown, I will remind you which side to pay attention to.

Because each headlamp pattern is different, you may be unsure about exactly where a particular lamp is supposed to be aimed. In all cases, try to follow the guidelines shown in these figures. However you choose to aim a particular lamp, please try to aim it the same way each of the several times that you aim that particular lamp. One of the main things we are interested in is how consistently people can aim these lamps. I will occasionally change the room lighting between trials. Please try to disregard those changes, and keep aiming the lamp the same way. Do you have any questions?

Figure A

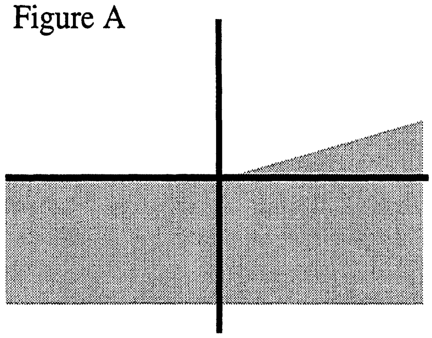
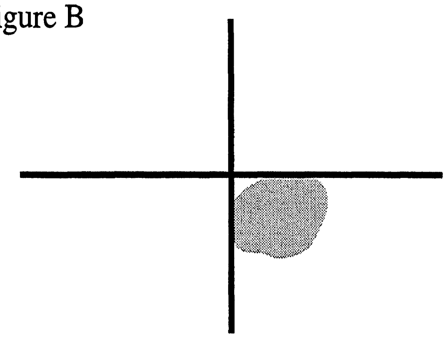


Figure B



References

Olson, P. L. (1985). *Measurement of crash avoidance characteristics of vehicles in use* (Report No. UMTRI-85-20). Ann Arbor: The University of Michigan Transportation Research Institute.

Poynter, D., Plummer, R. D., & Donohue, R. J. (1992). Automobile headlamp alignment by visual aim: Photometric correlates of the visual cutoff and aim variability. *Lighting Research and Technology, 24*, 137-142.

Sivak, M., Flannagan, M., Chandra, D., & Gellatly, A. W. (1992). *Visual aiming of European and U.S. low-beam headlamps* (SAE Technical Paper Series No. 920814). Warrendale, Pennsylvania: Society of Automotive Engineers.

Sivak, M., Flannagan, M. J., & Sato, T. (1994). *The relative importance of horizontal and vertical aim of low-beam headlamps* (SAE Technical Paper Series No. 940640). Warrendale, Pennsylvania: Society of Automotive Engineers.

Society of Automotive Engineers. (1981). *Standard SAE J599: Lighting inspection code.* Warrendale, Pennsylvania: Author.

Society of Automotive Engineers. (1995). *Recommended practice SAE J1735: Harmonized vehicle headlamp performance requirements*. Warrendale, Pennsylvania: Author.