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Motorcycle Headlighting Research

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August 1975

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16. Abstract

A research program was conducted which: (1) quantified the characteristics of currently available motorcycle headlamps; (2) examined the headlamp aim of 90 in-service motorcycles; (3) examined the eye fixations of two motorcycle drivers while operating a motorcycle in daylight; (4) provided subjective ratings of a number of quantitatively different low beam headlamps which were evaluated in terms of photometric characteristics of the lamps; (5) determined subjectively desirable headlamp aim by enabling 20 motorcyclists to aim a headlamp while driving at night at two different speeds; and (6) provided comparisons of the relative efficiency of a number of high and low beam headlamps in field target identification tests. Results of these studies indicate that motorcycle headlamps should distribute illumination in areas on and about the road surface that are not dealt with by the low beam motorcycle photometric standard (SAE J584) specified in FMVSS 108. New photometric standards, based on the various findings, are recommended for three classes of motorcycles representing three maximum speed categories. Recommendations are also made concerning standardization of physical specifications of motorcycle headlamps, maintenance of electrical system design voltage, and improvement of the aimability of motorcycle headlamps.

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Mr. Stephen Orth provided invaluable assistance in the conduct of the field tests and the in-service motorcycle headlamp aim and operator-generated aim studies. He was also responsible for fabrication and modification of much of the mechanical apparatus used in these studies.

Dr. Rudolf G. Mortimer served as Project Director of this contract until January, 1975. He and Mr. Craig M. Jorgeson were responsible for the design, execution, and reporting of the eye fixation experiment.

Mr. John C. Campbell, Instrumentation Services Group, HSRI, designed the headlamp intensity control apparatus and the data acquisition apparatus used in the field test experiments. Mr. George Popp, under the direction of Mr. Campbell, constructed all of the electronic instrumentation.

Ms. Judith Becker and Mr. Arthur Bernstein developed the computer simulation programs used to predict identification distances.

Ms. Pat Markey was responsible for typing the final report. A number of the tables and figures contained in the report were typed by Ms. Leda Ricci. Mrs. Marion Damberg provided secretarial services throughout the project.

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The American Honda Motor Co., Inc., provided the 350 cc motorcycle used in the subjective evaluation and the operator generated aim and identification distance/object avoidance experiments.

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Stanley Electric Co., Ltd.
Yamaha International Corp.
Guide Lamp Division, General Motors Corp.
General Electric Co.
Joseph Lucas North American, Inc.
Harley Davidson Motor Co., Inc.
Wagner Electric
Cibie (EFPE Co.)
Westinghouse Electric Corp.

The Electrical Systems subcommittee of the SAE Motorcycle Committee provided a large number of moped and motorcycle headlamps.

Mr. J. Neill provided the use of a Solex moped for the subjective evaluation study.

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SUMMARY OF FINDINGS AND CONCLUSIONS

1. Motorcycle headlamps supplied as original equipment on motorcycles sold in the U.S. vary widely in diameter, filament contact wiring technique and mounting method. This lack of physical standardization limits the sources of replacement headlamps and may be an impediment to the replacement of burned out headlamps. Institution of a dimensional specification standard (similar to SAE J571c) would increase the general availability of motorcycle headlamps and would aid motorcyclists who may wish to upgrade their headlighting systems.

2. The headlamp aim of 90 in-service motorcycles was found to vary greatly, and to a much greater extent than the headlamp aim found in a population of in-service automobiles. Passenger loading was found to significantly change vertical headlamp aim on a majority of these motorcycles. For the benefits of any motorcycle headlamps to be fully realized, some means (mechanical or optical) must be provided to improve the aimability of headlamps.

3. Photometrically sufficient motorcycle headlamps must be operated at design voltage to provide full effectiveness. Institution of a standard requiring reliable maintenance of electrical system design voltage is desirable.

4. Minimum photometric specifications for low beam motorcycle headlamps based on the findings of a number of objective and subjective studies are presented. These specifications differ from those required in SAE J584 in that minimum intensities are increased, and additional minimum test points have been added to reflect the need of motorcyclists for nighttime illumination of a large and diverse area on and about the road surface. Separate recommendations are made for large displacement motorcycles, small displacement motorcycles, and mopeds, acknowledging their disparate maximum speed capabilities.

5. Additional research is recommended to determine maximum acceptable glare levels which could be produced by motorcycles headlamps as indicated by subjective reports of automobile drivers and objective measures of automobile drivers' nighttime visibility when opposed by motorcycle headlamps producing differing amounts of glare. This research would be valuable both for validating recommended maximum allowable motorcycle low beam headlamp intensities and for determining the effects of vertical misaim of motorcycle headlamps of different maximum intensities.

INTRODUCTION

Research concerning the development of headlighting systems for motor vehicles has received considerable attention in the past forty years. A great deal of this research is reviewed by Mortimer and Olson (1974). However, very little research effort during this time has been expended on the development and evaluation of headlighting systems for single-track vehicles such as motorcycles. Providing effective headlighting for these vehicles is made difficult by such problems as (1) limited information concerning the specific areas on the road ahead of the vehicle which are of most importance to the driver and should be illuminated adequately, (2) difficulty in achieving and/or maintaining accurate headlamp aim, (3) the effect of vehicle and thus headlamp roll in turns and on curved roads, and (4) a limited capacity for producing power to operate headlamps and other electrical systems.

Previous motorcycle headlighting research sponsored by DOT has been directed toward the development of optimum headlighting systems for an experimental safety motorcycle, and is reported in Bartol, Livers and Hirsch (1973) and Bartol, Livers and Miennert (1975). The Bartol et al. (1973) study relied on the subjective ratings of an expert panel of nine engineers to make static relative performance comparisons within a group of 14 conventional and experimental headlighting systems. Conclusions of this study were that lamp effectiveness is not directly correlated with (1) maximum candlepower, (2) lamp voltage requirements or (3) lamp trade number designations. The authors recommended that further research be conducted to quantify the characteristics of "a good motorcycle lighting pattern." It was noted that several two-lamp experimental systems which were evaluated provided a significant subjective improvement over conventional systems in terms of light output. Two-lamp systems also have the benefit of providing lamp redundancy in case of a filament outage.

Bartol et al. (1975) provided further examination of motorcycle headlighting through evaluations of the beam patterns, target detection distances, glare production and durability of seven headlighting configurations. The beam pattern analysis reported was purely subjective and was conducted by inspection of isocandela diagrams and photographs of beam patterns on an aiming board. Target detection distances were empirically determined in dynamic field tests conducted on a straight road with the participation of five subjects. No statistical analysis was performed on the detection distance data, which are reported as mean detection distances. These means are compared in terms of maximum safe speeds according to required stopping distances calculated in accordance with braking-reaction time data from the American Association of State Highway Officials. Although none of the motorcycle lighting systems was found to provide visibility distances equivalent to those provided by automobile systems, six of the seven configurations examined were felt to be acceptable for low beam operation with no opposing traffic at speeds of up to 60 mph.

Photometric analysis of the glare produced by the headlamp tested indicated that veiling brightnesses were in each case lower than those produced by correctly aimed automobile headlighting systems.

Results of the headlamp durability tests were considered inconclusive and further research in this area was recommended.

One of the major outputs of this study is a pair of diagrams depicting "optimum" high and low beam headlamp intensity patterns for motorcycle applications. These diagrams were ostensibly generated through the consideration of a number of subjective conclusions regarding motorcyclists' visual requirements. It is not stated how the specific intensity values were derived, although it is reported that a two-lamp system which was favorably evaluated provided values approaching those recommended.

While this past research is valuable for its examination of and recommendations toward optimization of headlighting systems for large high speed motorcycles, it has not addressed the headlighting requirements of smaller, lower speed motorcycles, nor has it provided detailed information concerning the effectiveness in providing illumination of the many diverse headlamps currently supplied on production motorcycles. Additionally, it has not addressed the problem of headlamp aim which, as noted by Olson and Mortimer (1973), is a major impediment to the improvement of vehicular headlighting. In fact, no previous research has examined the variability of headlamp aim in the motorcycle population. Some knowledge of the degree of this variability would allow inferences to be made concerning the utility of currently available headlighting systems and the benefits to be derived from improved headlighting systems. Finally, additional research concerning the design optimization of motorcycle headlighting systems is desirable to corroborate the research efforts conducted to date. Of specific interest is the development of an optimum relationship between high and low beam intensity patterns. Bartol et al. (1975) state, for instance, without detailed explanation, that high and low beam hotspots should be separated 1° vertically and 2° horizontally. Some additional quantitative data are desirable to substantiate this conclusion.

OBJECTIVES

The object of this project has been to: (1) quantify the current state-of-the-art of motorcycle headlighting; (2) identify more fully the visibility requirements of motorcycle operators; (3) make relative comparisons of a number of qualitatively different motorcycle headlamp beams; and (4) make recommendations concerning improved photometric standards for three classes of motorcycles representing three maximum speed categories. Toward these goals, a number of tasks were completed.

I. Survey of the State-of-the-Art of Motorcycle Headlighting.

A. Motorcycle headlamp useage survey. A large sample of representative motorcycle headlamps was solicited from motorcycle and headlamp manufacturers for inventory and comparison of specific features. Photometric data for a subsample of the above headlamps were acquired for use with two identification-visibility distance computer simulation programs developed at HSRI for making relative comparisons of the visibility afforded by automotive headlighting systems.

B. In-service motorcycle headlamp aim survey. The headlamp aim of 90 motorcycles in the Ann Arbor, Michigan area was measured to determine: (a) the extent to which recommended aim is maintained; (b) whether motorcyclists specifically aim their headlamps out of recommended specifications to improve visibility in areas they consider important; and (c) the effect of passenger loading on vertical aim.

C. Survey of motorcycle manufacturers headlamp design and selection procedures. A direct mail survey of motorcycle manufacturers was conducted to determine the procedures used by manufacturers to design or select headlamps for use on production motorcycles.

II. Studies Conducted to Identify the Visibility Requirements of Motorcycle Operators.

A. Eye fixation experiment. The daytime fixations of two motorcyclists were collected when operating both a motorcycle and an automobile, to provide a better understanding of the areas in the visual field from which motorcyclists gather information when performing the driving task.

B. Subjective evaluation of low beam patterns. Three experienced motorcyclists evaluated 19 motorcycle headlighting systems. Their subjective impressions of desirable and undesirable features of each system were recorded and evaluated in terms of the photometric characteristics of the lamps. Results of this study also enabled selection of headlamps for use in the identification distance-object avoidance experiment described later.

C. In-service aim survey questionnaire. The 90 motorcyclists participating in the in-service aim survey were each asked to rate the most important objects or areas in the visual field to be able to see when driving at night. These data were compared with results of the eye fixation and subjective evaluation studies.

D. Operator-generated aim experiment. Twenty experienced motorcyclists drove a motorcycle equipped with a headlamp which was aimable by means of controls mounted on the handlebars. These subjects were instructed to "optimally" aim a low beam headlamp at 30 mph and 50 mph during short drives on roads with no overhead illumination. Resultant headlamp aim was found to differ markedly from design aim in both horizontal and vertical axes.

III. Studies Conducted to Provide Relative Comparisons of the Efficiency of Headlamps in Target Detection and Identification Tasks.

A. Computer simulations of identification distances. Two computer programs were used to predict identification distances based on lamp photometric data and the experimental procedure used in the target identification distance experiment described later.

B. Target identification distance experiment. The identification distances afforded by two high-beam headlamps, six low beam headlamps, and two moped headlamps were evaluated on 917' radius left and right curves and on straight roads by 10 subjects both with and without opposing glare from automobile headlamps. The lamps were tested on a moped and 60 cc and 350 cc motorcycles.

C. Object avoidance experiment. During the target identification distance experiment, subjects were required to maneuver the motorcycle as smoothly as possible around road surface targets which resembled potholes and which were placed at several locations on the test course. The maximum roll angle and roll rate generated during these maneuvers was recorded and comparisons of these measures were made between headlamps for each of the three motorcycles used.

IV. Integration of Research Findings and Synthesis of Photometric Standards for Low Beam Motorcycle Headlamps. The findings of the objective and subjective studies were integrated and used in conjunction with available photometric data to devise photometric standards for low beam headlamps for three classes of motorcycles, categorized by engine displacement and reflecting differences in maximum speed capabilities. Additional recommendations are made concerning lamp dimensional specifications, maintenance or electrical system design voltage, and improvement of headlamp aimability.

SURVEY OF THE STATE-OF-THE-ART OF MOTORCYCLE HEADLIGHTING

MOTORCYCLE HEADLAMP USEAGE SURVEY

OBJECTIVE

To obtain samples of a wide range of currently produced motorcycle headlamps in order to quantify current motorcycle headlighting practices.

METHOD

A preliminary survey conducted at motorcycle dealerships in Southeastern Michigan indicated that little or no standardization of motorcycle headlamp configurations exist, either between or within manufacturers. It was not possible to inventory production motorcycle headlamps by examining either motorcycles on display or parts catalogues because of this lack of standardization. Assistance in this effort was given by members of the SAE Motorcycle Committee who were conducting a similar survey for their own purposes, and had compiled a substantial list of currently available motorcycle headlamps referenced by motorcycle manufacturer and motorcycle engine displacement. On this basis, representatives of several motorcycle manufacturers and headlamp manufacturers were contacted and asked to provide samples of headlamps and associated photometric data for evaluation. Samples were thus obtained from:

Stanley Electric Co., LTD.
Yamaha International Corp. (Koito Headlamps)
Wagner Electric
Harley Davidson Motor Co. (CEV Headlamps)
Joseph Lucas North America, Inc.
General Electric Co.
Guide Lamp

Several lamp samples were also donated by the Electrical Systems Subcommittee of the SAE Motorcycle Committee's Headlight Task Force. These included products of the following manufacturers:

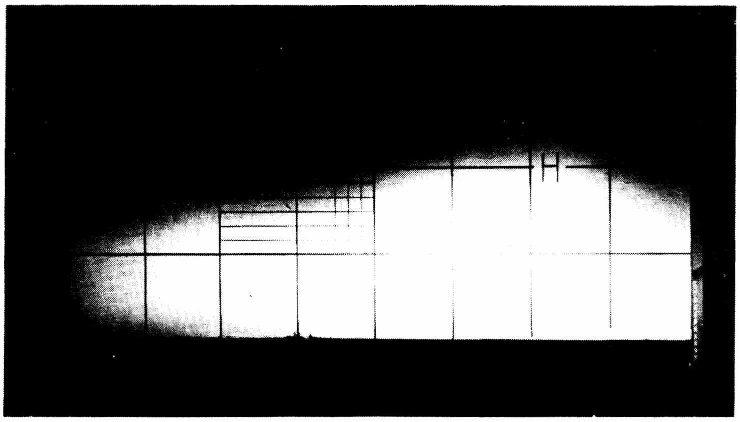
- Guide Lamp
- Lucas
- Westinghouse
- Traizet Luxor (Motobecane)
- Peugeot
- Cibie
- Soubitex

In all, 31 motorcycle lamps, 11 moped lamps, and six experimental/special purpose/automotive lamps were obtained. These lamps are listed by trade number (or other number) designation and manufacturer in Appendix A. Represented among the group of 31 motorcycle lamps alone are seven different lamp diameters or shapes, six filament contact wiring configurations, three basic low beam pattern shapes, and a wide range of power requirements.

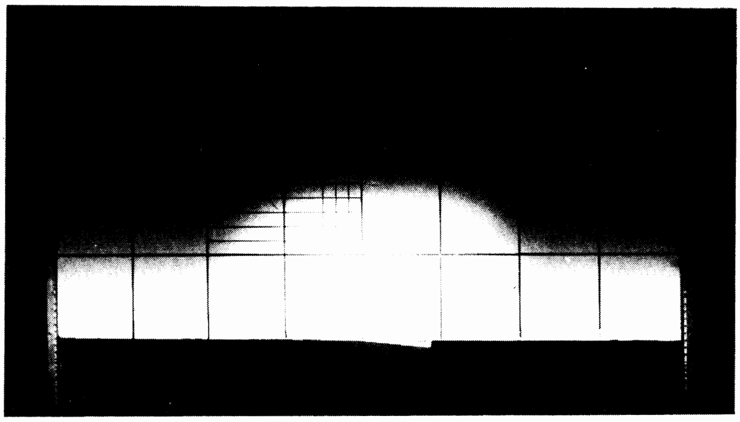
An illustration of the lack of standardization is provided by the case of one headlamp manufacturer who submitted 14 samples representing lamps supplied to three motorcycle manufacturers. Among this group alone were found six different lamp diameters and five different filament contact wiring techniques. Except for one pair of lamps, none are interchangeable because of differences in diameter, wiring technique, and/or mounting hardware configuration.

Many motorcycle owners must thus be restricted to obtaining replacement headlamps exclusively from motorcycle dealers or more specifically, from dealers of the make of motorcycle they own. (Some large displacement motorcycles, i.e. 450 cc's and greater, are designed to accept 7" headlamps, and in these cases, automobile headlamps can be installed, if desired or necessary, without extensive modification.) This lack of standardization contrasts sharply with the standardization afforded the automobile owner who may purchase replacement headlamps from a wide variety of sources, including many that may conduct business outside of normal business hours. Automobile owners also have the option of installing high intensity or other special headlighting systems sold on the automotive aftermarket. The standardization of automobile headlamps has also contributed to a considerably lower unit price than that typically charged for most motorcycle headlamps.

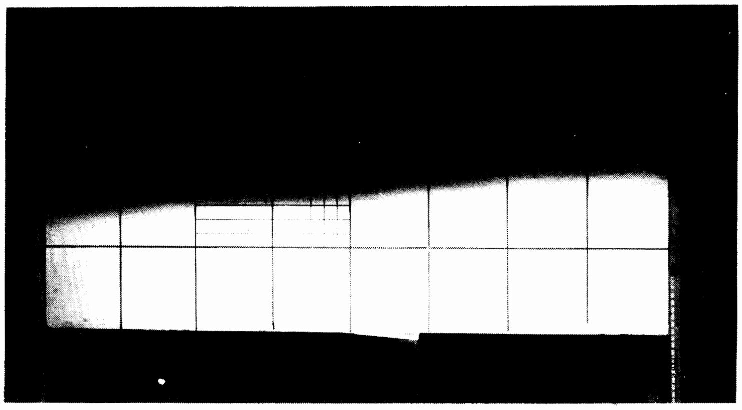
The lack of standardization in physical design of motorcycle headlamps was also found to extend to the beams produced by the lamps. Basically, motorcycle headlamps are designed to produce one of three general low beam patterns. Most U.S. manufactured motorcycle headlamps and some Japanese headlamps produce asymmetric low beams, i.e., the low beam hotspot falls below that of the laterally centered high beam, and is offset 2° to 4° to the right, similar to the pattern produced by a U.S. automotive low beam headlamp (Figure 1, top). Many of the motorcycle headlamps manufactured in Japan produce symmetric low beams, i.e., the low beam hotspot falls below the high beam, but is not offset laterally (Figure 1, center). This has the effect of directing most of the illumination towards the center of the lane rather than towards the right edge of the lane. The third general type of low beam pattern is typical of European design and manufacture and is characterized by a very sharp reduction in intensity above the horizontal axis of the lamp (Figure 1, bottom). This pattern resembles the European style automotive low beam and will be referred to in this report as a sharp cutoff pattern. The low beam hotspot in this design is typically located asymmetrically, as above, in relation to the high beam hotspot.



Asymmetric



Symmetric



Sharp Cutoff

Figure 1. Typical asymmetric, symmetric, and sharp cutoff beam patterns.

Within the three general groupings of lamps by low beam pattern, further differences were found to exist in the exact separation of high and low beam hotspots and in the power requirements of high and low beams (Table 1).

The 11 moped lamps acquired are all single beam lamps, and vary in required power from 6w to 25w (Appendix A). All are apparently intended to be aimed symmetrically with respect to the vertical axis of the lamp.

SUMMARY

The currently existing variability in design is ostensibly attributable to the fact that there are no existing industry or governmental standards regulating the physical design of motorcycle headlamps, and that the current low beam photometric standard (SAE J584) specified in Federal Motor Vehicle Safety Standard 108 requires conformance with a small number of minimum value photometric test points. It would undoubtedly be beneficial to the motorcycle driver if photometric motorcycle headlamp standards were accompanied by dimensional specification standards which might increase the availability of motorcycle headlamps and possibly encourage motorcyclists to replace headlamps with beam outages.

Table 1. Spatial relationship of high and low beams of representative asymmetric, symmetric, and sharp cutoff lamps, and power requirements of high and low beams.

Headlamp Type	Manufacturer and Number	Low Beam Hotspot Location	High Beam/ Low Beam Power
Symmetric	Stanley 1201	6°D, 0°	50w/40w
	Stanley 0730	3.4°D, 0°	35w/25w
	Stanley 24M-S	3.9°D, 0°	50w/35w
	Stanley 0740	4.5°D, 0°	35w/35w
	Stanley 16M-S	3.1°D, 0°	35w/25w
	Koito 31877	2.5°D, 0°	15w/15w
Asymmetric	Koito 4438	3.5°D, 2.8°R	50w/40w
	Guide 4458	2.5°D, 2.5°R	60w/50w
	GE 4020	2.5°D, 2.5°R	30w/30w
	Guide 4431	2.5°D, 2.5°R	50w/40w
	Westinghouse W4 (exp.)	2.0°D, 2.5°R	80w/60w
Sharp Cutoff	CEV-158	5.0°D, 0°	35w/35w
	Lucas MNP-69	4.0°D, 3°R	45w/40w
	Hella H4 (auto.)	1.5°D, 3.5°R	60w/55w
	Cibie 6670062	1.0°D, 2.0°R	60w/55w

IN-SERVICE MOTORCYCLE HEADLAMP AIM SURVEY

OBJECTIVES

To provide an estimate of the range of headlamp aim found in motorcycles in daily operation and to determine if there is any consistent bias in the manner in which motorcyclists aim their headlamps. The effect of the weight of a passenger on headlamp aim was also measured. An interview administered during the study enabled quantification of day-night driving exposure rates, annual driving mileage, operator ages and years of driving experience, and opinions of operators concerning the utility of their headlamp, safe speeds for operation at night, and physical areas in the driving environment of importance for illumination by headlamps. Motorcyclists were also asked if they had aimed their headlamps and if so, what adjustments they had made.

METHOD

TECHNICAL CONSIDERATIONS IN THE MEASUREMENT OF MOTORCYCLE HEADLAMP AIM. Motorcycle headlamp aim is functionally referenced to the direction of travel of the motorcycle (as determined by the longitudinal or tracking axis of the front wheel) and to the height of the headlamp (as determined by the physical location of the headlamp on the motorcycle and the compression of the front and rear suspensions). The H-V axis is thus defined by the intersection of a plane parallel to the road and coincident with the height of the headlamp and a plane perpendicular to the road and coincident with the longitudinal axis of the front wheel at the road surface.

The apparatus described below enables the location of the H-V axis to be determined for a wide range of motorcycle configurations.

APPARATUS. An aiming jig constructed of steel and plywood was fastened to the floor of a flat (slope < .25" in 25') garage area in the HSRI building. This jig enabled rough alignment of the front and rear wheels of a motorcycle with a line perpendicular to and in the center of an aiming board fixed 12 ft. from a reference mark on the jig. The aiming board was marked with a grid of 2° squares (Figure 2). Precise horizontal alignment of the front wheel of the motorcycle was achieved by attaching a headlamp spot aiming device (which produced a collimated beam of light parallel to its longitudinal axis) in a steel channel and attaching it to the front wheel of the motorcycle with rubber shock cords (Figure 3). The horizontal distance from the longitudinal centerline of the front wheel to the center of the spot aiming device was measured, and a reference mark placed on the aiming board at the measured distance from the V line. The driver was instructed to keep the light spot produced by the spot aimer precisely on this mark at all times. A measurement was then made of the headlamp center height and a second reference mark placed on the V line of the aiming board at the appropriate height. Underexposed Polaroid photographs were then taken of the low beam and high beam with driver only, and the high beam with a 180 lb. passenger sitting behind the driver. Underexposure of the film allowed easier determination of the beam hotspot. The driver was instructed to keep his weight on the motorcycle in a manner similar to driving while the photographs were being taken. Aim measurements were then made by locating in the photograph the beam hotspot on the aiming board with reference to the V line and the headlamp height reference mark.

Identified sources of measurement error associated with tha apparatus and procedure are listed in Table 2. From this table it can be seen that consistent measurement bias could be produced only by incorrect calibration of the spot aiming

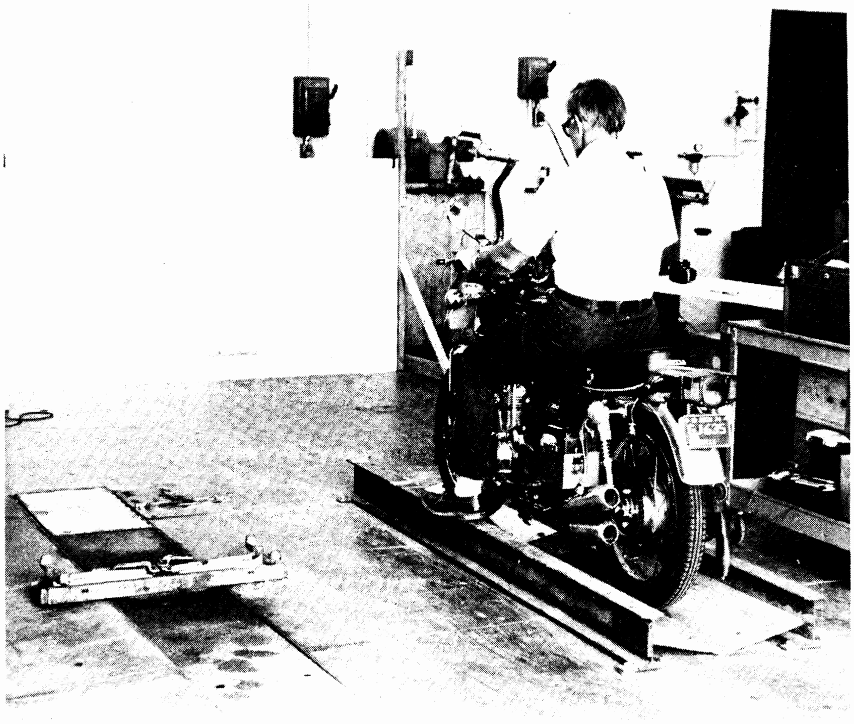


Figure 2. The in-service aim study aiming board and motorcycle alignment jig.

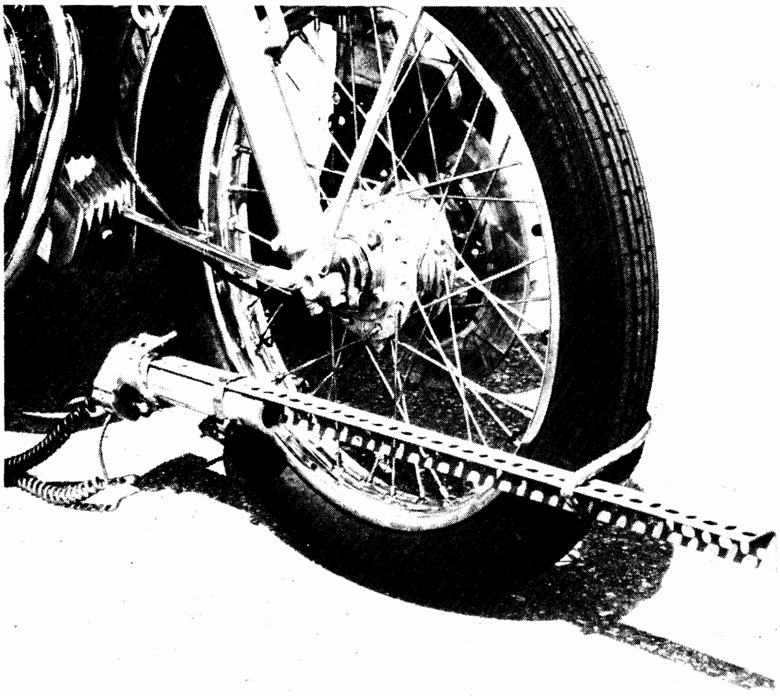


Figure 3. The spot aiming device in position on the front wheel.

Table 2. Potential sources of aim measurement error in the in-service aim survey.

Aiming Plane	Source	Expected Variation	Resultant Measurement Error
Horizontal	Calibration of spot aimer	(Constant ±.1°)	±.1°
	Lean of motorcycle	±5°	±.6°
	Interpretation of photographs	±.25°	±.25°
	Σ of variable sources in worst case		±.85°
Vertical	Front wheel alignment in aiming jig[1]	±.5"	±.1°
	Rear wheel alignment in aiming jig[1]	±.5"	±.1°
	Headlamp height measurement	±.25"	±.1°
	Floor slope determination	(Constant ±.1°)	±.1°
	Headlamp distance from aiming board	± 1"	±.05°[2]
	Interpretation of photographs	± .25°	±.25°
	Σ of variable sources in worst case		±.5°

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[1] These sources are interdependent, i.e., error occurs only when variation of one source is greater than the other.

[2] Resultant error calculated for 5° beam misaim. Error is reduced with reduction of beam misaim.

device and/or incorrect determination of the slope of the floor. Since considerable effort was expended in making this calibration and measurement, consistant measurement error is estimated to be on the order of ± 1/8° both horizontally and vertically. Random sources of error are estimated to sum to introduce possible worst case total errors of ±.85° horizontally and ± .5° vertically. A potential source of error which is difficult to measure and account for and which has not been included in the above analysis is vertical error introduced by suspension compression. Since suspension compression in the dynamic case is a function of motorcycle loading and acceleration and because all motorcycles were subject to the same procedure in this static study, this factor has been disregarded.

SUBJECTS. Initially, subjects were procured by sending HSRI personnel out at night to locate motorcyclists and try to interest them in the program. Flyers describing the program were also left on motorcycles parked in non-residential areas at night. Unfortunately, this procedure generated less than 20 subjects and it soon became apparent that motorcyclists would have to be approached during daylight hours. Flyers were then also distributed at motorcycle dealerships and service garages. A number of subjects were informed of the survey by friends who had participated. In all, 90 subjects participated. A summary of their characteristics in given in Table 3. In brief, the mean subject age was 26 years (S.D. = 8.3), the mean number of years driving experience was 7.25 (S.D. = 7.26), the mean yearly mileage driven was 5700 (S.D. = 3266), and the mean percentage of yearly mileage driven at night was 21% (S.D. = 13.7). Four of the subjects were female. Subjects were paid $5.00 for participating in the survey.

DESIGN. This study enabled determination of the range of headlamp aim of high and low beams, with and without passenger, for motorcycles ostensibly representative of those operated in

Table 3. Characteristics of the subjects participating in the in-service aim study.

Measurement	N	$\bar{X}$	S.D.	Min.	Max.
Age	90	26.3	8.3	16	65
Years experience	90	7.3	7.3	1	45
Yearly mileage	90	5703.0	3266	500	17000
% mileage driven at night	90	21.4	13.7	1	50
% mileage driven with passenger	90	19.3	21.6	0	99
Number of motorcycles owned in life	90	3.8	4.8	1	30
Number of accidents involved in	90	1.0	1.4	0	7

the Ann Arbor, Michigan area. Additional data were acquired concerning the motorcycle operator's age, number of years of driving experience, estimated annual motorcycle driving mileage, night driving frequency, passenger carrying frequency, attempts to aim motorcycle headlamps, and whether or not the headlamp is operated during the day. Motorcyclists' opinions were also solicited concerning the effectiveness of the headlamp in use, maximum safe driving speeds in daylight and when operating at night with high and low beams, and areas of visibility of importance in night driving. The make, displacement, model, year, and indicated mileage of the motorcycle, and the make, model, and replacement history of the headlamp were also recorded.

PROCEDURE. Although an attempt was made to schedule subject's appearances for participation in the survey, a large number simply appeared on the premises and were tested as time permitted.

When subjects arrived at HSRI, they were instructed to drive their motorcycles into the aiming jig and remain on the motorcycle throughout the procedure. While the spot aiming equipment was being attached to the front wheel, the interview was administered. Upon completion of the interview, photographs were taken of high, low, and any auxilliary beams. An additional photograph was taken of the high beam with a 180 lb. experimenter sitting in the passenger's position behind the driver. Subjects were instructed to try to keep their weight on the motorcycle as though it was being driven. When the photography was completed, the subjects were paid and sent on their way. A number of more experienced and knowledgeable subjects were recruited for the operator generated aim study (described later) at this time.

None of the subjects seemed intimidated by the procedure and all appeared very candid in their responses.

IN-SERVICE MOTORCYCLE HEADLAMP AIM. Of the 90 motorcycles examined, 79 were found to have functioning low beams, 83 had functioning high beams and 72 had functioning high and low beams. One motorcycle had no functioning beams and one was equipped with a single beam lamp. In other words, 11 (12%) motorcycles were operating with a low beam outage and six (7%) were operating with a high beam outage, for a total of 16 motorcycles (18%) with at least one outage. This outage rate is more than twice as great as the outage rate of 8% found in random passenger car and motorcycle inspections conducted by the Michigan State Police in 1974 (Michigan State Police, 1975). The effect of a 180 lb. passenger's weight on lamp aim was determined for 76 motorcycles which had at least one functioning beam and were equipped or used for carrying passengers.

Scatter plots of the measured aim in degrees of high and low beams are presented in Figures 4 and 5, respectively. These

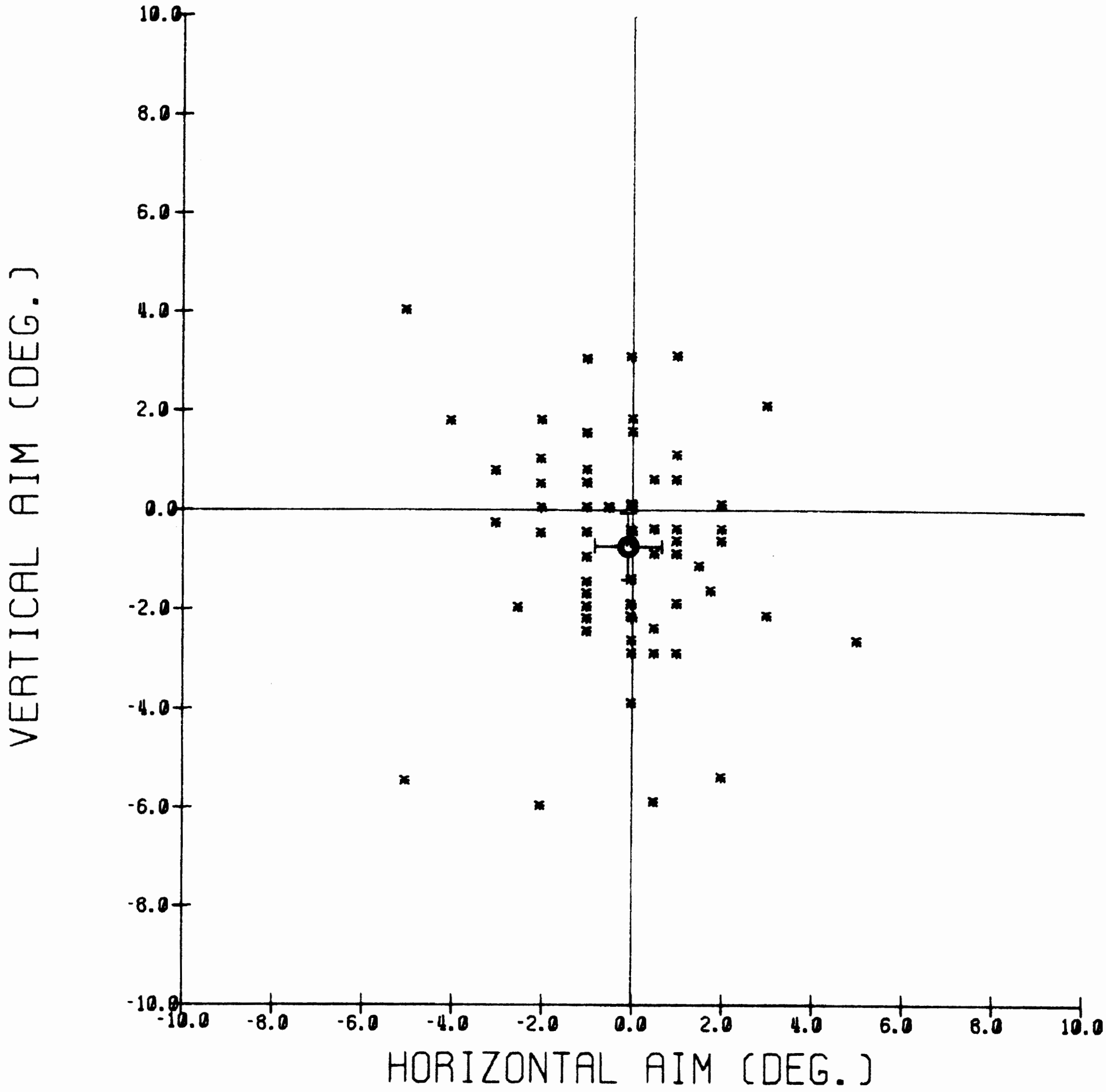


Figure 4. Scatter plot of the high beam headlamp of 83 motorcycles surveyed in the in-service aim study.

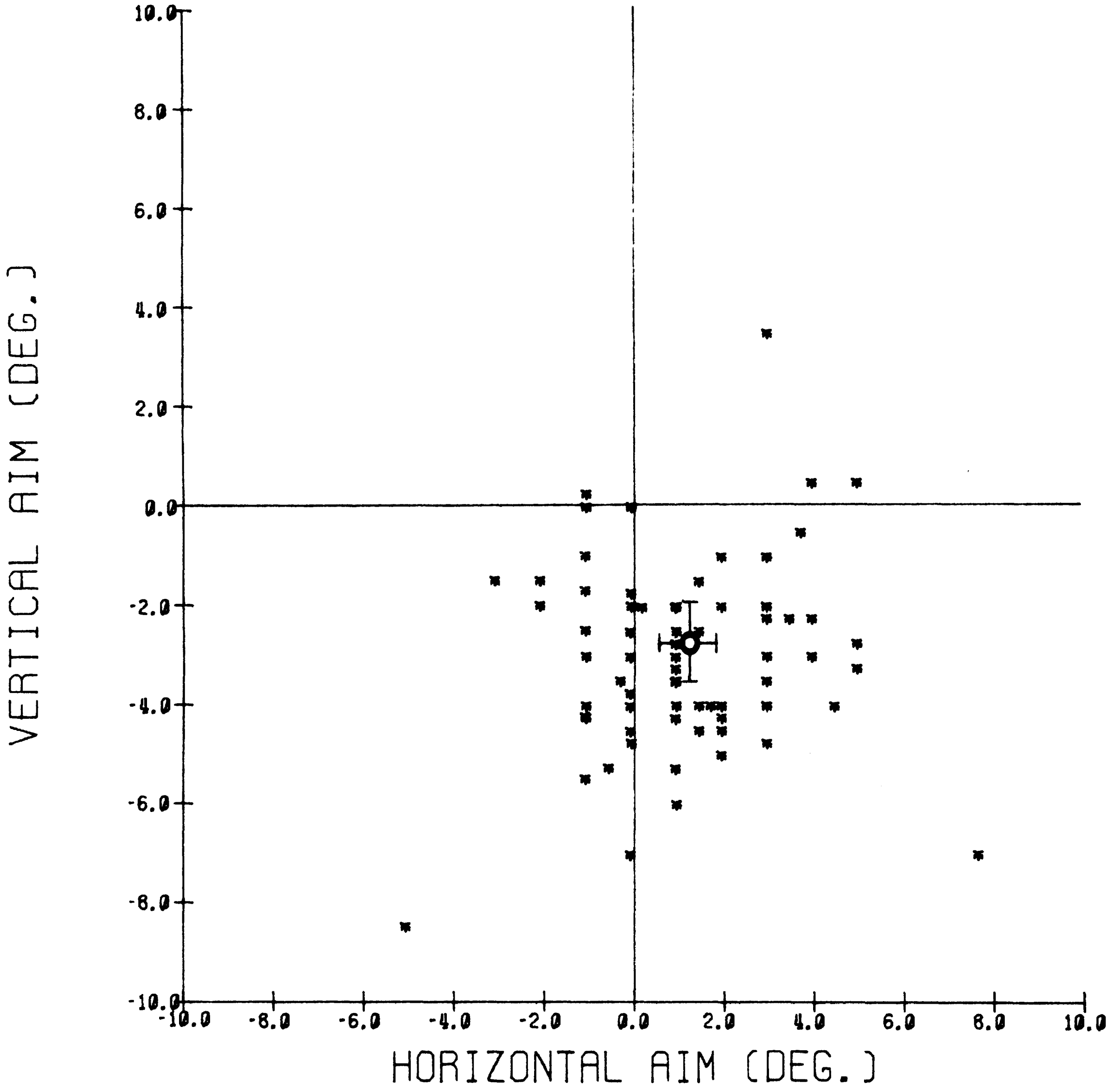


Figure 5. Scatter plot of the low beam headlamp aim of 79 motorcycles surveyed in the in-service aim study.

figures also indicate mean horizontal and vertical aim and the 99% confidence intervals associated with these means.

Visual inspection of Figure 4 indicates no consistent aim bias, as the mean high beam aim (.1° left (L), .7° down (D)) is quite close to the SAE recommended standard of 0° horizontal, .4°D vertical aim. The dispersion of aim about this point, however, is substantial, with the standard deviation (SD) of vertical aim (SD = 1.9°) slightly greater than that of horizontal aim (SD = 1.6°).

The scatter plot of low beam aim (Figure 5) again shows considerable horizontal ($\bar{X}$ = 1.3°R, SD = 2.0°) and vertical ($\bar{X}$ = 2.7°D, SD = 2.5°) dispersion. However much of this variation is attributable to rather large variations in the design characteristics of the lamps. Figure 6 shows the variation in low beam aim attributable to design and production differences. In this figure, high beam aim has been referenced to the SAE norm of .4°D, 0° horizontal by subtracting from the respective low beam aims, the difference between measured high beam aim and the SAE standard; i.e., this figure shows how the low beams would have been aimed had the high beams all been set to SAE specifications. It can be seen from this figure that high and low beam hotspots vary -.5° to 4° horizontally and 0° to 4.75° vertically.

To further examine possible systematic aim bias, the aim data were grouped on the basis of low beam symmetry. Twenty-six lamps were classified as symmetric (high beam horizontal aim (HH) - low beam horizontal aim (LH) = ±.5°) and 32 lamps were classified as asymmetric (HH - LH = 1.5° to 3.0°). The remaining 15 dual beam lamps were omitted. Figures 7 and 8 respectively illustrate scatter plots of the high and low beam aim of the 26 symmetric lamps. The mean symmetric high beam aim was found to be .5°L (SD = 1.34°), .5°D (SD = 1.98°) and mean low beam aim was found to be .4°L (SD = 1.43°), 3.4°D (SD = 2.1°).

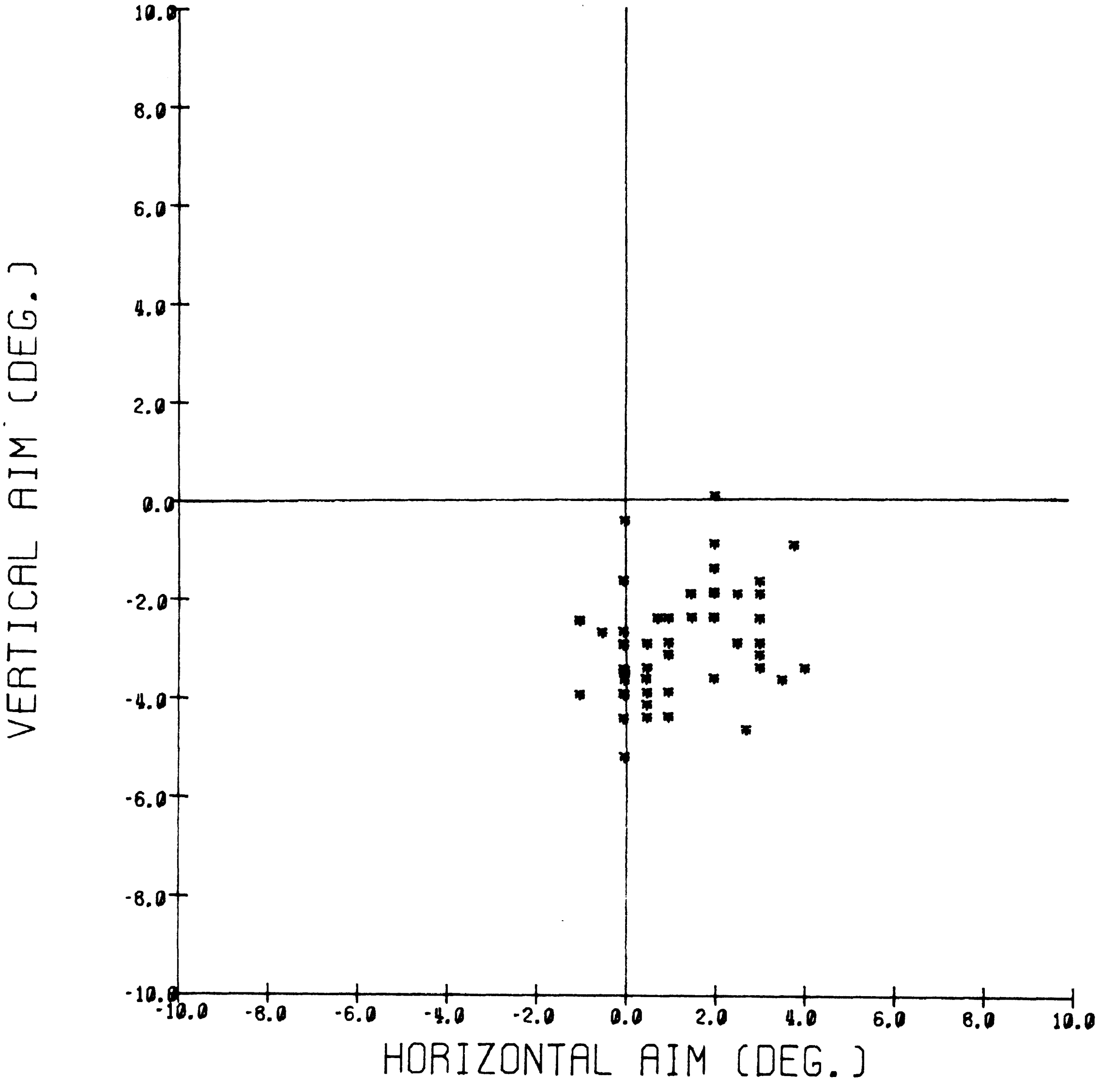


Figure 6. Scatter plot of the low beam headlamp aim of 72 motorcycles surveyed in the in-service aim study, referenced to SAE recommended high beam aim.

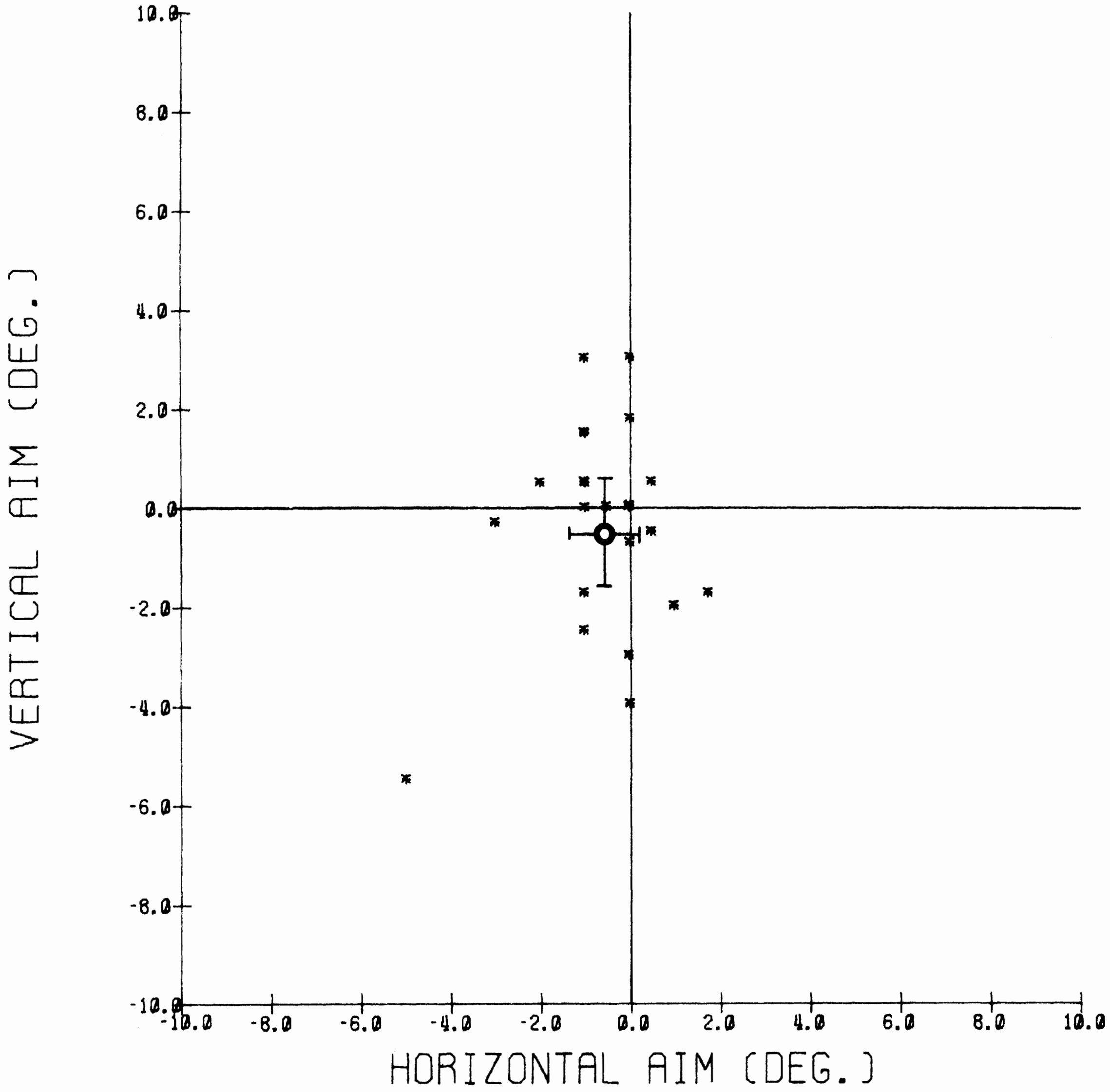


Figure 7. Scatter plot of the high beam headlamp aim of 26 symmetric motorcycle headlamps surveyed in the in-service aim study.

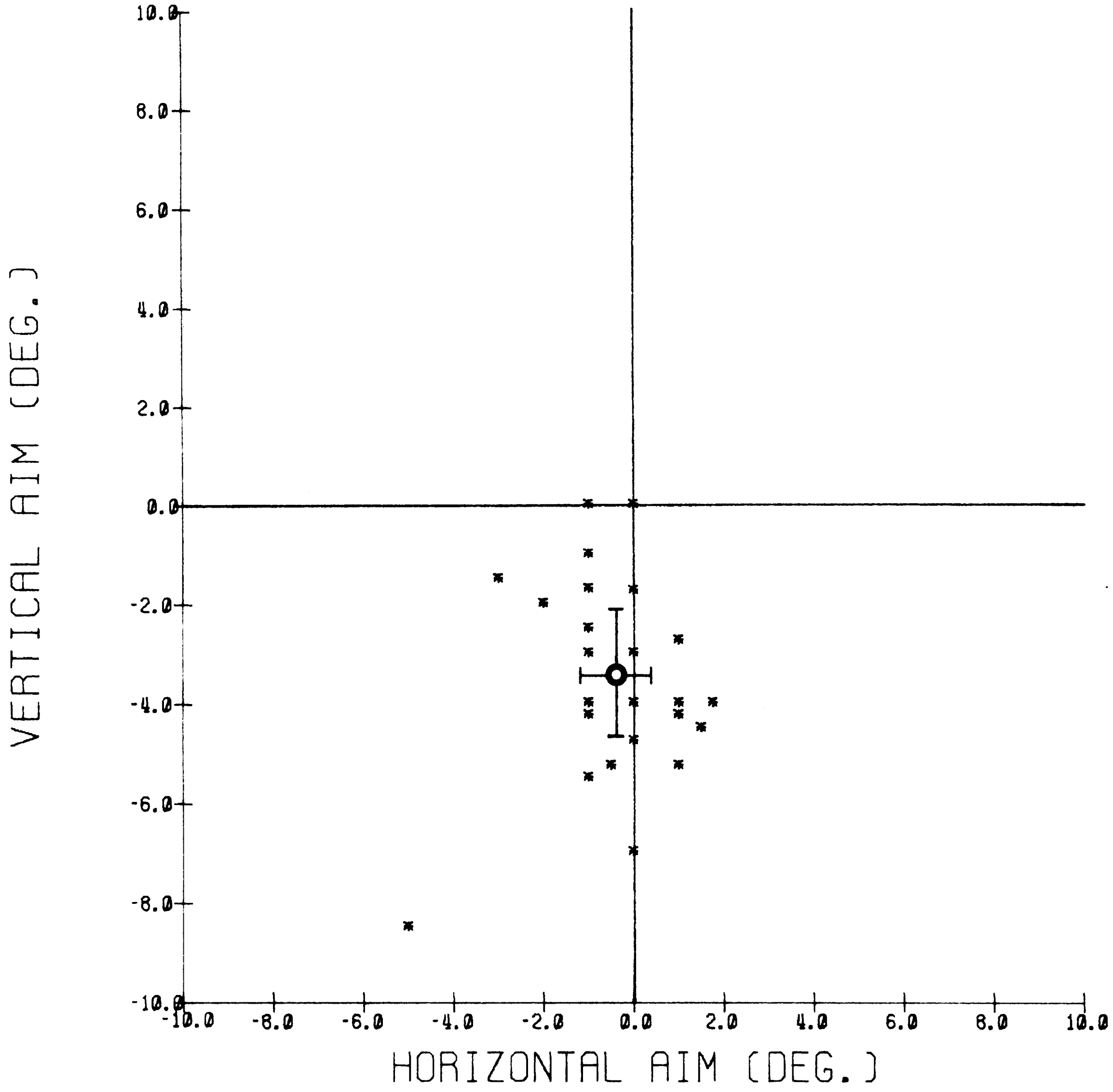


Figure 8. Scatter plot of the low beam headlamp aim of 26 symmetric motorcycle headlamps surveyed in the in-service aim study.

Scatter plots of the high and low beam aim of the 32 asymmetric lamps are shown in Figures 9 and 10, respectively. Mean high beam aim of these lamps was found to be .5°R (SD = 5.3°), .9°D (SD = 1.33°), and mean low beam aim was found to be 2.8°R (SD = 1.55°), 2.8°D (SD = 1.78°).

There is thus no indication that motorcyclists on the whole intentionally misaim their headlamps to either direct their symmetric beams to the right or their asymmetric beams to the left.

The effect of the weight of a 180 lb. passenger on the vertical aim of 76 beams is shown in a histogram in Figure 11. Increases varied from 0° to 1.5° with a mean of .8° (SD = 33°). In over half (56%) of the cases, aim was raised by at least 1°.

CHARACTERISTICS OF THE MOTORCYCLES AND HEADLAMPS SAMPLED. Figures 1b-5b in Appendix B depict histograms and bar graphs showing distributions of motorcycle manufacturer (Figure 1b), model year (Figure 2b), total odometer mileage (3b), engine displacement (Figure 4b), and headlamp manufacturer (Figure 5b).

Japanese motorcycles accounted for 82% of those surveyed with Honda (37%), Yamaha (20%), Kawasaki (12%), and Suzuki (11%) representing 80% of the total. A relatively large number of BMW motorcycles (9%) were included in the survey. At least 10 headlamp manufacturers were represented with Japanese manufacturers (Koito = 40%, Stanley = 30%) accounting for 70% of the total. No other manufacturer accounted for as much as 10%. Non-OEM replacement headlamps (11% of the total) included in U.S. automobile headlamps (6%), quartz-halogen lamps (3%), one non-halogen European type lamp (1%) and one U.S. manufactured motorcycle headlamp (1%).

A majority of the motorcycles surveyed (85%) had engine displacements of 200 cc's or greater and were manufactured in 1970 or later model years (87%). The mean indicated odometer

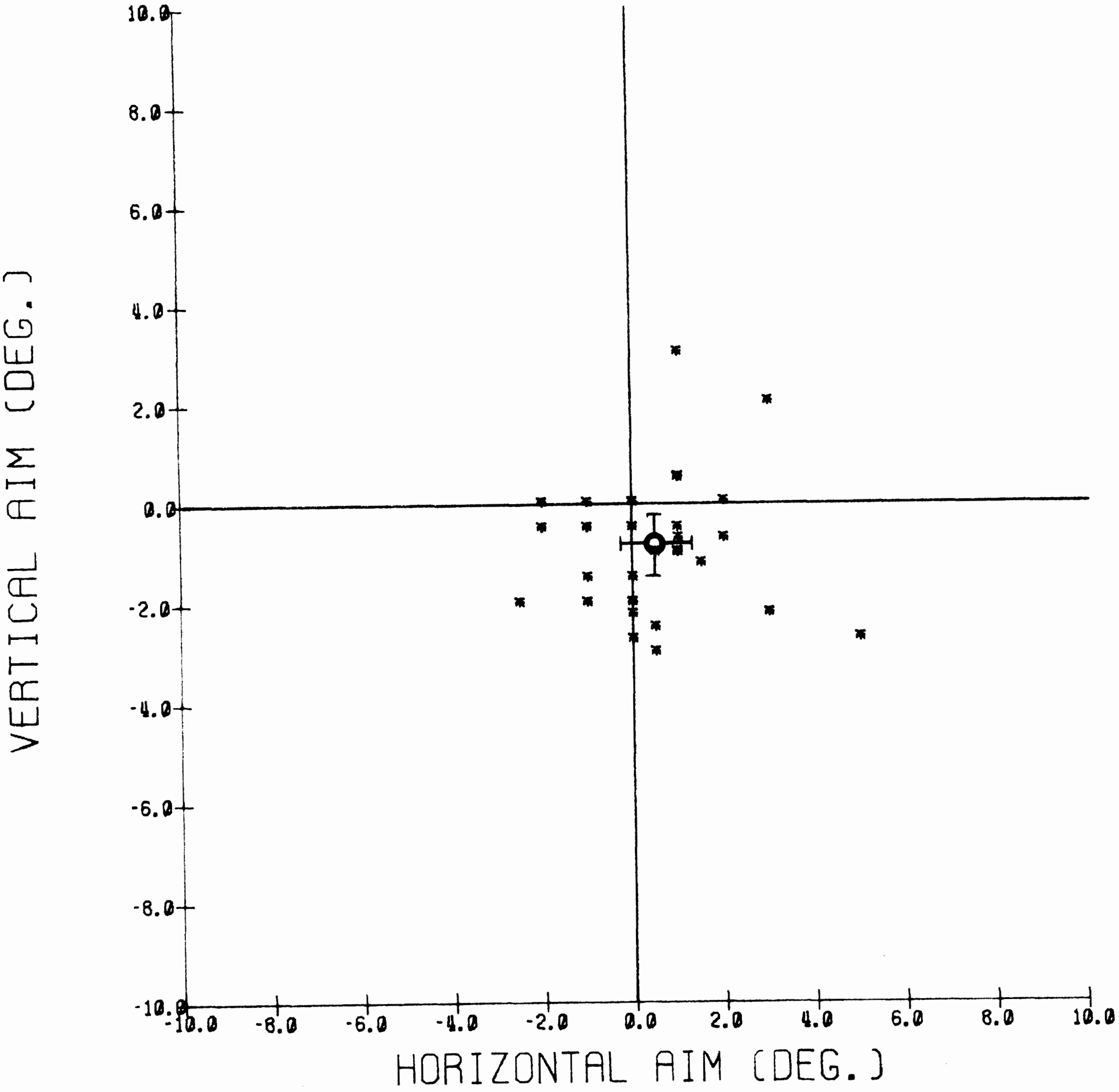


Figure 9. Scatter plot of the high beam headlamp aim of 32 asymmetric motorcycle headlamps surveyed in the in-service aim study.

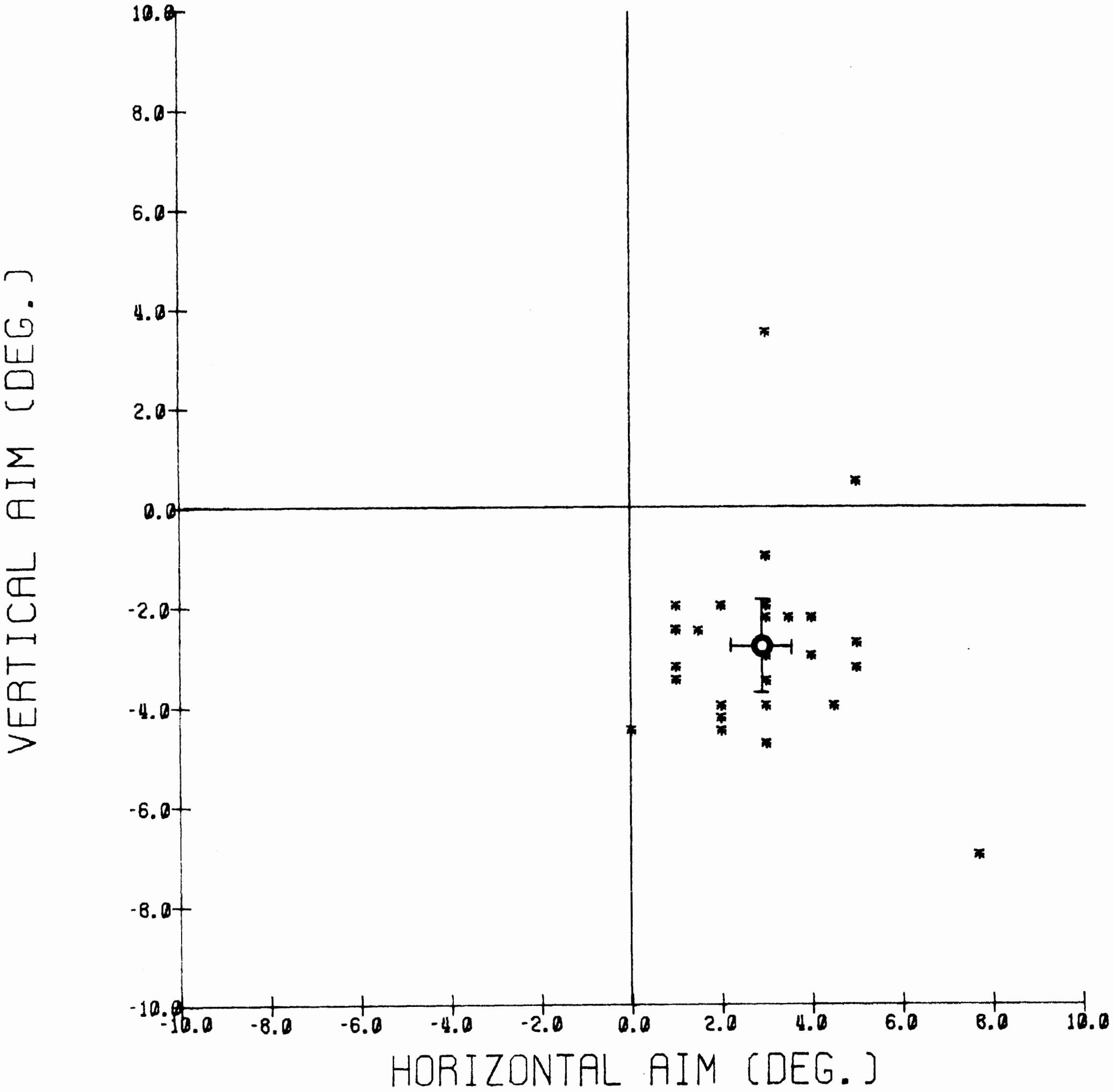


Figure 10. Scatter plot of the low beam headlamp aim of 32 asymmetric motorcycle headlamps surveyed in the in-service aim study.

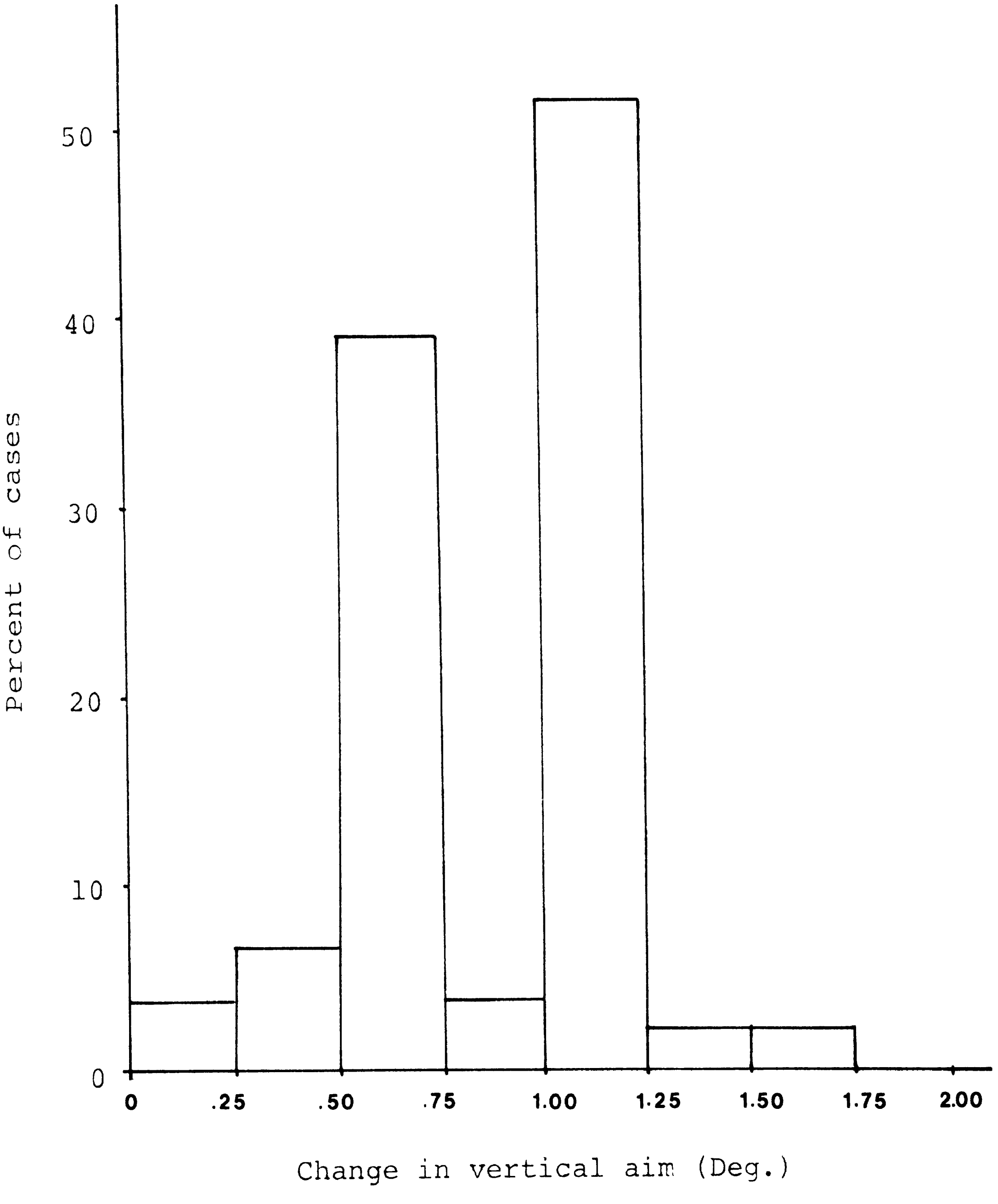


Figure 11. Percentage distribution of vertical headlamp aim change attributable to the weight of a 180 lb. passenger.

mileage was 8783 miles (SD = 9421).

PERCEIVED EFFECTIVENESS OF MOTORCYCLE HEADLAMPS. Each subject participating in the survey was asked if the headlamp in use was effective at night, or if it had deficiencies in terms of either beam pattern or intensity. A majority (60%) of the subjects felt that their headlamp was effective for their purposes. The remaining 40% were mainly concerned with inadequate intensity but mentioned intensity in conjunction with poor beam shape (usually too narrow) in 19% of the cases. Several subjects reported that the relationship between high and low beams was bad because the vertical separation was too great.

In Table 4 the lamps rated not effective for any and all reasons are listed by the displacement of the motorcycle on which they were found. Comparisons made among these data are

Table 4. Frequency of headlamps rated "not effective" by motorcycle engine displacement.

Displacement Category	N	Number Rated "Not Effective"	% Rated "Not Effective
< 100cc	3	3	100%
100 - 199cc	10	5	50
200 - 299	8	3	38
300 - 399	17	5	29
400 - 499	7	4	57
500 - 599	11	4	36
600 - 699	9	6	67
700 - 799	16	5	31
> 800cc	9	1	11
Σ	90	36	40%

tenuous because of the low frequencies per group and the lack of knowledge of several pertinent factors such as the actual operating voltage of the headlamp, but it can be readily seen that no overall trend is evident except possibly that headlamps associated with smaller displacement motorcycles (<200 cc's) are more frequently rated "not effective" than are the headlamps associated with the larger displacement motorcycles.

Another subjective measure of headlamp effectiveness is illustrated by Figure 12 which shows cumulative percentage distributions of estimated "maximum safe speeds" for daylight driving and nighttime driving on low and high beams, under good road and traffic conditions. The 50th percentile maximum safe speeds for low beam, high beam, and daylight driving are 52, 61, and 74 mph, respectively. From these data it can be inferred that the current speed limit of 55 mph is regarded a safe maximum by 90% of the subjects for daylight driving, 70% for nighttime driving on high beam, and only 40% for nighttime driving on low beam.

AIM MAINTENANCE AND DRIVING BEHAVIOR. Subjects were also asked if they had ever aimed their headlamp to achieve or maintain better nighttime visibility. A large percentage (77%) replied affirmatively and a number of these subjects reported that they vertically aim their headlamp quite frequently, depending on the type of road, passenger loading, and amount of fixed illumination present. Several subjects reported that they leave the headlamp bucket mounting bolts somewhat loose to make vertical aim easier to adjust.

Since motorcycles can be driven within a wide range of lateral positions within a traffic lane and since the lateral position assumed has a direct relationship to the illumination provided by the headlamp on the road, subjects were also asked what lane position they characteristically assume or prefer. Positions to the left of the lane center, in the center, and

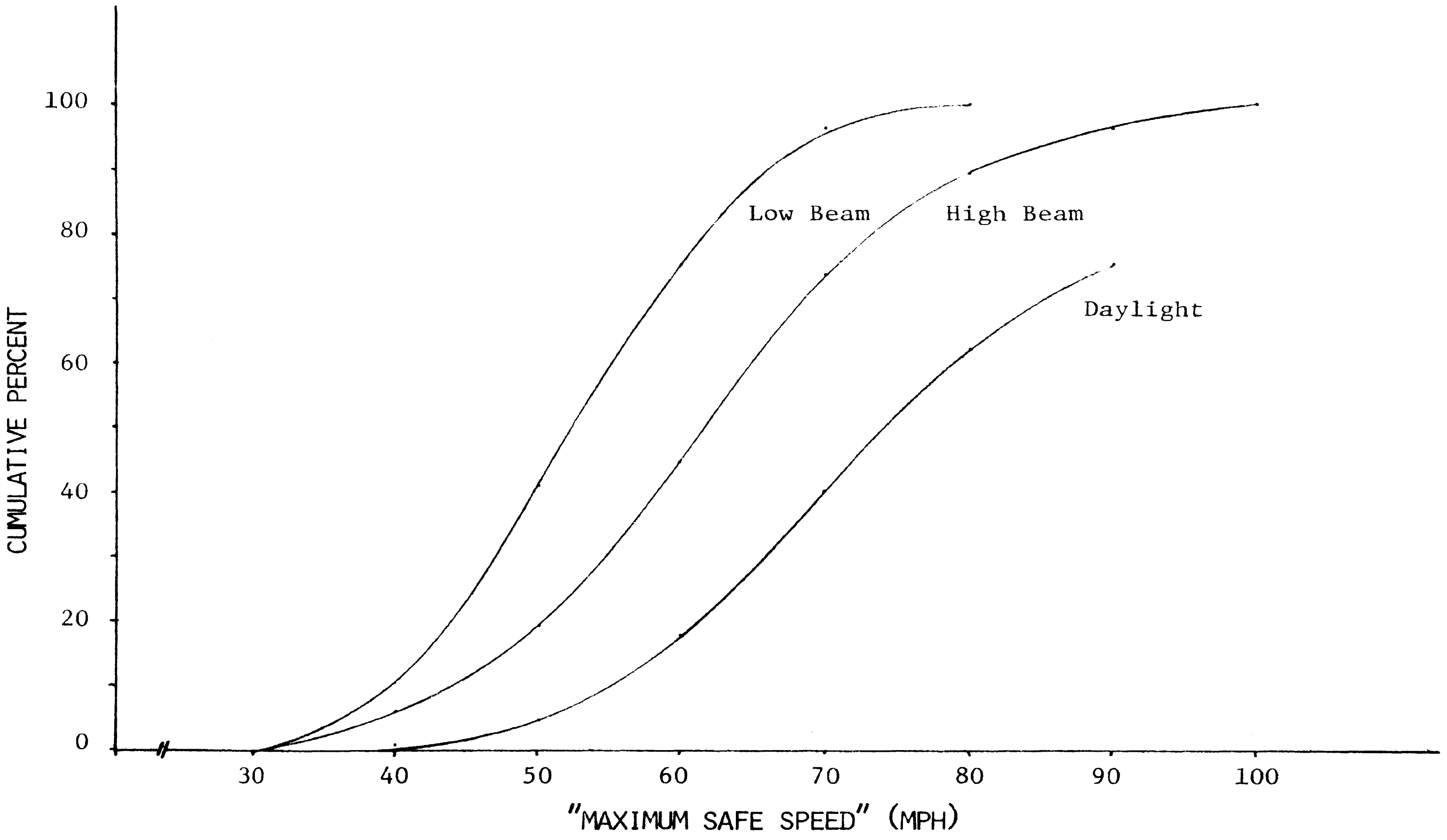


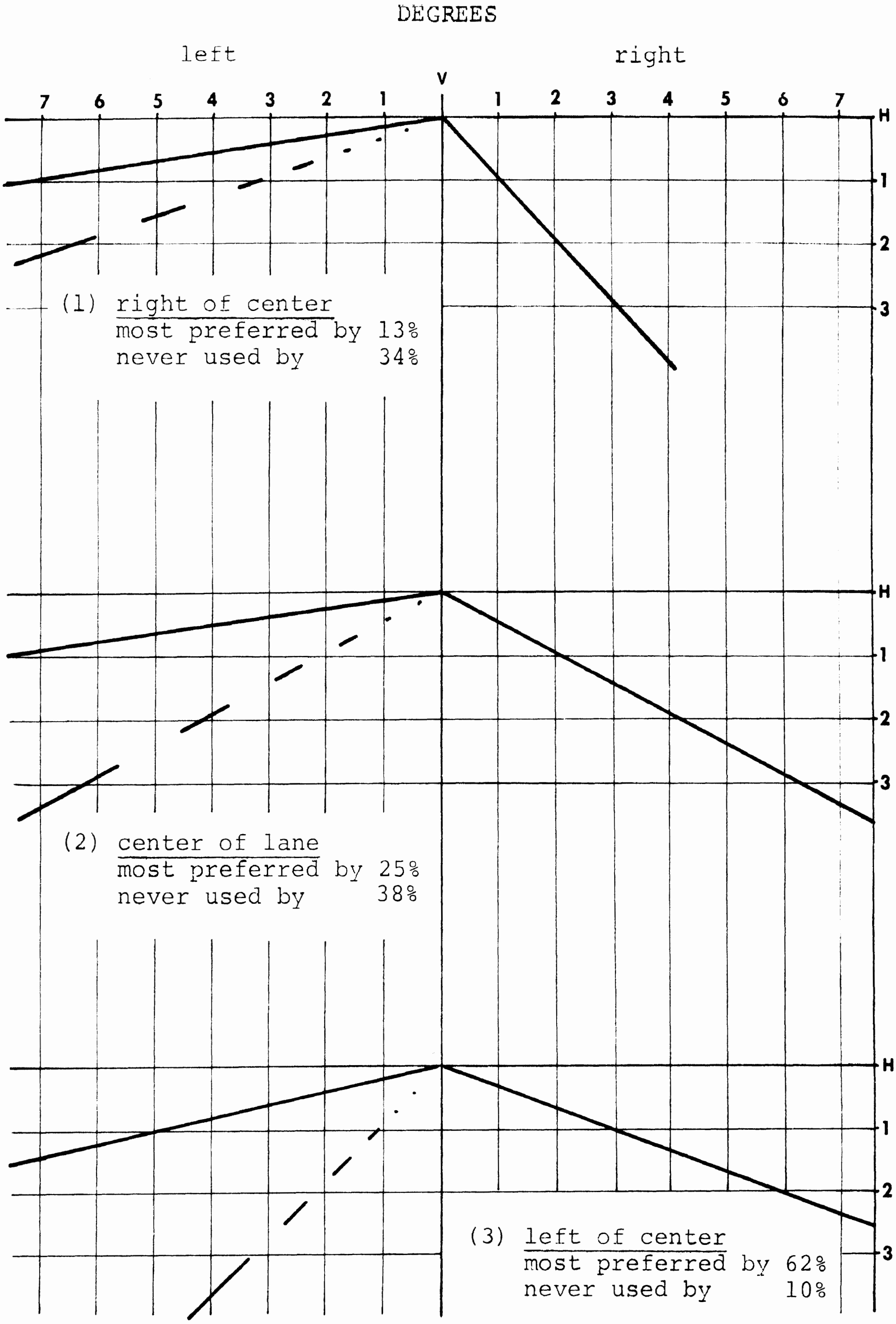
Figure 12. Cumulative percentage distribution of "maximum safe speeds" for driving (1) in daylight; (2) at night on high beam; and (3) at night on low beam, according to the 90 subject in the in-service aim study.

to the right of center were the preferred choices of 62%, 25%, and 13% of the subjects, respectively. Ten percent, 38% and 34% of the subjects reported that they never assume positions to the left, center and right of the lane, respectively. Figure 13 illustrates perspective views of a straight two lane, 24' wide road from these three vantage points from a typical motorcycle headlamp height of 34". It is quite evident that a given headlamp in a fixed position will provide different amounts of illumination on specific areas of the road surface depending on the position assumed in the lane. This fact may have meaningful implications for the development of an improved headlamp beam pattern.

Other driving habits of the 90 subjects are shown as cumulative percentage distributions in Figures 6b (estimated yearly motorcycle driving mileage), 7b (percentage of yearly mileage driven with passenger), and 8b (percentage of yearly mileage driven at night) in Appendix B. The 50th percentiles of these distributions show the average yearly mileage to be 5700 miles, 21% of which on average was driven at night and 14% of which on average was driven with a passenger. The actual percentage of mileage driven with the headlamp in operation, however, is undoubtedly greater than the average of 21% driven at night, as 69% of the subjects reported continuous daytime use of the headlamp to increase conspicuity.

SUMMARY AND CONCLUSIONS

The headlamp aim of the 90 in-service motorcycles examined in this study was found to be highly variable, both because of physical misaim and because of variation in the design and apparently production of the headlamps represented. The standard deviation of high beam headlamp aim is nearly twice that found in a population of automobiles (Table 5), even though 77% of the participating motorcyclists reported that they had aimed their lamps to improve or maintain nighttime visibility.



(1) right of center
most preferred by 13%
never used by 34%

(2) center of lane
most preferred by 25%
never used by 38%

(3) left of center
most preferred by 62%
never used by 10%

Figure 13. Perspective illustrations of a straight, two-lane, 24 ft. wide road from a height of 34 in., from positions: (1) to the right of center, (2) in the center, and (3) to the left of center of the right hand traffic lane.

Table 5. Comparison of standard deviations (in degrees) of headlamp aim of automobiles[1] and motorcycles in service.

	AUTOMOBILES		MOTORCYCLES
	(5-3/4" Lamps)	(7" Lamps)	(All Lamps)
Vertical Aim	.80°	.69°	1.9°
Horizontal Aim	.86°	.99°	1.6°
N	33		82

[1] Automobile headlamp aim data from Olson and Mortimer (1973).

There was no indication of consistent bias in the aim data which suggested that either symmetric or asymmetric beam relationships were favored or disfavored, as the mean high beam aim of 32 asymmetrically patterned lamps (which bias low beam illumination toward the right) was directed slightly toward the right, and mean high beam of 26 symmetrically patterned lamps (which project low beam illumination straight ahead) was directed slightly toward the left.

Passenger loading was found to raise vertical headlamp aim an average of .8° and as much as 1.5°. Although the loading weight used in this study (180 lbs.) probably represents the upper end of the passenger weight distribution, uncorrected vertical misaim due to passenger loading could significantly alter the driver's nighttime visibility distance and could potentially impair the visibility of oncoming drivers. because of increased glare.

A large percentage (18%) of the motorcycles examined were found to have at least one filament outage. This problem is quite serious because of the lack of redundancy should the remaining filament fail during nighttime operation.

Finally, although 60% of the participating motorcyclists reported that their headlamps provided adequate illumination, only 40% reported that the current speed limit of 55 mph was a safe speed for nighttime driving on low beam.

These findings indicate that while most motorcyclists (77%) are concerned with the aim of their headlamps and have attempted to change or maintain aim, they cannot perform the task accurately, as indicated by the variance found in the distribution of aims. It may thus be desirable to design and implement an improved aiming/mounting technique which would allow rapid adjustment of headlamp aim, but would be resistant to accidental or inadvertant misaim. It may be possible, for instance, to provide a factory calibrated indicator system which would provide a visual indication of radical vertical misaim to the driver. In any case, even a photometrically optimum beam pattern will be dependent upon proper aim for its possible benefits to be realized.

A number of approaches to solution of the problem of motorcyclists driving at night with a beam outage are available. It may be possible to motivate drivers to replace defective headlamps by more stringently enforcing traffic codes prohibiting the operation of motorcycles with defective lighting systems, and by standardizing physical designs of headlamps to hopefully make them more readily available and less expensive. Outage rates could also be reduced in some cases by improving lamps or lamp mounting designs to increase expected life and by insuring that motorcycle electrical systems are well regulated and do not allow lamp design voltages to be exceded.

SURVEY OF MOTORCYCLE MANUFACTURERS' HEADLAMP DESIGN AND SELECTION PROCEDURES

OBJECTIVES

Given the wide range of motorcycle headlamp configurations currently in production, it was felt to be valuable to determine the procedures used by motorcycle manufacturers to design and/ or select headlamps for use on production motorcycles.

METHOD

Letters of inquiry concerning the criteria used by manufacturers to design or select headlamps were sent to representatives of each of the major motorcycle manufacturers. These letters outlined the intent of the research program, noted the wide range of headlamps with differing beam patterns, power requirements, etc. currently in production, and asked what logic was used in the selection of headlamps for use on production motorcycles. Manfacturers were informed that their replies would be reported anonymously. Unfortunately, only two manufacturers responded. Their paraphrased replies are shown below.

RESPONSE 1. Our manufacturing and research facilities are in close proximity to those of a major electrical equipment supplier who provides us with lighting equipment which they insure is to the particular legislative requirement for the country of destination. Our experimental department works with this firm's development department in the development and testing of any new electrical products.

RESPONSE 2. We take the following factors into account:

(1) Results of human-panel lighting evaluation.

(2) On-vehicle rider reaction.

(3) Candela diagrams provided both by lamp manufacturers and outside testing laboratories.

(4) Results of on-vehicle lamp-life testing.

(5) Cost benefit analysis of proposed lighting and required electrical support system.

(6) Field feedback on existing systems.

(7) Styling considerations.

We place a heavy emphasis upon lamp durability and have developed well regulated electrical systems accordingly. We feel that the lack of redundancy in motorcycle headlighting systems creates a hazardous situation when one filament is out and we therefore have some bias toward reliability in a reliability vs. light output tradeoff. We feel that in-service life is an important factor and should be addressed by future lighting standards.

DISCUSSION

Because of the lack of response in this survey, little can be said about general industry practices. It is of some value to know, however, that at least one manufacturer is concerned with headlamp service life and the problem of motorcycles operating with filament outages. The extent to which some logic governs the selection of specific beam patterns is still unknown. It would appear that beam pattern selection is most heavily dependent upon the subjective impression of the particular engineering staff involved and the general availability of headlamps from headlamp suppliers. The beam patterns of headlamps supplied as original equipment on motorcycles appear to be most directly a function of the country of origin; i.e., most American-made and some Japanese-made motorcycle headlamps produce asymmetric low beam patterns similar to American automotive headlamps; most European-made motorcycle headlamps produce sharp cutoff low beam patterns similar to European automotive headlamps; and many Japanese manufactured headlamps produce symmetric low beam patterns which are unlike any currently used automotive headlamps.

The symmetric design is the most innovative since it is apparently unique to motorcycles. Unfortunately, no explanation of why it was developed is available.

STUDIES CONDUCTED TO IDENTIFY THE VISIBILITY REQUIREMENTS OF MOTORCYCLE OPERATORS

EYE FIXATION EXPERIMENT

OBJECTIVE

The eye fixations of two motorcyclists were recorded while driving a motorcycle on two lane roads during daylight, in order to obtain an indication of the areas in the visual field which are of importance for that driving task. Additional measurements were made for the same two motorcyclists when operating an automobile on the same roads to determine if fixation patterns differ between the two driving tasks.

METHOD

SUBJECTS. Two males, aged 21 and 28 years, were used in this study. Neither subject had prior experience with the Eye Marker, and a number of practice runs were made for this reason. The younger subject had accumulated about 7000 miles of accident-free driving on motorcycles over a period of seven years and primarily used a 125 cc cycle. The older subject had accumulated about 100,000 miles on motorcycles over a period of eight years. His 600 cc BMW motorcycle was used for this study.

APPARATUS. A portable videotape recorder was strapped to the gas tank of the motorcycle to record the video and audio data. The controls for the intensity of the lamp illuminating the cornea, and for the horizontal and vertical remote calibration of the eye fixation spot, were attached on top of the recorder. Two additional 12-volt motorcycle batteries provided power for the recorder and eye spot lamp (Figure 14). Over the Eye Marker the motorcyclist wore a helmet, modified to accept the Eye Marker under it (Figure 15). The experimenter rode as a passenger on the motorcycle holding a small television monitor in his right hand so that the road scene, focus of the eye spot and the calibration could be

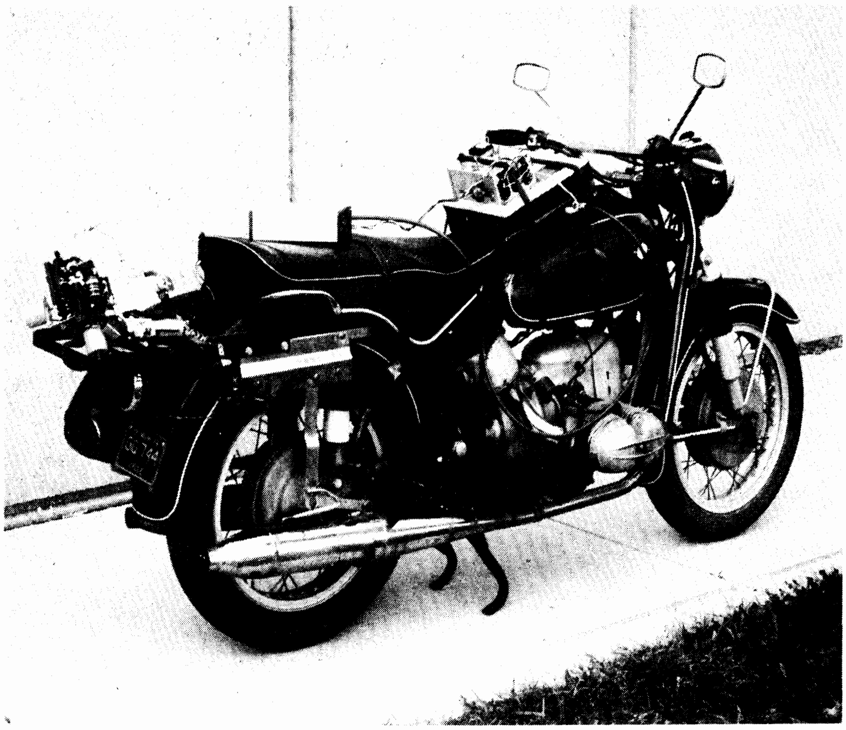


Figure 14. The motorcycle with eye mark recorder controls and video recorder.

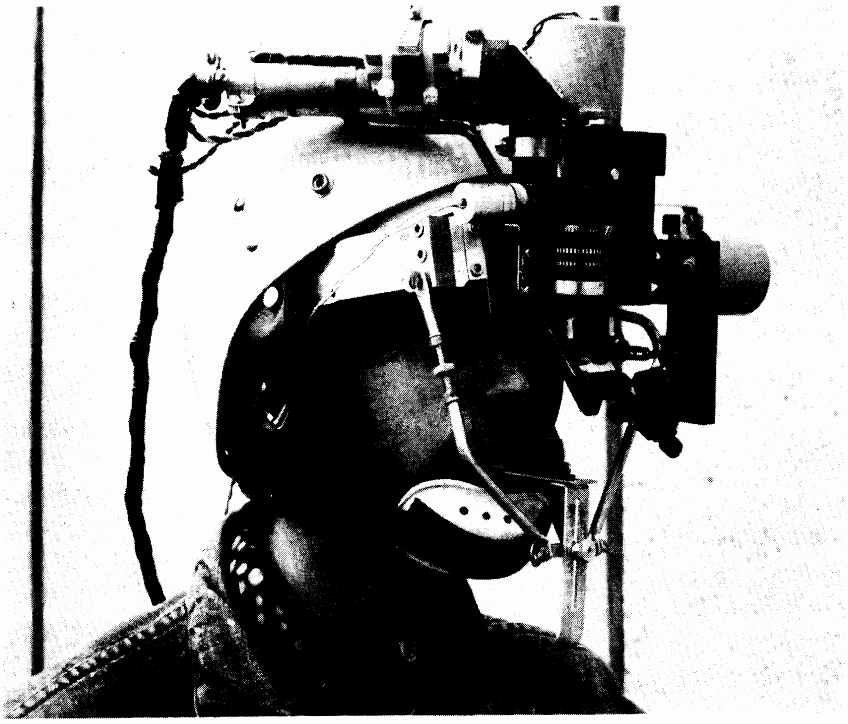


Figure 15. The eye mark recorder worn by a motorcyclist.

continuously monitored (Figure 16). The experimentor could adjust the eye spot lamp intensity, calibration, and focus, as well as turn the recorder off and on without the need to stop the motorcycle. For the tests conducted in the automobile, the experimenter and the equipment were in the back seat, as was done in previous tests (Mortimer and Jorgeson, 1972: 1974) illustrated in Figure 17.

DATA COLLECTION PROCEDURE. An automobile containing the equipment and the motorcycle were driven to the test site. This consisted of two sections of two-lane rural roads, one with edgeline delineation and one without. Each road was relatively flat, but contained straight and curved sections. The equipment was left in the car or mounted on the motorcycle, the Eye Marker was positioned on the driver's head and calibrated, and the driving task began. The subjects were instructed to drive at approximately 45 mph. Runs were made on several days until enough data were obtained to satisfy the requirements of the analyses to be made.

DATA REDUCTION PROCEDURE. In analyzing the videotapes an overlay was placed over the TV monitor which divided the image of the roadway scene into three vertical sections of 100-250 feet, 250-500 feet, and > 500 feet down the road. The scene was also divided into three lateral sections of 0-5° right of the driver's forward line of sight, 0-5° left, and 5-10° left. The matrix of these azimuth distance sections provided nine areas of viewing. All blinks and glances outside these areas were accumulated in an out-of-view category. During a second viewing of the videotapes, the roadway scene was divided into ten object categories and the eye fixations classified according to whether they were: off the road to the left, in the left lane looking at an opposing vehicle, in the left lane not looking at an opposing vehicle, center line, straight ahead in the lane, right edge, off the road to the right, mirrors, dash and interior of the car, and blinks and out-of-view.

Figure 16. An eye mark test subject and experimenter with video monitor.

Figure 17. The eye mark recorder as used in an automobile.

The data reduction was accomplished in the laboratory by continuously viewing the position of the point of regard on the monitor, shown by a spot of light, determining which one of the ten categories was applicable, and holding down a switch on a keyboard containing ten push-button switches, for the time duration with which the eye spot was in a specific category. This resulted in the continuous accumulation of data in terms of time of an eye fixation within a specified category, and the frequency of eye fixations within each category. These data were subsequently analyzed for each of the dependent variables of interest.

DEPENDENT VARIABLES. The dependent variables were the percent duration, percent frequency, and the mean duration of eye fixations in each of the ten azimuth-distance zones and in each of the ten categories of objects described above.

RESULTS

The mean duration of eye fixations of these drivers was greater when they were operating a motorcycle than an automobile, when looking in the lane straight ahead of them. For example, Table 6 shows that on left curves the mean duration of eye fixations in the lane was 1.08 seconds and 0.51 seconds, respectively, when operating the motorcycle and automobile. Analogous findings were obtained on the straight sections and right curves.

Table 6. Mean Durations (Seconds) of Eye Fixations Straight Ahead in the Lane in Motorcycle and Car Driving, Without Oncoming Vehicles.

Road Geometry	Motorcycle	Car
Left curve	1.08	0.51
Straight	1.18	0.77
Right curve	2.04	1.45

Evaluation of the percent frequency of eye fixations in azimuth and preview distance, averaged over curved and straight sections of road, showed that there were some significant differences between the subjects operating the motorcycle and the automobile, and when there was an oncoming vehicle compared with a situation when there was no oncoming vehicle.

Table 7 shows that the lateral distribution of eye fixations is more to the right for the motorcycle riders than for those same subjects operating an automobile, when there is no opposing traffic. When there is an opposing vehicle, the distributions, in azimuth, are similar for motorcycle and car driving. But, in both, there is a shift of the eye fixations to the left - in the direction of the oncoming vehicle.

Table 7. Percent Frequencies of Eye Fixations by Azimuth with and without Oncoming Vehicles for Motorcycle and Car Driving*

	Azimuth		
	10°L-5°L	5°1-0°	0°-5°R
Without Oncoming Vehicle			
Motorcycle	6.4	24.2	69.4
Car	12.0	31.7	56.3
With Oncoming Vehicle			
Motorcycle	14.4	36.9	48.7
Car	11.9	42.5	45.6

---

*Averaged over curved and straight road sections.

Table 8 shows the percent frequency of eye fixations in terms of the preview distance ahead of the vehicle, with and without opposing vehicles. Without opposing vehicles, the motorcycle riders looked more frequently closer to the vehicle than the car drivers. For example, 14.1% of the eye fixations were between 30-76m (100-250 ft.) in front of the motorcycle, compared to 7.7% ahead of the automobile. When there was an oncoming vehicle, the motorcycle riders slightly increased their median preview distances, although examination of Table 7 shows that this was due to looking at the opposing vehicle. In spite of this phenomenon, 11.8% of the eye fixations were in the range of 30-76m (100-250 ft.) ahead of the motorcycle. When driving the automobile and meeting an oncoming vehicle, the preview distances were reduced compared to the case where there was no oncoming vehicle, and were more like those used when riding the motorcycle.

Table 8. Percent Frequencies of Eye Fixations by Preview Distance With and Without Oncoming Vehicles for Motorcycle and Car Driving*

	Preview Distance, Feet			
	100-250	250-500	500	Median
Without Oncoming Vehicle				
Motorcycle	14.1	54.5	31.4	415
Car	7.7	49.5	42.8	463
With Oncoming Vehicle				
Motorcycle	11.8	55.2	33.0	423
Car	7.5	62.7	29.8	419

---

*Averaged over curved and straight road sections.

Table 9 shows that there was a large effect on the lateral distributions of eye fixations due to road geometry, which are shifted in the direction of the curve. But, in each case, the motorcycle riders viewed to the right of the field-of-view directly ahead of them more than when driving the car.

Table 9. Percent Duration of Eye Fixations by Azimuth Without Oncoming Vehicles for Motorcycle and Car Driving on Curves and Straight Sections of Road.

Road Geometry	Azimuth 10°L-5°L	 5°L-0°	 0°-5°R
Left Curve			
Motorcycle	27.2	33.8	38.9
Car	37.7	37.1	25.2
Straight			
Motorcycle	1.5	17.9	80.6
Car	5.7	27.0	67.3
Right Curve			
Motorcycle	0.3	8.7	91.0
Car	0.4	13.6	86.0

DISCUSSION

There appear to be several differences in the manner in which the drivers obtain visual information when riding a motorcycle than driving a car. When on the motorcycle, the mean dwell times of eye fixations were longer in the most commonly fixated area - the road lane being used - than in car driving (Table 6). This, coupled with an increase in eye fixations closer to the vehicle (Table 8) and more to the right (Table 7), suggests that motorcyclists are more concerned with the character of the pavement over which they are moving. Discussions with motorcyclists confirms that they need good visibility of the pavement to determine its frictional characteristics, to see road ruts, potholes, and small objects that need to be avoided.

The eye fixations of the drivers on the motorcycle shifted in the direction of the road, to the left on left curves, in the central 10° cone of visibility on straight sections, and to the right on right curves. This general tendency was also found for them when driving the car and is a stable phenomenon that has been obtained in previous studies made on two-lane roads (Mortimer and Jorgeson, 1974). However, on the motorcycle, the drivers looked more to the right than in the car (Table 9). Thus, the right side of the road provides relatively more valuable information for steering to motorcycle riders than car drivers. Part of this effect is probably also attributable to the continuous need for information of the condition of the pavement.

The presence or absence of roadway edgeline delineation had little effect on the frequency of viewing the right edge of the road by the drivers when controlling the motorcycle or the car. About 11% of the eye fixations were directed at the right edge of the road with and without delineation. This compares with about 18% of glances at the right edge of the road in daytime, irrespective of delineation, found in a previous study (Mortimer and Jorgeson, 1974)of car driving. It should be noted, however, that at night a large beneficial effect of edgeline delineation was reported in that investigation.

The drivers used in this test were concerned with viewing oncoming vehicles, with 42.5% of the eye fixation time devoted to them, when present (Table 10). In a previous study (Mortimer and Jorgeson, 1974) about 14% of the viewing time was at oncoming vehicles, in daytime, and 21% at night. This difference in these studies could be due to experienced motorcyclists being used in this test and car drivers in the other, and may reflect a greater concern with oncoming vehicles on the part of the motorcyclists.

Table 10. Percent Duration of Eye Fixations in Various Locations on Straight Sections of Road With and Without an Oncoming Vehicle: Means for Motorcycle and Car Driving

Location	With Oncoming Vehicle	Without Oncoming Vehicle
Off road to left	3.9	1.9
In left lane at opposing vehicle	42.5	---
In left lane not at opposing vehicle	3.2	10.1
Center line	1.3	3.6
Straight ahead in lane	32.5	50.1
Right edge	4.5	9.7
Off road to right	5.5	10.7
Mirrors	1.4	5.1
Dash/Interior	2.1	3.0
Blinks, out-of-view	3.1	5.8

Fundamentally, it appears that operators of motorcycles view the pavement closer to the vehicle and more to the right than is the case in car driving. This finding has some implications for the development of headlamps that will provide an appropriate distribtuion of illumination on the pavement for safe steering of motorcycles. The beam should provide adequate foreground illumination to allow the motorcycle rider to discern the character of the pavement, and illumination of the right side of the lane at greater distances to obtain adequate preview for the prupose of guiding the vehicle.

Since the median preview distances used by the drivers on the motorcycle were about the same as in the car, this confirms what is intuitively evident - namely, that they require at least the same level of visibility ahead of them as do drivers of automobiles at night. However, motorcycles are equipped with only one headlamp, which would tend to preclude this possibility, particularly because headlamps of motorcycles are generally of lower power than those used in automobiles.

The results of this study indicate that a motorcycle meeting beam should minimally provide adequate foreground intensities and reach as far as possible with sufficient illumination provided on the right side of the road.

SUBJECTIVE LOW BEAM PATTERN EVALUATION

OBJECTIVES

To provide a qualitative comparison of the low beams of a subset of the lamps acquired in the useage survey(described earlier) in order to: 1) enable comparisons to be made between subjectively desirable and undesirable beam pattern characteristics and the actual photometric characteristics of the lamps; and 2) provide a basis for the selection of a smaller group of lamps for use in the identification distance/object avoidance experiment described later.

METHOD

APPARATUS. Since a goal of the project is to recommend photometric specifications for headlamps for three classes of motorcycles of different top speed capabilities, three such motorcycles, a Ciao moped (max. speed = 25 mph), Yamaha 60 cc (max. speed = 45 mph), and Honda 350 cc (max speed > 70 mph) were used in these and subsequent studies. Each motorcycle was equipped with a self-contained, battery based regulated power supply to operate the headlamps under test (6.4 or 12.8v) at design voltage (Figure 18). Each motorcycle was also equipped with a calibrated headlamp mounting fixture which enabled headlamps to be quickly installed and removed with proper aim maintained (as per SAE J584) throughout (Figure 19).

SUBJECTS. Three subjects, all employees of HSRI, evaluated the various lamps. Their ages were 22, 27, and 41 years. Each subject had at least six years of previous motorcycle driving experience.

PROCEDURE. Each of the motorcycles was operated by each of the subjects on roads representative of the type suitable for the maximum speed capabilities of each of the motorcycles. The roads used included two and four lane urban roads for the

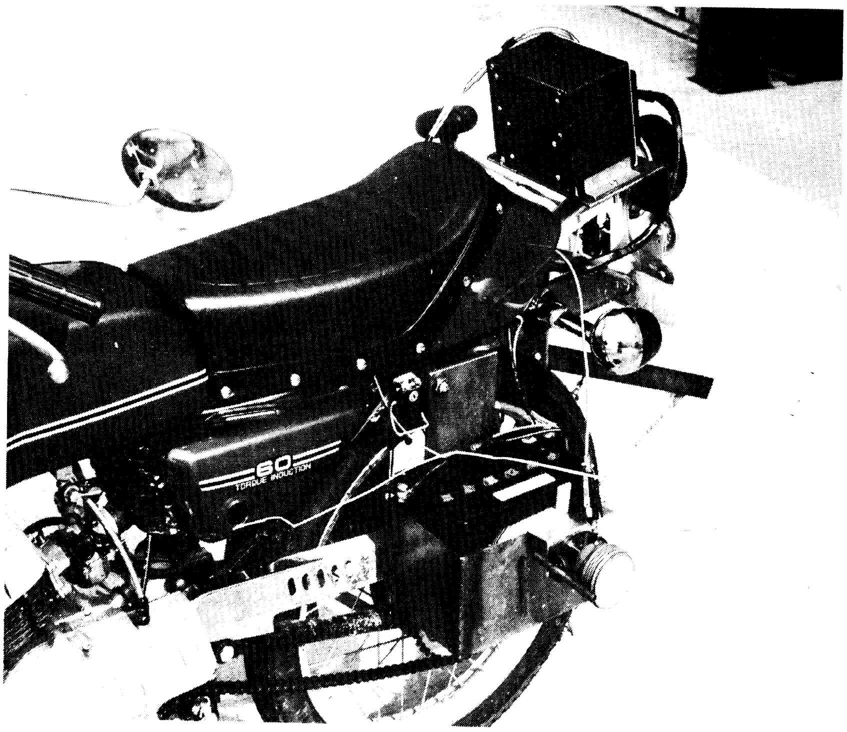


Figure 18. A test motorcycle with power supply battery and target detection device.

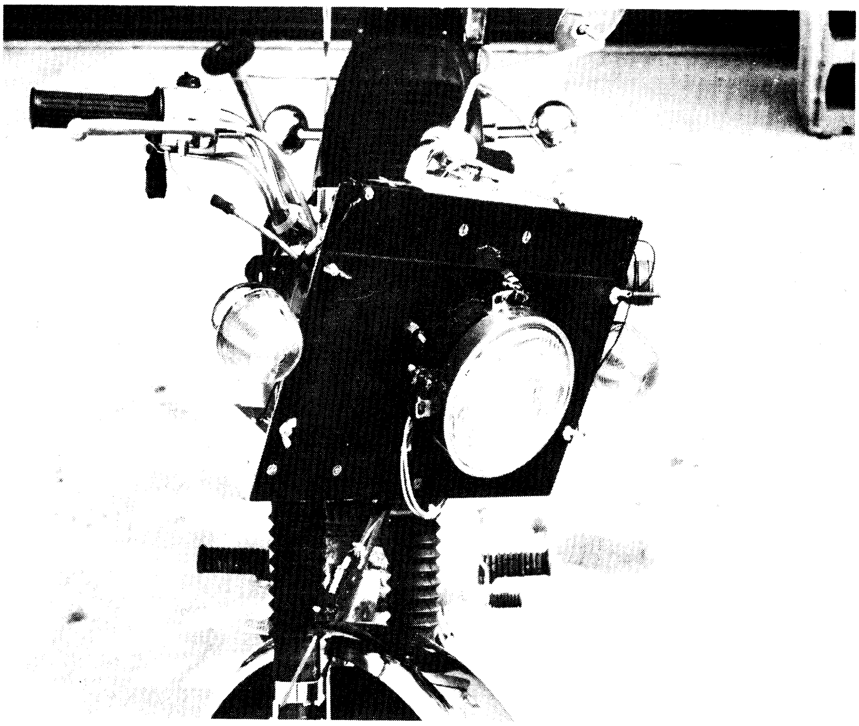


Figure 19. A test motorcycle with headlamp mounted on the calibrated aiming fixture.

moped, the same four lane urban road and an additional higher speed rural road for the 60 cc motorcycle, and a section of limited access freeway as well as the roads used for the 60 cc motorcycle, for the 350 cc machine. A majority of the roads used had no fixed illumination.

When each of the subjects had completed a test drive with one of the lamps, he was questioned as to the desirable and undesirable characteristics of the lamp and its suitability for the motorcycle on which it was tested. He was then sent out to evaluate a different lamp on the same motorcycle. Each subject evaluated lamps on only one motorcycle on each test night. Each subject thus participated on at least three separate occasions. Subjects were not informed of the manufacturer, model, or intended application of the lamps evaluated.

DESIGN. The headlamps evaluated in this study are listed in Table 11. Lamps were selected on the basis of their low beam pattern configuration (asymmetric, symmetric, sharp cutoff) and their intended application, generally as indicated by their power requirements. Each motorcycle was operated with headlamps characteristic of current original equipment supply practices as well as with headlamps characteristically supplied on larger displacement machines. Several headlamps were used on more than one motorcycle to examine the perceived effectiveness as a function of the motorcycle application. Several two-lamp systems were used on the 350 cc motorcycle that provided a mid-beam or auxilliary low beam which augmented the conventional low beam. Such mid-beam systems have been favorably evaluated for automotive headlighting applications. Two-beam headlamps were visually aimed on high beam as prescribed by SAE J584, except for the sharp cutoff lamps (CEV 158, Lucas MNP-69, and Hella H4) which were laterally centered on high beam and vertically aimed on low beam so that the edge of the sharp cutoff was located at approximately 0.5° down. This resulted

Table 11. Headlamps evaluated in the subjective test.

		Beam Design			
Motorcycle	Moped Lamps	Asymmetric	Symmetric	Sharp Cuttoff	Mid-Beam Lamps
Moped	CEV 171 (20w) Stan 10N-S (15/15w) Cibie (6w) GE 4568 (25w)	GE 4020 (30/30w)	Stan 9M-S (35/25w)	CEV 158 (35/35w)	
60 cc		Guide 4458 (60/50w) GE 4020 (30/30w)	Stan 24M-S (50/35w) Stan 9M-S (35/25w) Koito 31877 (15/15w)	Hella H4 (60/55w) CEV 158 (35/35w)	
350 cc		Guide 4458 (60/50w) Koito 4438 (50/40w)	Stan KH-15 (50/40w) Stan 1201 (50/40w)	Hella H4 (60/55w) Lucas MNP-69 (45/40w)	Guide 4458 +West 7701 (50w) +Guide XVL (30w) Hella H4 +Guide XVL Stan KH-15 +Guide XVL

in vertical misaim of the high beam in each case. The three single beam moped lamps (CEV 171, GE 4568, and Cibie 6w) were laterally centered and vertically aimed so that the top edge of the high intensity region was located at 0.5° down.

RESULTS

GENERAL FINDINGS. Once the evaluation procedure was begun it rapidly became apparent that the perceived effectiveness of each of the beams was chiefly dependent upon the amount of illumination provided in three characteristic areas: 1) the immediate foreground; 2) at a distance down the road; and 3) towards the periphery of the lane. Some lamps were considered to provide inadequate illumination overall. Table 12 lists the lamps which were felt to provide insufficient illumination by at least two of the subjects by the characteristic area of inadequate illumination, and by the motorcycle on which they were tested. Table 13 lists the overall rank ordering of lamps generated by the subjects, reported by the motorcycles on which they were tested. This table also lists the rated adequacy of the lamps for the particular motorcycle application. Some lamps which were felt to be adequate for the smaller displacement machines received lower ratings on larger machines because of their inherent higher speed capabilities. In fact, none of the low beams tested on the 350 cc motorcycle were rated adequate without qualifications because they were not felt to provide sufficient illumination for higher speeds such as 55-60 mph.

MOPED LAMP CONCLUSIONS. Of the seven lamps evaluated on the moped, three were felt to provide adequate illumination, three were considered adequate but had specific undesirable characteristics, and one was felt to be completely inadequate (Tables 12 and 13). Generally, headlamps which produced wide and long areas of illumination were most highly favored and lamps which produced limited illumination either laterally or

Table 12. Undesirable characteristics of headlamps evaluated in the subjective test.

Inadequate Foreground Illumination

Moped -- GE 4568
Stanley 10N-S
60 cc -- Koito 31877
350 cc -- None

Beam Too Narrow

Moped -- GE 4020
Stanley 10N-S
Stanley 9M-S
60 cc -- Koito 31877
GE 4020
Stanley 9M-S
350 cc -- Koito 4438

Inadequate Down Road Illumination

Moped -- Cibie (6w)
60 cc -- CEV 158
Stanley 24M-S
350 cc -- Stanley 1201
Lucas MNP-69
Stanley KH-15
Koito 4438 (to a lesser degree)

Inadequate Overall Intensity

Moped -- Cibie (6w)
60 cc -- Koito 31877
350 cc -- None

Table 13. Rank order of headlamps evaluated in subjective test.

Motorcycle		Ratings
Moped		
CEV-158	(35/35w)	Adequate
CEV-171	(20w)	
GE-4020	(30/30w)	
GE-4568	(25w)	Adequate - qualifications
STAN-9M-S	(35/25w)	
STAN-10N-S	(15/15w)	
CIBIE	(6w)	Inadequate
60 cc		
GUIDE-4458	(60/50w)	Adequate
HELLA-H4	(60/55w)	
STAN-24M-S	(50/35w)	Adequate - qualifications
GE-4020	(30/30w)	
CEV-158	(35/35w)	
STAN-9M-S	(35/25w)	
KOITO-31877	(15/15w)	Inadequate
350 cc		
GUIDE-4458	(60/50w)	Adequate - qualifications
-4458+7701	(50w+50w)	
-4458+XVL	(50w+30w)	
HELLA-H4	(60/55w)	
-H4+XVL	(55w+30w)	
KOITO 4438	(50w/40w)	
STAN-KH-15	(50/40w)	Less adequate, qualifications
-KH-15+XVL	(40w+30w)	
LUCAS-MNP-69	(45/40w)	
STAN-1201	(50/40w)	Inadequate

longitudinally were disfavored. The Cibie 6w and GE 4568 lamps were more highly favored when their beam centers were aimed approximately 5° below the H-V axis. However, even with this aim, the 6w lamp was considered inadequate by all three subjects. The 20w CEV 171 lamp, which was supplied as original equipment on the Ciao moped purchased for these tests, was well received by all subjects as it provided adequate illumination close to the vehicle as well as at a distance down the road. In addition, its pattern was wide enough to illuminate both edges of the lane adequately.

SMALL DISPLACEMENT (60 cc) MOTORCYCLE CONCLUSIONS. Because of the higher speed capabilities of this motorcycle (> 40 mph) only two lamps were considered completely adequate (Table 13). Of the remaining lamps, four were considered adequate for operation at more moderate speeds. One lamp, the Koito 31877, which was supplied as original equipment on the 60 cc motorcycle, produced a very tightly concentrated pattern and was thus considered inadequate by all three subjects.

LARGE DISPLACEMENT (350 cc) MOTORCYCLE CONCLUSIONS. None of the headlamps evaluated on this motorcycle were felt to provide sufficient down the road illumination on low beam for speeds greater than 50 mph. However, some were more effective than others, as shown in Table 13. The mid-beams tested were not felt to add substantially to down the road visibility, although one of the subjects reported that they did increase his driving confidence. All lamps produced acceptable foreground illumination and on the whole, wide enough patterns. The one lamp which was rated "inadequate" (Stanley 1201) directed very little light down the road, and was considered inadequate for speeds greater than 40 mph. The high beams of the Lucas MNP-69 and CEV 158 lamps were found to provide marginal illumination on the road when aimed optimally on low beam. The Hella H4 high beam, although also aimed high, provided very adequate illumination.

DISCUSSION

In this study, the subjective effectiveness of motorcycle headlamps was found to be a function of the amount of illumination provided: 1) in the immediate foreground; 2) at some distance down the road; and 3) towards the periphery of the lane. Figure 20 shows how these descriptive areas can be quantified in terms of a coordinate system based on the H-V axis of the headlamp. Figure 20 is a perspective drawing of the field-of-view of a 24 ft. wide, two-lane, straight road from the center of the right lane at a height of 34 in., the mean headlamp mounting height (SD = 1.2 in.) of the three motorcycles used in this study. Deviations in degrees from the H-V axis of the lamp are shown on the right and bottom edges of the figure. Since the photometric characteristics of headlamps are custommarily referenced to the same coordinate system, this figure enables equation of photometric values with actual areas on and about the road. The "characteristic areas" described earlier can thus be translated (albeit arbitrarily) into degrees of deviation from the H-V axis of the headlamp to allow comparison of the specific photometric characteristics of the lamps tested.

SELECTION OF PHOTOMETRIC TEST POINTS FOR COMPARISON. The current SAE recommended practice concerning the photometric characteristics of motorcycle headlamps (SAE J584b) specifies four test points (2°D, 3°R; 2°D, 3°L; 2°D, 6°R; 2°D, 6°L) at which minimum intensity values are required. These test points are noted in Figure 20. For the lamp mounting height referenced above, it can be calculated that these points at 2°D refer to points on the road at a longitudinal distance of 81.2 ft. Laterally, as can be seen in Figure 20, these points fall close to the center line and right edge of the lane. These points can be used to represent the periphery of the lane, one of the characteristic

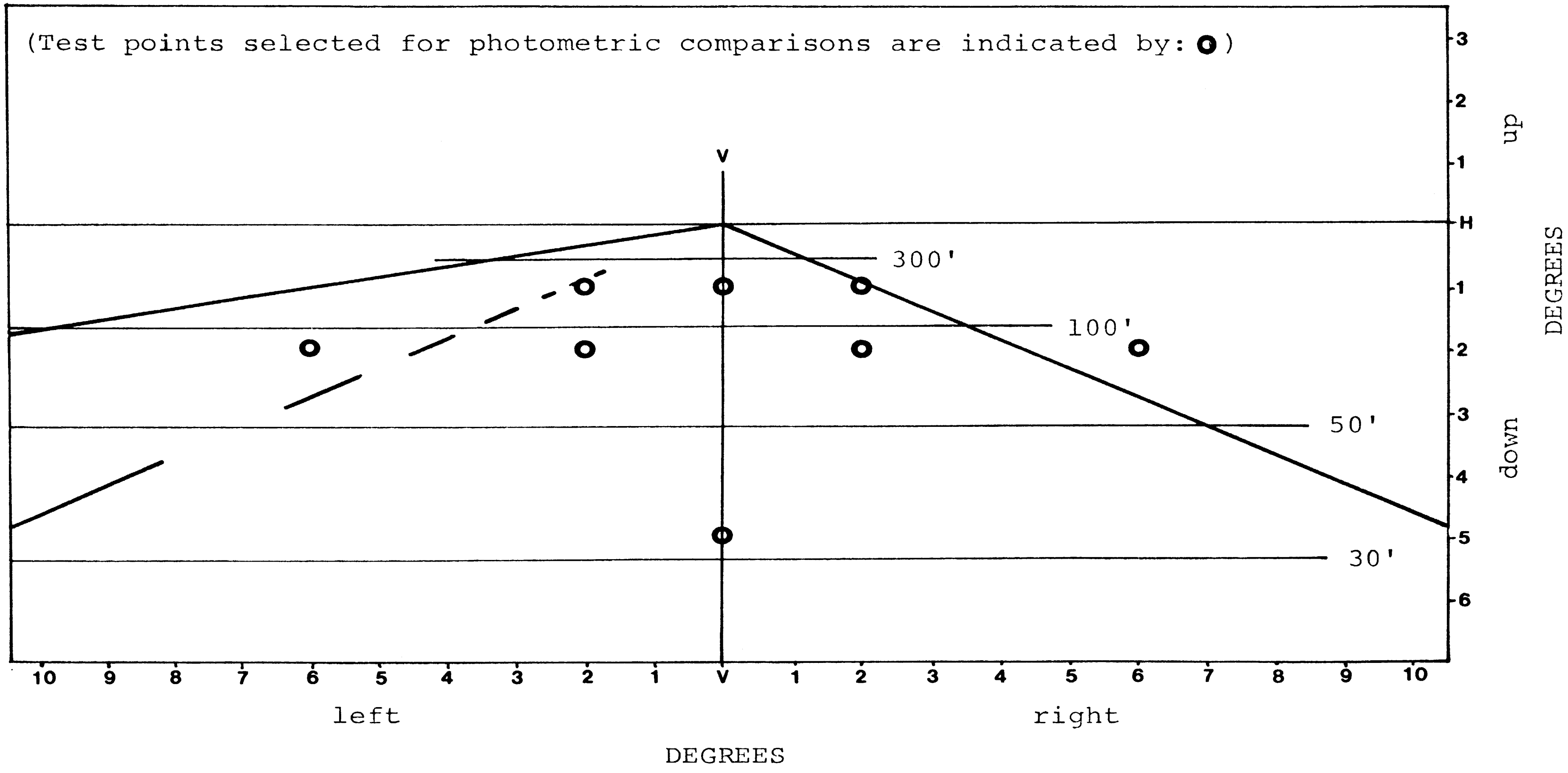


Figure 20. Perspective illustration of a straight, two-lane, 24 ft. wide road from the height (34 in.) of a typical motorcycle headlamp located in the center of the right lane.

areas determined earlier. Another characteristic area, the immediate foreground, can be represented by a point at 5°D, 0° horizontal. This point is in the center of the lane directly ahead of the headlamp, at a distance of 32.5 ft. Finally, the characteristic area described as "some distance down the road" can be characterized by points at 1°D, 2°R; 1°D, 0°; and 1°D, 2°L, representing points 162 ft. down the road, at the right edge, center, and left edge of the lane, respectively. These eight test points, although somewhat arbitrary, realistically represent areas on and around the road of subjective importance to motorcyclists.

COMPARISON OF PHOTOMETRIC CHARACTERISTICS OF THE LAMPS EVALUATED. Table 14 lists the intensities produced at each of the test points for the lamps as aimed and evaluated on the moped, 60 cc., and 350 cc. motorcycles, respectively. (The intensity values listed were supplied to HSRI by a subcontractor and thus do not represent intensities of the specific lamp used, as installed and aimed. However, because of the considerable care taken in aiming each of the lamps for these tests, it is believed that the values shown are quite representative.)

Photometric values which produced undesirable ratings (from Table 12) are indicated in Table 14 and can be directly compared with photometric values which produced favorable ratings. With few exceptions, undesirable ratings correspond to relatively low intensities. For instance, the GE-4568 lamp which produced unfavorable foreground illumination on the moped produces only 300 candelas (cd) at 5°D, 0°V, compared to 1300 to 4300 cd produced by some of the more favorably rated lamps. Several lamps tested on the moped produce beam patterns that were felt to be too narrow and these lamps (GE-4020, Stanley 9M-S, and Stanley 10N-S), produce intensities at some of the 2°D testpoints that are considerably lower than

Table 14. Intensity characteristics (in cd/100) at selected test points of headlamps evaluated in the subjective study.

Lamps evaluated on moped

Test Point	CEV 158	CEV 171	GE 4020	GE 4568	Stan. 9M-S	Stan. 10N-S	Cibie 6w
1D, V	29	104	34	54	34	13	6*
1D, 2L	33	94	17	54	23	12	6*
1D, 2R	38	92	85	56	24	11	6*
2D, 6L	36	32	12*	41	10*	11*	4*
2D, 3L	44	70	21*	44	28*	25*	5*
2D, 3R	44	61	117*	44	46*	24*	6*
2D, 6R	35	32	73*	42	13*	13*	4*
5D, V	-	24	13	3*	43	34*	1*

Lamps evaluated on 60 cc motorcycle

Test Point	Guide 4458	Hella H4	Stan. 24M-S	GE 4020	CEV 158	Stan. 9M-S	Koito 31877
1D, V	88	100	21*	34	29*	34	50*
1D, 2L	24	68	10*	17	33*	23	23*
1D, 2R	118	186	21*	85	38*	24	36*
2D, 6L	31	68	14	12*	36	10*	8*
2D, 3L	45	81	34	21*	44	28*	50*
2D, 3R	172	125	45	117*	44	46*	59*
2D, 6R	83	100	16	73*	35	13*	16*
5D, V	46	39	84	13	-	43	3*

Lamps evaluated on 350 cc motorcycle

Test Point	Guide 4458	Hella H4	Koito 4438	Stan. KH-15	Lucas MNP-69	Stan. 1201
1D, V	88	100	51*	53*	33*	15*
1D, 2L	24	68	20*	29*	23*	13*
1D, 2R	118	186	63*	37*	33*	16*
2D, 6L	31	68	27*	15	28	17
2D, 3L	45	81	50*	46	37	34
2D, 3R	172	125	171*	64	48	42
2D, 6R	83	100	65*	15	33	14
5D, V	46	39	31	125	-	118

* Indicates areas of subjectively inadequate illumination.

lamps which received favorable beam width ratings. At 2°D, 6°L, these three lamps produced intensities of 1200 cd, 1000 cd, and 1100 cd respectively. The minimum intensity produced at this test point by a more favorably rated lamp was 3200 cd (CEV 171). The Cibie 6w moped lamp produced uniformly low intensities at all eight test points indicating why its overall rating was "inadequate".

Photometric characteristics of lamps tested on the 60 cc and 350 cc motorcycles may be compared in the same fashion, and a general framework of "minimum subjectively adequate" photometric values may be developed. This procedure is pursued in a later section of this report to provide a basis for the development of photometric standards for the three classes of motorcycles.

SELECTION OF HEADLAMPS FOR USE IN THE IDENTIFICATION DISTANCE/OBJECT AVOIDANCE EXPERIMENT. Since several lamps of each of the three basic low beam pattern types (symmetric, asymmetric, and sharp cutoff) were found to provide subjectively adequate illumination, it was decided through consultation with the contract technical monitor to select groups of lamps for further test from each of the three basic beam pattern categories. It was additionally deemed appropriate to select lamps representing current production practices as well as lamps which in some way represent optimization of design. On the basis of these criteria, six lamps were selected for low beam evaluation (Table 15). These lamps were all rated "adequate" or "adequate with qualifications" in the subjective evaluation, with the exception of the Westinghouse W4, which was not evaluated but was included at the request of NHTSA. Two lamps, representing current production practice and "optimized" design were also evaluated on high beam. An additional two lamps were selected for evaluation on the moped. These

Table 15. Characteristics of headlamps evaluated in the field identification distance/object avoidance tests.

Large Motorcycle (Honda 350cc)

Low Beams

Lamp	Power	Beam Shape	Present Usage
Westinghouse W4	60w	Asymmetric	Experimental
Stanley KH-15	40w	Symmetric	Experimental
Hella H4	55w	Sharp Cutoff	European Halogen Low Beam

High Beams

Lamp	Power	Present Usage
Westinghouse W4	80w	Experimental
Koito 4438	50w	Supplied as original equipment on several large displacement motorcycles

Small Motorcycle (Yamaha 60cc)

Low Beams

Lamp	Power	Beam Shape	Present Usage
Koito 4438	40w	Asymmetric	Large Displacement Motorcycles
Stanley 24M-S	35w	Symmetric	Medium Displacement Motorcycles
CEV 158	35w	Sharp Cutoff	Medium Desplacement Motorcycles

Moped

Lamp	Power	Beam Shape	Present Usage
CEV 171	20w	Symmetric	Mopeds
Cibie	6w	Symmetric	Mopeds
(GE 4568)	25w	Symmetric	Replacement lamps for mopeds

lamps represented the upper and lower ends of the distribution of subjective adequacy and operating power required by original equipment moped lamps. The GE-4568 lamp listed in Table 15 was not originally selected for further evaluation, but was included during the identification distance/object avoidance experiment as extra test time became available.

IN-SERVICE MOTORCYCLE HEADLAMP AIM SURVEY
VISIBILITY REQUIREMENT QUESTIONNAIRE

OBJECTIVES

Because of the relatively small number of subjects used in the eye fixation and subjective beam pattern evaluation studies, it was considered desirable to obtain additional subjective data concerning motorcyclists' nighttime visibility requirements, to substantiate the findings of these studies.

METHOD

Each of the 90 motorcyclists participating in the in-service headlamp aim survey described earlier was asked to rank order the most important areas or objects in the driving environment to be able to see when operating a motorcycle at night. Although most of the subjects were prepared to make immediate replies to the question, others were hesitant and had to be prompted somewhat. For this reason, all subjects were told that the type of response desired was something such as: "straight down the road or to the left or right sides, either at a great distance down the road, a short distance, or somewhere in between, or any specific objects or road conditions." Although this prompting could have biased the response of some subjects, the experimenter made it quite clear that no bias was intended, that any and all replies were acceptable, and that the subject was acting, in effect, as an expert whose response was quite valuable.

RESULTS AND DISCUSSION

A maximum of three rank-ordered responses were recorded for each subject. However, since less than three responses were made by a majority of subjects, the total number of responses received was 179. The open ended construction of the question encouraged diversity in response, and it was found that 14 response categories were required to group the various responses accurately. These 14 categories and their associated response frequencies are shown in Table 16. Because of the relatively small number of second and third "most important" responses, it was found that differential weighting of responses by rank order of importance had little effect on the resultant overall rank ordering of the various response categories. Responses are thus reported as actual frequencies and response categories are rank ordered by total frequency of mention.

Table 16. Response frequencies to the in-service motorcycle headlamp aim visibility requirement questionnaire.

	Most Important	Second Most Important	Third Most Important	Σ	% of Total	Response Category
	24	9	5	38	22%	Down road, at distance, center of lane
	23	8	--	31	18	Down road, close in, center of lane
	8	12	8	28	16	Periphery, other than on road
	4	15	3	22	12	Animals, objects on road
	12	7	1	20	11	Road surface, potholes, defects
	7	3	1	11	6	Right of lane
	4	2	--	6	3	Down road, midrange, center of lane
	3	3	--	6	3	Road surface deliniation
	2	1	1	4	2	Cars--parked, slow moving
	1	2	1	4	2	Left of lane
	1	1	1	3	2	Curves
	1	--	1	2	1	Pedestrians
	--	2	--	2	1	Signing
	--	1	1	2	1	Intersections
Σ	90	66	23	179	100%	

The three most frequently mentioned areas of importance ("down road, at distance, center of lane"; "down road, close in, center of lane"; and "periphery other than on road") closely correspond to the three "characteristic areas" of importance defined by subjects in the subjective beam pattern evaluation study described earlier, and further illustrate the need of motorcyclists for vision in a very large area ahead of them. The fourth and fifth ranked areas of importance ("animals, objects on road"; and "road surface, potholes, defects") reflect specific objects or conditions which motorcyclists must concern themselves with that are of generally lesser concern to automobile drivers. The animals and objects described by the 22 subjects who reported them were for the most part small (raccoons, cats, dogs, opossums, debris and cargo dropped by trucks, etc.) and representative of things that cannot be identified accurately at great distances because of their limited size. Less frequently mentioned response categories included: right edge of lane; down road; midrange, center of lane; road surface delineation; parked and slow moving cars; left edge of lane; curves; pedestrians; signings; and intersections.

The results of this survey provide considerable support to the definition of the three characteristic areas of importance developed in the subjective beam pattern evaluation study. They also support the finding of the eye fixation study that motorcyclists are concerned with adequate vision of the road in the immediate foreground. Limited support is given, however, to the eye fixation study finding that the right side of the road is an area of primary importance for vision. This area was specifically mentioned by 11 subjects and represented only 6% of the total responses, while the center of the road was mentioned specifically in 40% of the responses. In any case, both areas are probably of considerable importance to the motorcyclist, who must not only be concerned with tracking or directional information, but must attend continually to road surface defects and objects in his immediate path. The operator generated aim experiment, described next, attempts to resolve the issue by enabling motorcyclists to aim a headlamp to their own specifications while driving a motorcycle at night.

OPERATOR GENERATED AIM EXPERIMENT

OBJECTIVE

To determine subjectively optimum motorcycle headlamp aim by enabling motorcycle drivers to aim a single low beam motorcycle headlamp while driving a large motorcycle at night at two maximum speeds.

METHOD

SUBJECTS. Twenty male motorcyclists were selected from the sample population participating in the in-service headlamp aim study on the basis of general and nighttime motorcycle driving experience, an awareness of safety problems specific to motorcycles, and a receptive attitude toward participation in the experiment. Subjects were paid for their participation in the experiment.

APPARATUS. The Honda 350 cc motorcycle used in the subjective beam pattern evaluation study described earlier was instrumented with a Koito 4438 motorcycle headlamp which was aimable in the horizontal and vertical planes by means of two control handles mounted on the left handlebar (Figure 21). The Koito 4438 headlamp was selected for use in this study because: 1) it is a commonly used lamp on larger displacement motorcycles; 2) it was evaluated favorably in the subjective beam pattern evaluation study; 3) the low beam hotspot is asymmetric relative to the high beam, but the low beam pattern appears symmetric to the eye and may be aimed effectively either symmetrically or asymmetrically.

Headlamp aim generated by the subjects was measured using the aiming jig and associated equipment described in the in-service aim study.

DESIGN. Two major questions were addressed by this study: 1) given motorcyclists' desire for illumination of both the

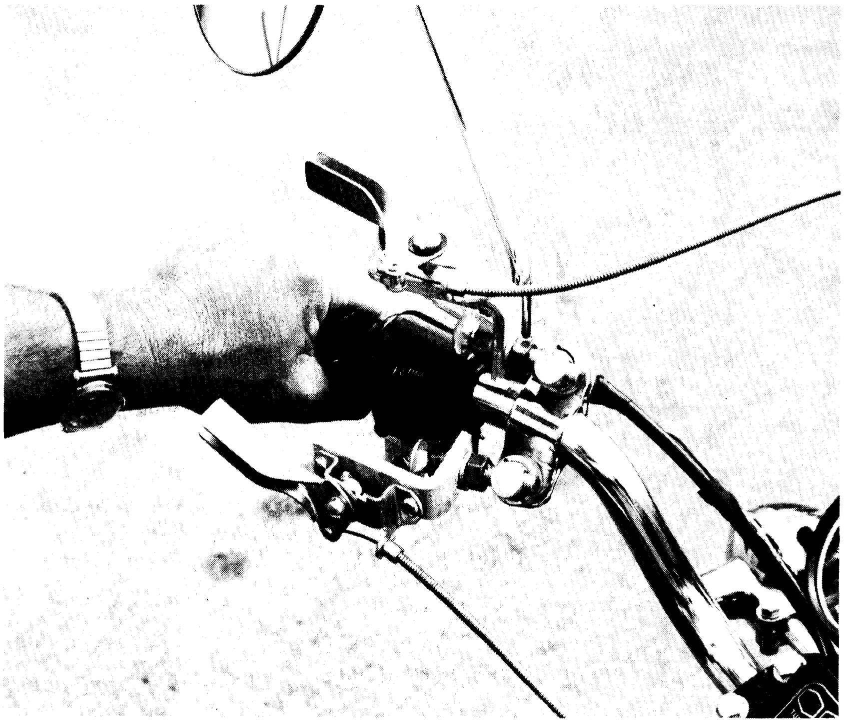


Figure 21. The aimable headlamp controls.

lane center and right edge as documented earlier in this report, would they aim the low beam straight ahead, or somewhat to the right as the beam was designed to be aimed; and 2) how does maximum operating speed affect desirable headlamp aim. To examine the effect of speed on desirable aim, subjects drove the instrumented motorcycle twice, on the same road, at speeds of 30 and 50 mph.

PROCEDURE. Four subjects were tested each night, in one-half hour periods. Upon arriving at HSRI, subjects were instructed in the operation of the aimable headlamp, and the test road course was outlined to them. All subjects were familiar with the roads used. Subjects were instructed to operate the motorcycle over the test course at either 30 or 50 mph and to aim the lamp optimally for the maximum speed used. It was emphasized that the lamp could be aimed in any position to the motorcyclist's liking, as long as he felt he was achieving optimum illumination. The headlamp was drastically misaimed by the experimenter who then sent the subject on his way. Half of the subjects began the procedure at each of the test speeds. Upon the subject's return, the operator generated aim was measured, and the lamp was again misaimed by the experimenter. The subject then made a second test run over the same course at the remaining of the two test speeds. Although subjects were allowed to make as many circuits of the test course as necessary to achieve the desired aim, this option was not taken by any subjects.

RESULTS. Operator generated low beam hotspot aims at speeds of 30 and 50 mph are illustrated in scatter plots in Figures 22 and 23, respectively. These figures also show mean horizontal and vertical aim with associated 99% confidence intervals, and the design low beam aim of the Koito 4438 headlamp.

A three factor analysis of variance was performed on the operator generated aim data with fixed factors of aiming plane (horizontal and vertical) and test speed (30 and 50 mph) and a random factor of subjects (20 levels). This analysis indicated a significant aiming plane x test speed interaction ($F = 16.0$, $df = 1,19$, $p < .01$). Mean horizontal and vertical aims were compared by Tukey (b) test within levels of speed. Mean horizontal aim was found not to differ at the two speeds (mean 30 mph horizontal aim and mean 50 mph horizontal aim both = .7°R), but mean vertical aim was significantly ($p < .01$) lower at 30 mph (1.6°D) than at 50 mph (.1°D).

Horizontal aim, on average, was thus the same for both speeds but was directed considerably closer to the vertical axis (.7°R) than was intended by the lamp's designers (design horizontal aim = 2.8°R). The vertical aims generated at 30 mph (1.5°D) and 50 mph (.1°D) also differed from design aim (2.5°D), and differed significantly from each other.

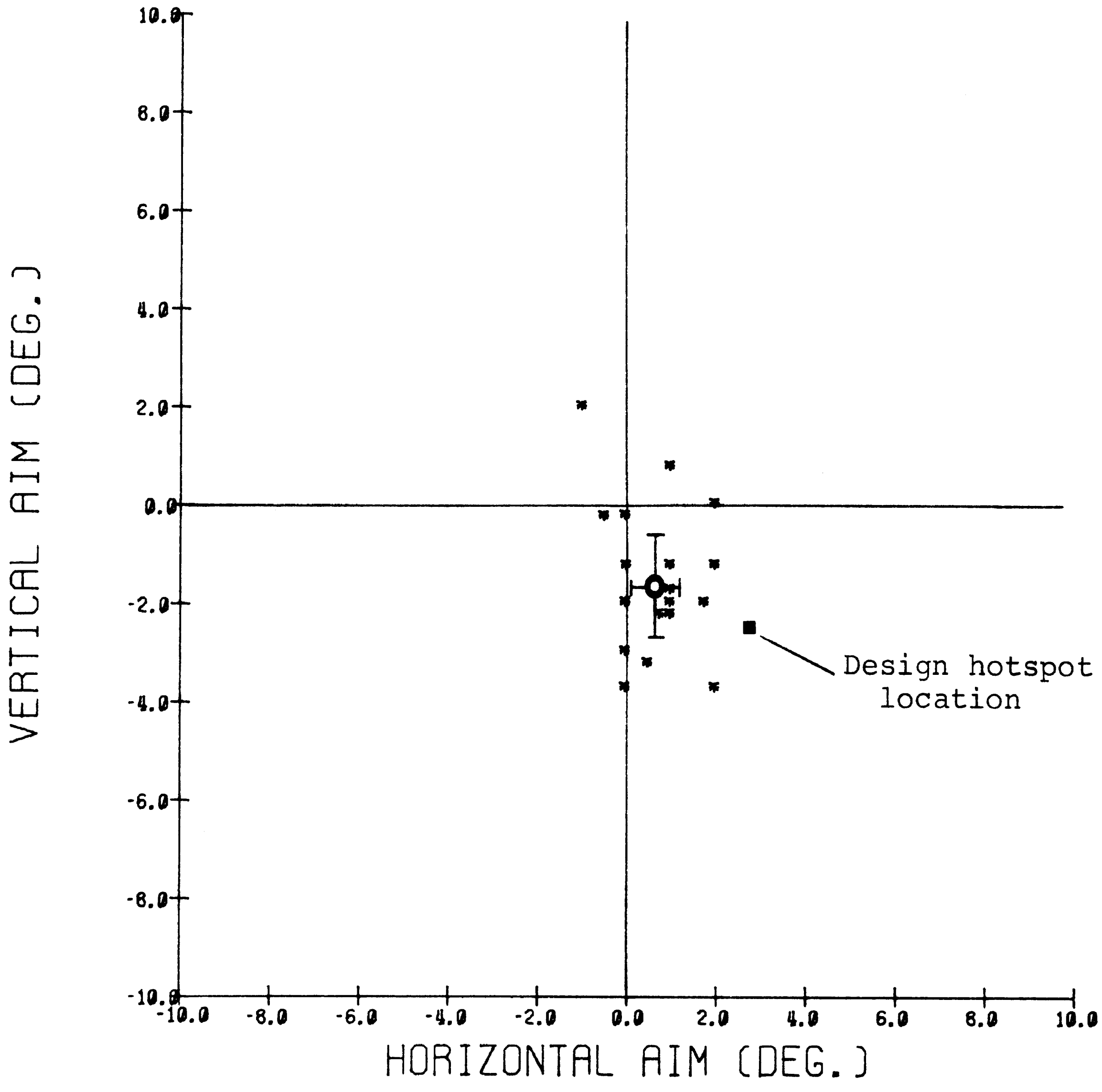


Figure 22. Scatter plot of the headlamp aim generated at 30 MPH by 20 subjects in the operator generated aim experiment.

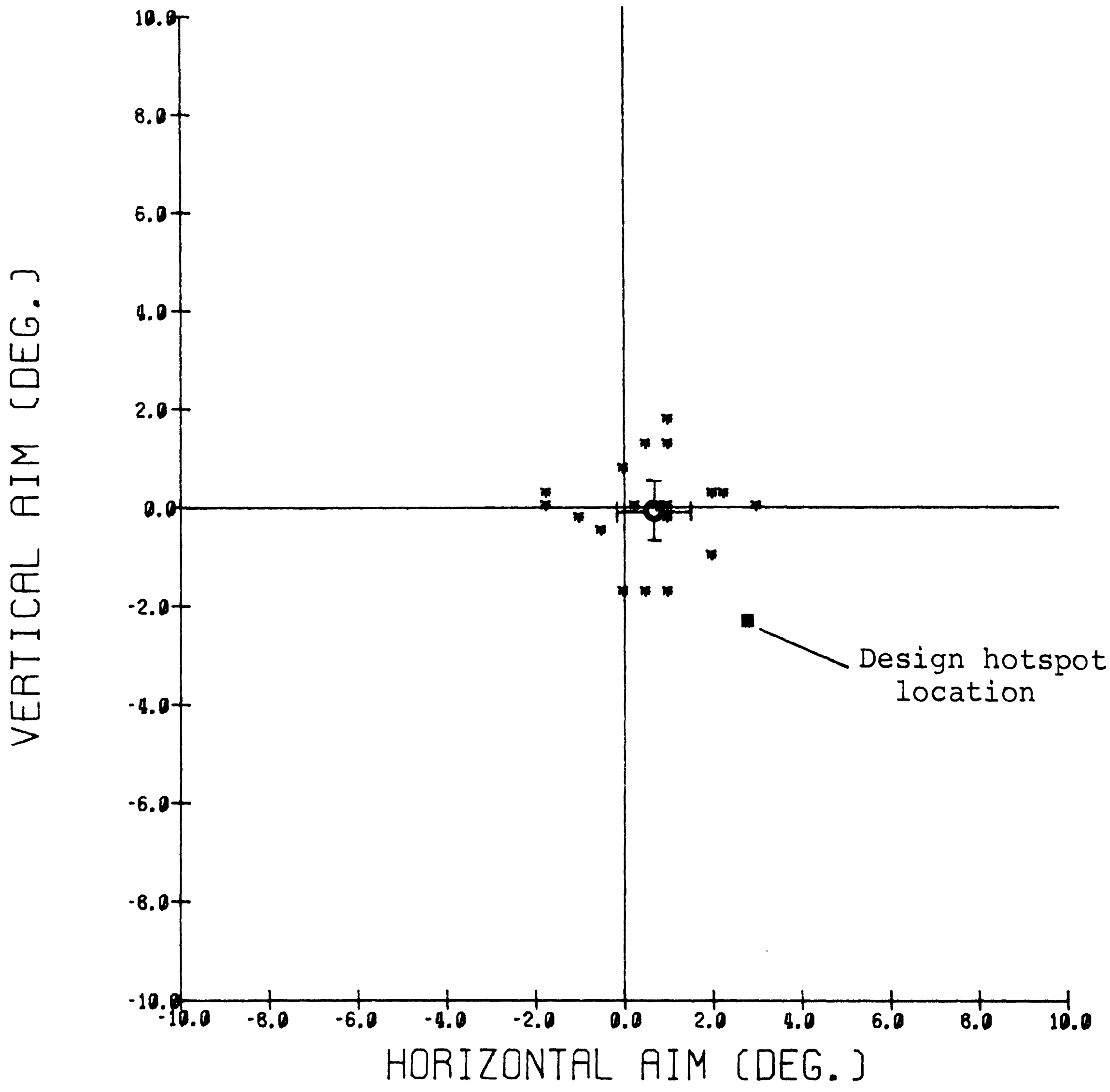


Figure 23. Scatter plot of the headlamp aim generated at 50 MPH by 20 subjects in the operator generated aim experiment.

In short, the asymmetrically designed lamp was aimed more symmetrically (on average) than was intended in its design. If the mean 50 mph aim can be taken to represent subjectively desirable high beam aim and the mean 30 mph aim can be taken to represent subjectively desirable low beam aim, it is seen that a lamp which would produce these aims would have a symmetric beam relationship, but would be aimed slightly to the right. The vertical separation between high and low beam hotspots would also be smaller (1.5°) than is typical of current design practices.

The somewhat contradictory findings of earlier studies conducted in this project are resolved to a great extent by these findings. Rather than aiming the lamp directly down the road, or considerably towards the right edge of the lane as its designers had intended, the subjects, in effect, split the difference by aiming the lamp (on average) between the two points. It thus appears from a subjective standpoint that an intensity bias toward the right is desirable, but should not be made at the expense of straight-down-the-road illumination.

STUDIES CONDUCTED TO PROVIDE RELATIVE COMPARISONS OF THE EFFICIENCY OF MOTORCYCLE HEADLAMPS IN TARGET IDENTIFICATION TASKS

COMPUTER SIMULATIONS OF IDENTIFICATION DISTANCES

OBJECTIVES

To predict identification distances offered by various motorcycle headlamps, based on lamp photometric data and the experimental procedure used in the test track experiments described later.

METHOD

SIMULATOR PROGRAM DESCRIPTIONS. Two computer simulation programs, developed at HSRI for use in evaluating automotive headlighting systems, were used. The first computer program used for this purpose (hereafter referred to as Simulation Program 1) is described by Mortimer and Becker (1973) and has been validated against identification distances collected in field tests with various automotive headlighting systems.

This program takes the geometric description of a two-vehicle night meeting situation, along with the photometric descriptions of the beam patterns used in the various lamps, the road pavement reflectivity and the target geometry and reflectivity, and computes the maximum down-the-road distance at which a target can be seen, first for a series of separation distances of main (subject) vehicle and glare (oncoming) vehicle and then without the glare vehicle. It does this in an iterative fashion, since the equations describing the various relations are too complex to be solved directly.

For any separation distance, an initial trial target distance is selected and the total intensity directed at the target from all lamps on the main vehicle is computed. Then the total veiling glare at the eye is computed, being summed over all the lamps of the glare vehicle. (This is a function of target distance because of the glare angle between the line connecting the eye and the glare lamp, and that connecting the eye and the target.) Foreground glare (from the main vehicle's own lamps relfecting back off the pavement ahead) is also computed, as a function of target distance. The foreground glare is then added to the veiling glare produced by the headlamps of the oncoming glare vehicle. This total veiling glare is used to predict the intensity from the main vehicle lamps needed to see the target at this distance. If the total intensity directed at the target is larget than that needed to see the target, the target is visible at this distance. In this case, the target distance is increased and the procedure repeated until the two intensities are equal, which indicates that the target is just visible. If, on the other hand, the total intensity directed at the target is smaller than that needed to see the target, then the target is invisible and the target distance is decreased until it becomes visible. For visibility distance predictions with no glare vehicle, only the computed foreground glare contributes to the veiling glare.

The HSRI type I identification target which was used in these simulations, and later used in the field tests, is described by Mortimer and Olson(1974). Basically, the type I target (Figure 24) presents an identification rather than a detection task, as a subject is required to detemine the right-left orientation of an 8 in. square which can be placed at either the left or right end of a 4 in. high, 10 in. long bar. The 12% reflectivity square and bar are mounted on a low (3%) reflectivity background which insures uniform background contrast and precludes identification of the target from backlighting. Use of this target has also been shown to reduce variation in response, compared with simple detection targets.

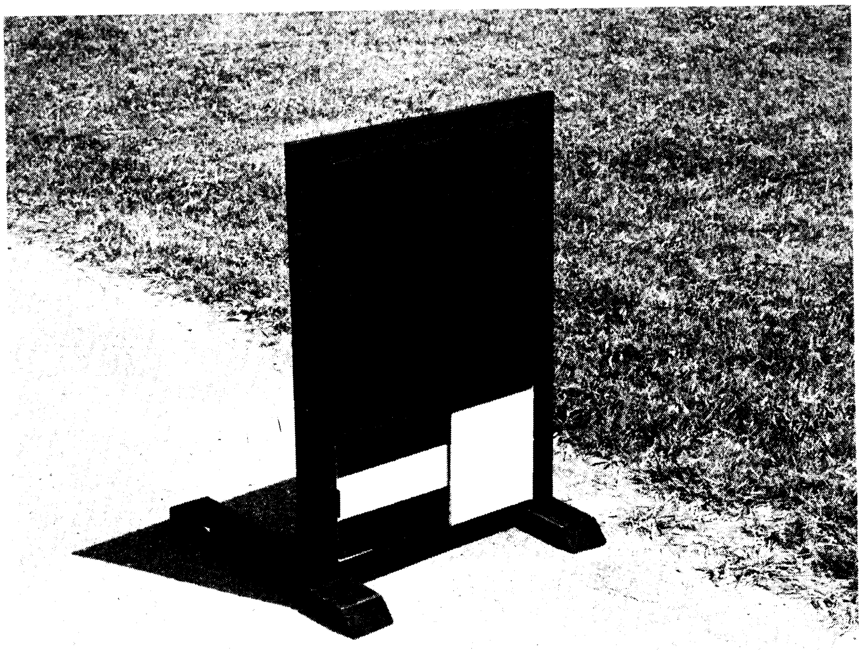


Figure 24. The HSRI type I identification target.

The second computer program used to predict identification distances (hereafter referred to as Simulations Program 2) to type I targets has been more recently developed and as such, does not have the capability to account for veiling glare from either an oncoming vehicle or from the retroreflection off the road surface of the subject vehicle's own headlamps. This program does, however, operate on the geometric description of the subject vehicle-roadway-target location configuration and the photometric description of the lamps used on the subject vehicle, in a fashion similar to the first program described above. The algorithm which calculates the target identification distance is based on contrast threshold data presented by Blackwell (1946)

PROCEDURE AND RESULTS

Complete photometric data for a number of motorcycle headlamps was supplied to HSRI under a subcontract with the General Electric Company Miniature Lamp Department, Nela Park, Ohio. Additional photometric data were provided by the Stanley Electric Co., LTD., Tokyo, Japan.

These data and data acquired by HSRI in earlier projects were initially used with simulation program 1 to predict identification distances to HSRI type I targets for all lamps evaluated in the subjective beam pattern evaluation study. The road-target geometry employed was that which was to be used in later field tests. Basically, identification distances were computed for each headlamp with and without glare produced by an oncoming automobile for type I targets located at the left and right edges of a 14 ft. wide lane, on a straight road, and on 917 ft. radius left and right curves. The predicted identification distances were then set aside for future comparison with results from the field identification distance studies which were then being conducted.

As data from the field studies became available, it became apparent that there was poor correspondence between the actual mean identification distances measured in the field, and the distances predicted by Simulation Program 1. Figure 25 illustrates identification distances of type I targets located on the right edge of a straight road, as measured in field tests, and as predicted by Simulation Program 1. It is evident from this figure that Simulation Program 1 alsways overestimated identification distances, compared to the field test results, but that the magnitudes of the overestimates are not functionally related to the magnitudes of the field test results, i.e., the predicted values can not be equated with the field test results by subjecting them to a mathematical transformation.

Simulation Program 2, which had until this time been under modification to enable its use on a new computer, became fully operational and was used to predict a limited number of identi-

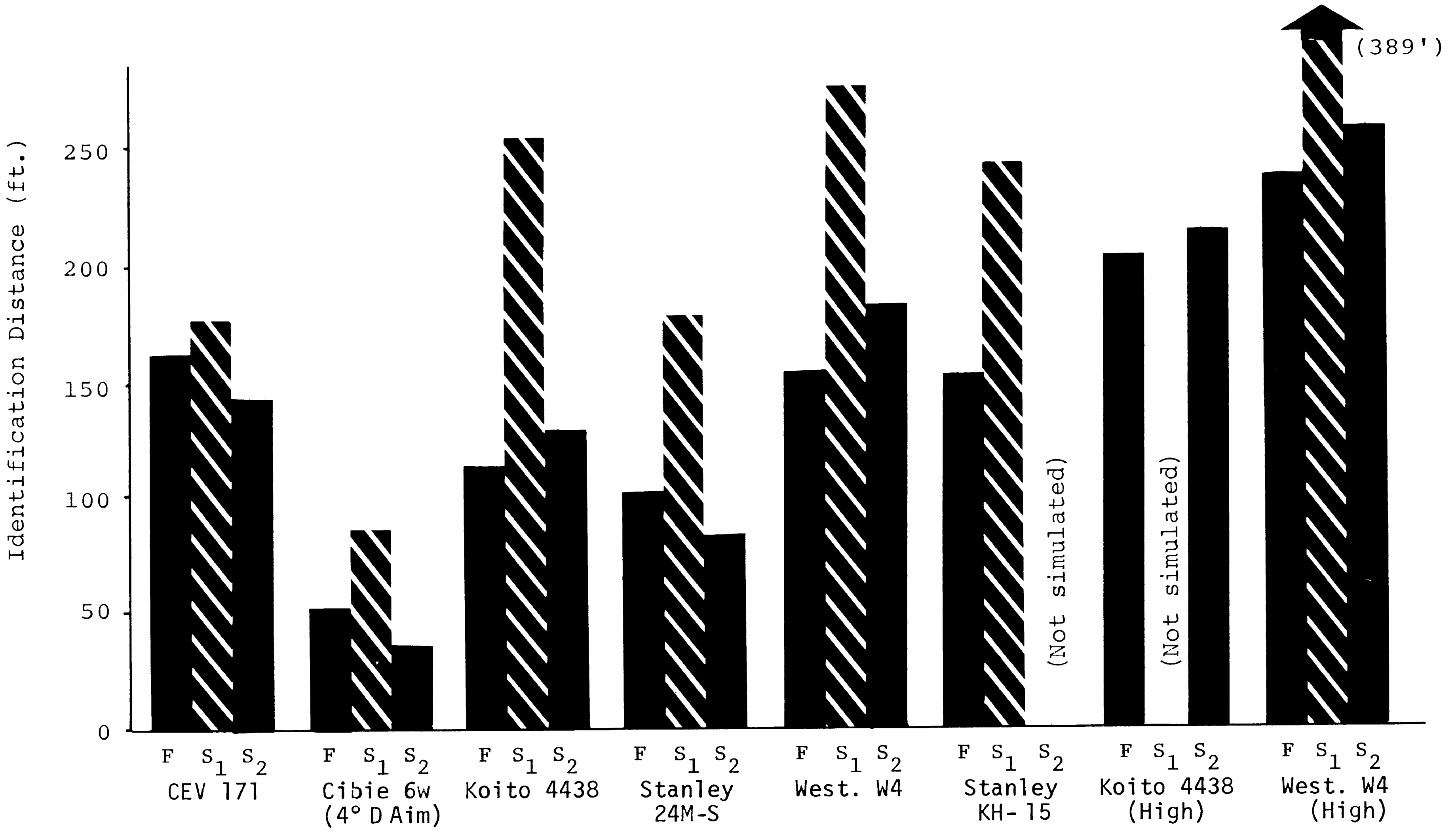


Figure 25. Comparison of no-glare identification distances to an HSRI Type I target on the right edge of a straight road as determined in field tests (f), and as predicted by two computer simulation programs (S_1 and S_2).

fication distances using the same geometric parameters and photometric data used earlier. The identification distances predicted by Simulation Program 2 are also shown in Figure 25, and can be seen to more closely correspond to the field test results.

DISCUSSION

It is not clear why Simulation Program 1, which has been found to accurately predict identification distances in automotive headlighting applications, produced the discrepant results shown here. The fact that there is considerable agreement between the field test results and the results of Simulation Program 2, however, supports the validity of the field test findings, and indicates that the procedure used in Simulation Program 1 to calculate identification distances may be specific to the particular automotive headlighting parameters on which it was originally validated. Several significant differences exist between automobile and motorcycle headlighting parameters (i.e. different driver eye heights, different headlamp mounting heights and lateral spacings, substantially different total intensity outputs) and apparently make the motorcycle headlighting condition a special case with which the program was not originally intended to deal.

Simulation Program 2, on the other hand, is based on generalizable contrast threshold data which are not unique to any set of headlighting parameters. Unfortunately, while this program produced results representative of the field test findings, it does not as yet have the capability to deal with veiling glare effects, which are of great importance in the evaluation of headlamp meeting beams. Because of a lack of resources with which to support further simulation research, the procedure was discontinued.

TARGET IDENTIFICATION DISTANCE/OBJECT AVOIDANCE EXPERIMENT

OBJECTIVES

To make relative comparisons in dynamic conditions of the identification distances afforded by a number of qualitatively different high beam, low beam, and moped headlamps. Measures were also made of the severity of avoidance maneuvers made in response to road surface targets, to determine if differences among headlamps in providing illumination would be exemplified in this control task common to motorcycle driving.

METHOD

SUBJECTS. Nine males and one female subject participated in the experiment. Their ages ranged from 19 to 34 years ($\bar{X}$ = 23 years) and their number of years of driving experience ranged from 1 to 15 years ($\bar{X}$ = 5 years). The subjects reported between 600 and 50,000 miles of driving experience ($\bar{X}$ = 8250 miles). Subjects were paid for their participation in the experiment.

APPARATUS. The Ciao moped, Yamaha 60 cc and Honda 350 cc motorcycles used in the subjective beam pattern evaluation study (described earlier) were also used in this experiment. Each motorcycle was equipped with two lead acid batteries and a voltage regulating system to power the headlamps. This system enabled the headlamps to be operated at design voltage without regard to engine speed or electrical load. (The manner in which the auxilliary batteries were attached to the motorcycles required the rear suspensions of the 60 cc and 350 cc motorcycles to be locked. This procedure, combined with the weight of the instrumentation, undoubtedly altered the handling characteristics of each of the motorcycles, limiting to some extent the generalizability of the magnitudes of the object avoidance measures. However, the change in handling characteristics is not felt to limit the validity of comparisons of avoidance maneuver severity made between headlamps, within motorcycles.) The instrumentation system described in Appendix C enabled recording, on two magnetic tapes, (1) an analog signal proportional to the roll angle of the motorcycle, and (2) an analog signal which enabled the determination of distance travelled, motorcycle speed, subject responses, and the passing of identification, pedestrian, and road surface targets. Other instrumentation consisted of a roll angle sensing arm equipped with a potentiometer attached to the frame of the motorcycle (Figure 26), a signal conditioning and coding package also attached to the motorcycle (Figure 27), and a tape recorder package which was carried in a small box which hung on a strap around the subject's neck (Figure 28). Touch-feedback microswitch pushbuttons were mounted on the handlebars of each motorcycle (Figure 29) and were operated by the subject's thumbs to signal the identification of right and left-hand type I targets, and the detection of pedestrian targets.

The headlamps selected for evaluation (Table 15) were mounted in removable buckets and were pre-aimed to enable rapid interchange. Aim of each of the headlamps was checked regularly and was found not to vary throughout the experiment. All headlamps were aimed using equipment similar to that described in the in-service aim study. Dual beam headlamps (except as noted below) were aimed on high beam with the center of the high beam hotspot centered laterally and aimed 0.4° below the horizontal axis of the lamps (per SAE J584). The two sharp cutoff lamps were aimed by centering the lamp laterally and placing the sharp cutoff of the low beam at 0.4° below the horizontal axis. The single beam moped lamps were aimed as follows:

1. CEV 171 - The beam was centered laterally, and the upper edge of the high intensity region was placed at 0.4° below the horizontal axis.

2. Cibie 6w - Appropriate aim for this lamp was determined by asking subjects in the subjective study to aim the lamp

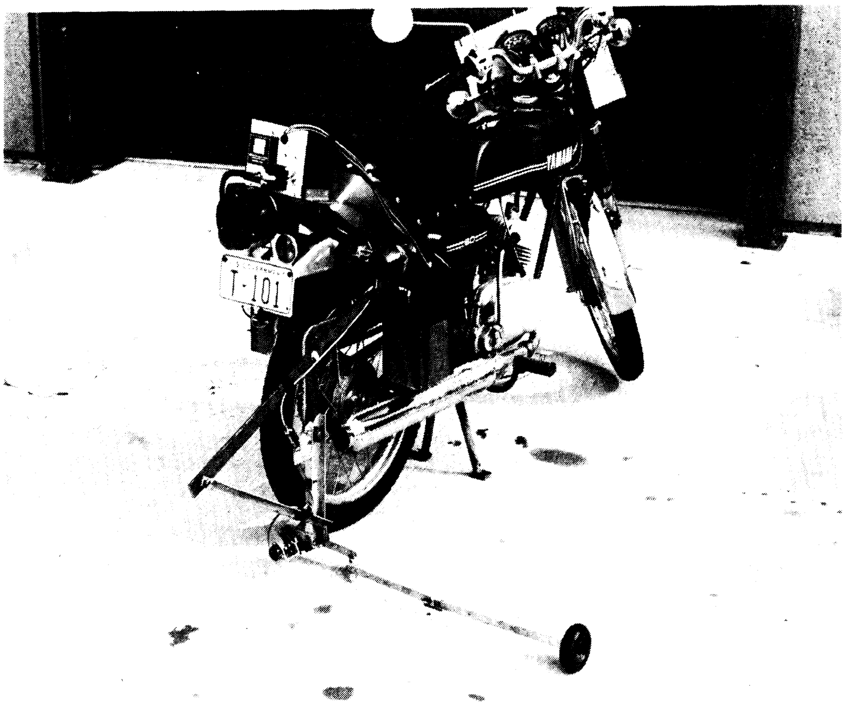


Figure 26. A test motorcycle with the roll angle sensing arm.

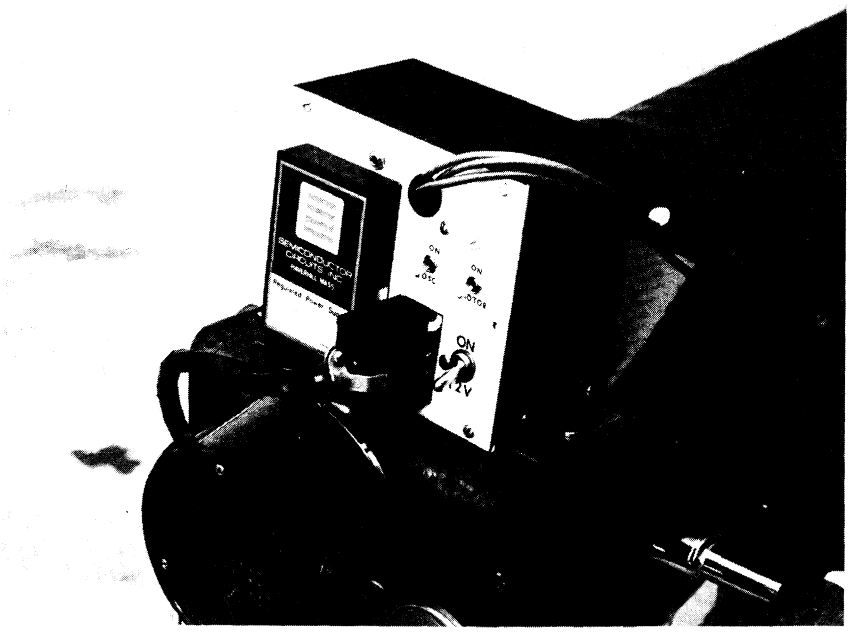


Figure 27. The data conditioning and coding package.

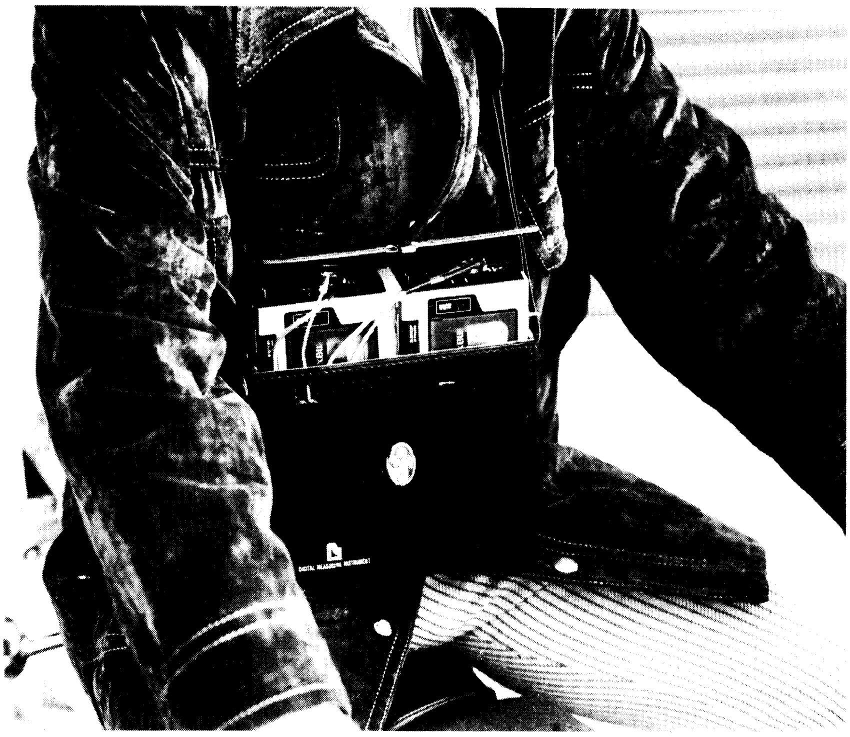


Figure 28. The recorder package carried by the subjects.

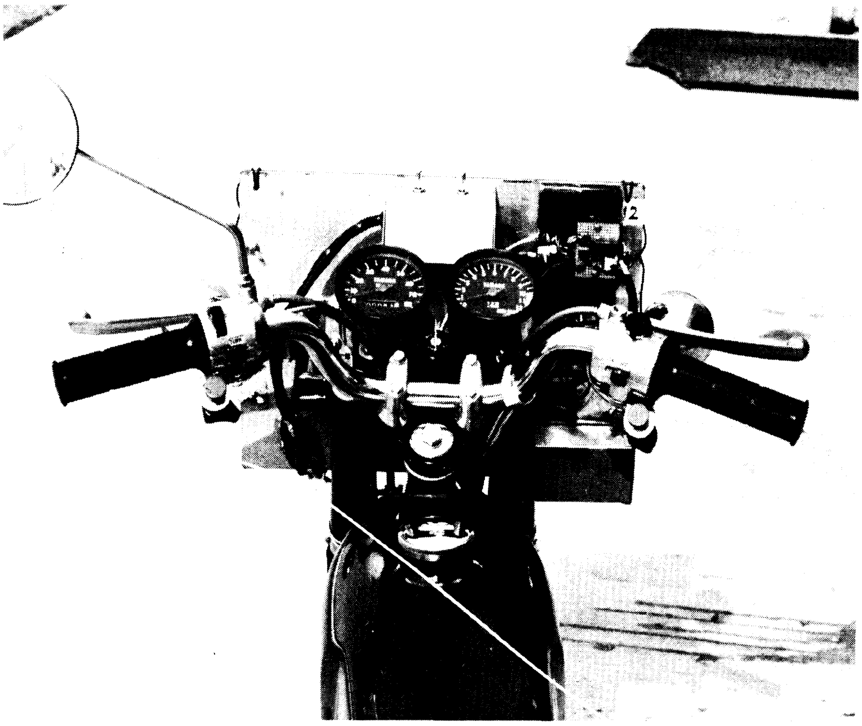


Figure 29. Response pushbuttons mounted on the handlebars.

"optimally". Resultant aim respective to the hotspot was found to be 0° horizontal, 4° down (below the horizontal axis). It was found necessary to aim the lamp this low to provide discernable illumination on the road. However, several additional tests were made with the center of this lamp's beam aimed at 0° vertical, 0° horizontal.

3. GE 4568 - Several tests were made with this lamp aimed to meet SAE J584 low beam specifications, i.e. with maximum intensities along a line 2° below the horizontal lamp axis.

All tests were conducted at the Dana Corporation test track in Ottawa Lake, Michigan. This facility is a three lane oval, 45 ft. wide and 1.75 miles in circumference, with two 1340 ft. straightaways, four 400 ft. spirals (straightaway-curve transitions) and two 2480 ft. curved sections of 917 ft. radius. The curved sections of the track are banked 6°.

Two target position courses were laid out on the track to enable tests to be made going in both directions around the track. These courses, shown in Figures 30 and 31, were mirror images and enabled measurement of identification distances on curves and straightaways both with and without disability glare created by the low beam headlamps of a stationary automobile. Each course required the identification of 23 HSRI type I targets (Figure 24) placed on the left and right edges of the lane and the detection of two rectangular 6 ft. by 16 in., 7% reflective "pedestrian" targets, and three elliptical 24 in. by 16 in. 3% reflective road surface targets.

PROCEDURE. Five subjects participated in the tests on each of five evenings. The first five subjects participated on two evenings, making runs with the 350 cc motorcycle on the first evening. These subjects drove the motorcycle in a counter-clockwise (left curve) direction only. The second five subjects participated on three evenings, driving the moped and 60 cc

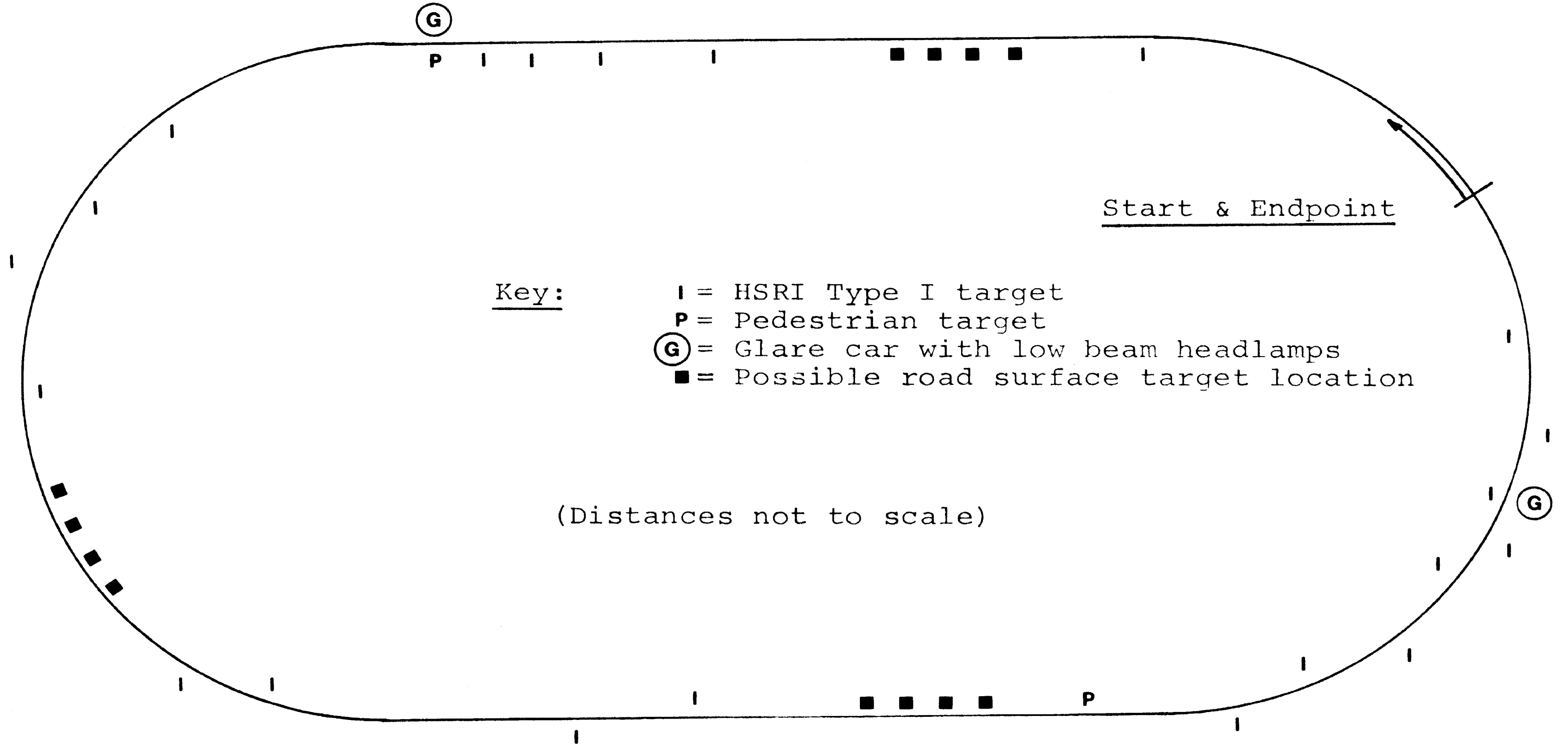


Figure 30. The test course configuration for counterclockwise (left curve) driving.

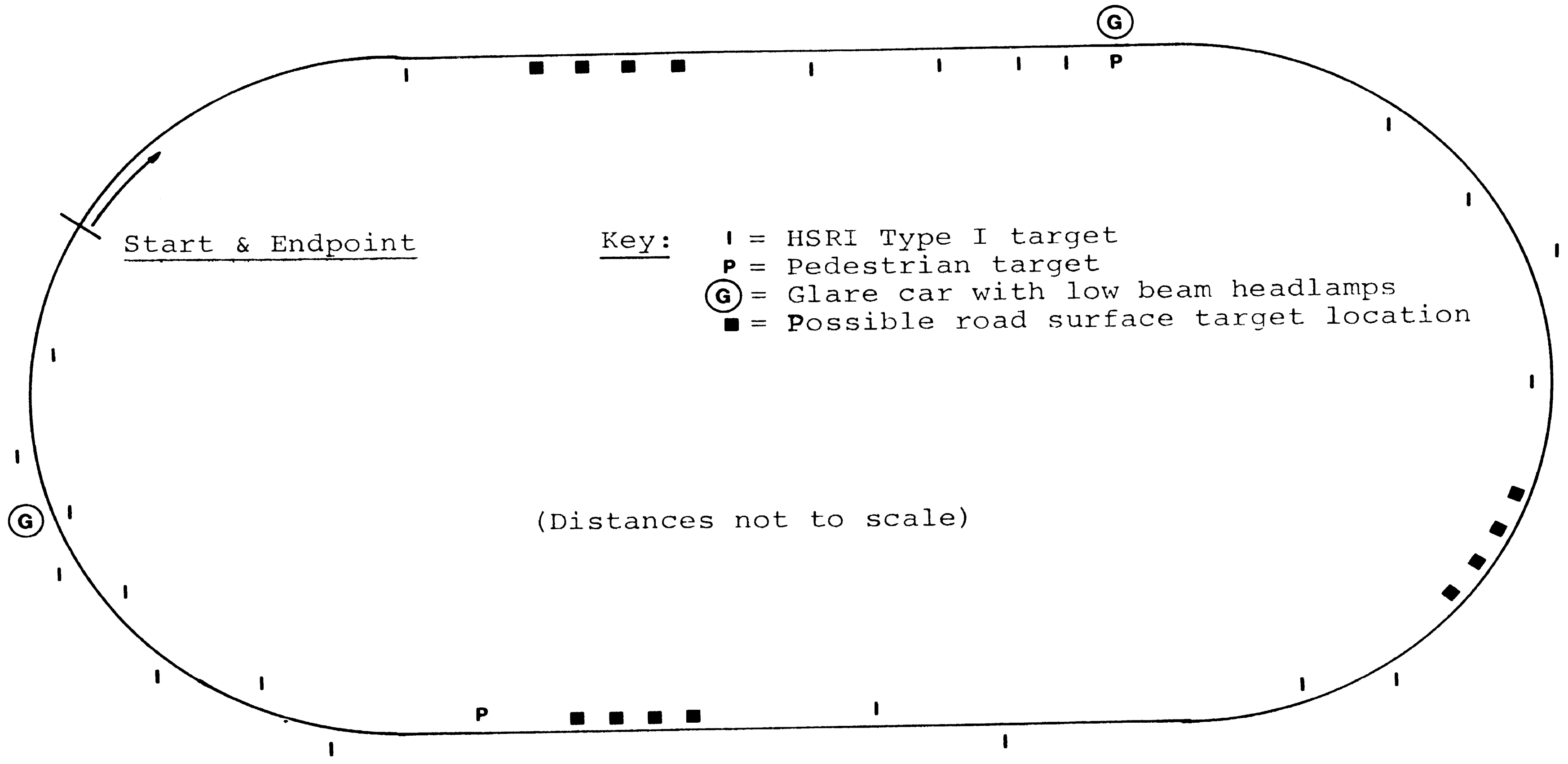


Figure 31. The test course configuration for clockwise (right curve) driving.

motorcycles the first and third nights and 350 cc motorcycle the second night. These subjects drove the motorcycle in a clockwise (right curve) direction exclusively. The second group of subjects was required to participate on the third occasion because a malfunction in the data recording system on their first night's testing resulted in the loss of some data recorded on the moped. Data for the GE-4568 lamp and the Cibie 6w lamp with 0° horizontal, 0° vertical aim were collected on this third evening.

On each evening of the experiment, the same basic procedure was followed: subjects were delivered to the test site at twilight so that they could be familiarized with the test course and operation of the instrumentation and motorcycles. The test procedure was also explained to them at this time. Subjects were instructed to drive the motorcycle in the center of the test lane at a constant speed of 30 mph (the moped was operated at its top speed of approximately 20 mph), to respond to type I targets by pressing either left or right handlebar mounted pushbutton switches to indicate the orientation of left or right identification targets, and to press both pushbutton switches at the same time to indicate the detection of pedestrian targets. Since the type I Targets can in some cases be detected before being identified, it was emphasized that responses should not be made until the direction of the target face could be positively identified. Subjects were instructed to respond to the detection of road surface targets by maneuvering the motorcycle from the center of the lane to the right edge of the lane as smoothly (i.e. with as little roll angle) as possible, but to be sure that the motorcycle was at the edge of the lane by the time the road surface target was passed.

Once the sun was down and each of the subjects had some practice in driving the motorcycles, practicing the road surface target avoidance maneuver, and operating the pushbutton switches, the experiment was begun. A lamp from the set of those scheduled to be tested was randomly selected and installed. Each subject made one circuit of the course with the given lamp before testing with another lamp was begun. Once all subjects had been tested with a lamp, an experimenter went out on the course and changed the positions of the road surface targets. This procedure was continued until all scheduled lamps and/or motorcycles had been tested. Between runs, subjects relaxed in a van stationed on the track for that purpose. At the conclusion of the identification tests each evening, each subject evaluated glare produced by each of the lamps tested, by rating the tolerability of the glare on a nine-point scale. Subjects were seated in an automobile during these evaluations and each of the lamps was rated after being driven toward them down a straight road by one of the experimenters.

It was originally planned for each subject to make one road surface target avoidance run with each of the lamps tested on the 350 cc and 60 cc motorcycles at a speed of 45 mph, if it was felt by all subjects and experimenters to be completely safe. These additional tests were conducted with the 350 cc motorcycle on the first night of the experiment without incident and all parties concerned felt that the task was safe and would not lead to any problems. On the second night of the experiment, however, one of the subjects performing the 45 mph test on the 60 cc motorcycle struck a type I target while on the course. Although the target was not struck by the motorcycle itself, but by a piece of the instrumentation fastened to the motorcycle, and although the subject claimed not to even be aware of the incident, part of the instrumentation was effectively destroyed. It was thus decided to conduct the 45 mph tests only with the 350 cc motorcycle, operating on the two high beams.

DESIGN. The low beam lamps evaluated in this experiment were selected to enable the comparison of three basic low beam patterns (symmetric, asymmetric, and sharp cutoff), as generated by lamps representative of current supply practices (Stanley 24M-S, Koito 4438, CEV 158), and lamps which represent greater optimization because of their higher power (Westinghouse W4 and Hella H4) or experimental nature (Stanley KH-15). Two high beams, representing current supply practices (Koito 4438), and design optimization (Westinghous W4) were also evaluated to enable comparison with each other and the various low beams. The lamps evaluated on the moped (CEV 171 and Cibie 6w) were selected to represent the extremes of the distribution of currently available moped lamps. Partial data was taken for another moped lamp (GE 4568) aimed to meet SAE J584 low beam photometric standards, and for the Cibie 6w lamp aimed to maximize identification distance.

The design of the experiment, the nature of the driving tasks and the similarities of eye height and lamp mounting height between the 60 cc and 350 cc motorcycles enabled the identification distance data generated for the six low beams and two high beams on these motorcycles to be statistically examined in one group. Since the moped was operated at maximum speed, which was lower than the speed used on the two larger motorcycles and did not require speed maintenance on the part of the drivers, identification distance data taken on the moped were examined separately. Because of the inherent differences in the handling characteristics of the three motorcycles, the object avoidance measures (roll rate and maximum roll angle) were also statistically examined independently. The remaining dependent variables, speed maintenance (mean speed and speed standard deviation) and subjective glare, were each examined in separate analyses.

The basic statistical analysis performed on the various data was the analysis of variance. Post hoc comparisons between levels of significant main effects and interactions were made by Tukey (b) tests.

In summary, the following independent variables and dependent variables were examined:

Independent variables

Headlamps (12 levels; Table 15)

Motorcycles (3 levels; moped, 60 cc and 350 cc)

Road geometry (three levels; straight, and left and right curves)

Presence of disability glare (two levels; with and without glare)

Distance of target from glare source (various levels)

Lateral target placement (left or right road edge)

Dependent Variables

Identification distance to HSRI type I targets

Detection distance of pedestrian targets

Mean motorcycle speed

Motorcycle speed standard deviation

Subjective glare

Maximum roll angle in the road surface target avoidance maneuver

Roll rate in the road surface target avoidance maneuver

Because of the large number of statistical comparisons made, an alpha level of .01 was chosen to indicate statistical significance.

RESULTS

IDENTIFICATION DISTANCES OF TYPE-I TARGETS: HIGH AND LOW BEAMS, STRAIGHT ROAD. A three factor unreplicated analysis of variance with factors of target distance from glare source (six levels, representing: right edge targets 700 ft., 400 ft., 200 ft., and 100 ft. from the glare source, and left and right edge targets with no glare), headlamp (eight levels: six low and two high beams) and subjects (10 levels) was performed on these data. The headlamp main effect and Target Distance x Headlamp interaction were found significant at the $p < .01$ level. Since the main effect was contained in the interaction, differences between headlamps were examined within levels of the target position factor. Figure 32 illustrates mean identification distances of the eight beams to the four right edge targets approaching the glare source. Identification distances to these targets associated with the W4 and 4438 high beams were found to be significantly greater than distances associated with all other lamps. Distances associated with the H4 and W4 low beams were significantly greater than those afforded by the 24M-S and KH-15 lamps at all targets. The H4 lamp provided significantly greater identification distances than the CEV 158 lamp at the 400 ft., 200 ft., and 100 ft. distances. No other differences between lamps were significant. There were not significant changes in identification distance as the glare source was approached. This figure also shows mean identification distances afforded by a conventional two lamp automobile low beam headlighting system, as measured by Mortimer and Olson (1974) in field tests with the same targets, road geometry, and glare source. It is quite evident that only the high beams tested on the motorcycle provide identification distances comparable to the automobile low beam system. While a great deal of this difference is attributable to the fact that the automobile headlamps are directing higher intensities down the road (and require roughly twice as much power to operate; 120w total automobile vs. 60-35w total motorcycle low beam), it should also be noted that the motorcycle driving task was more complex, as the motorcyclists had to maintain a particular speed (the automobile tests were run on cruise control) and may have limited their preview distances somewhat in order to scan the road surface for road surface targets. Figure 33 illustrates mean identification distances to the right and left road edge targets in the straight road no glare condition. Again, the W4 and 4438

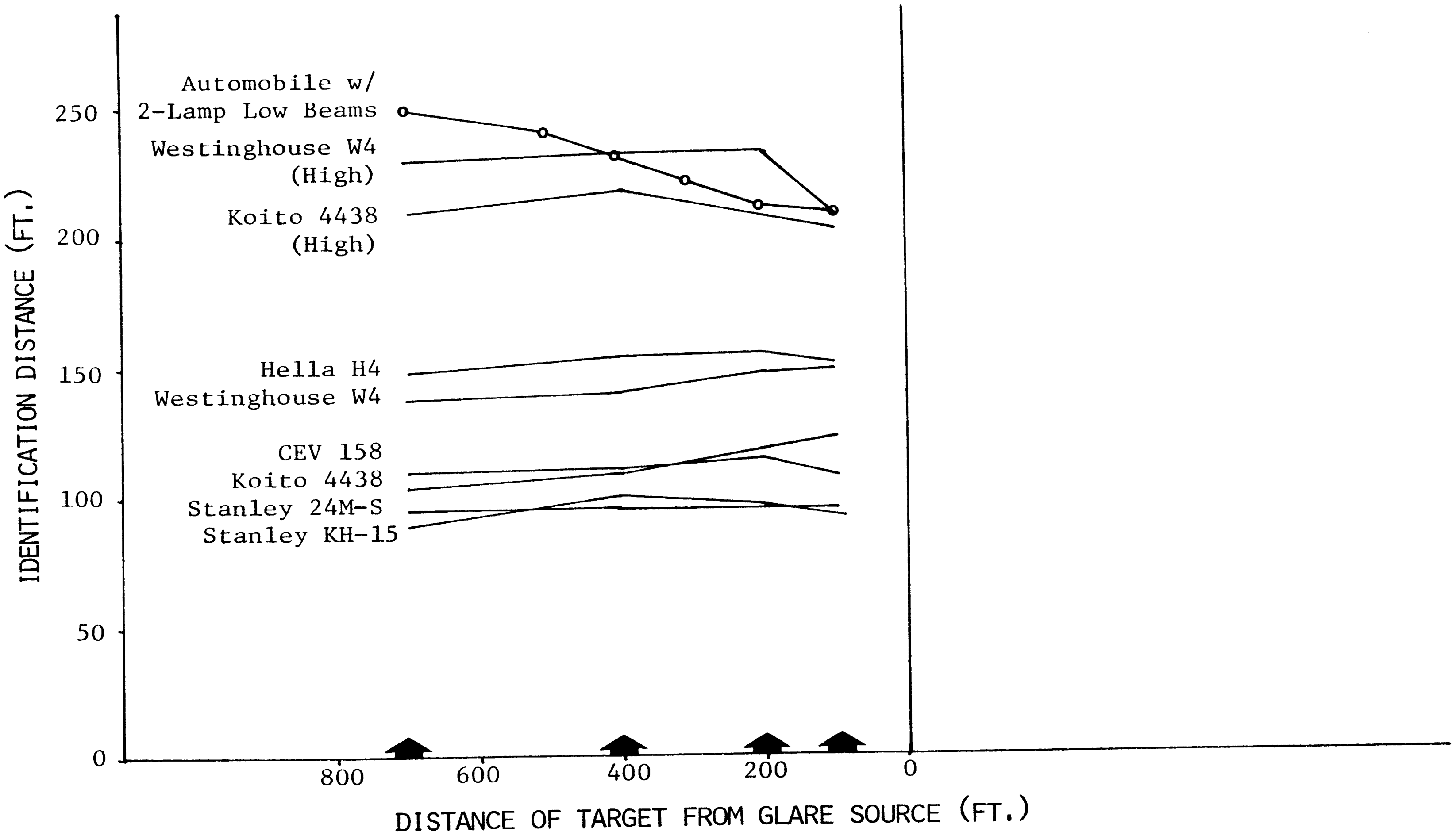


Figure 32. Mean identification distances of HSRI Type I targets afforded by high and low beams as a function of distance of target from glare source. (Straight road, target on right)

(Automobile Data from Mortimer and Olson, 1974)

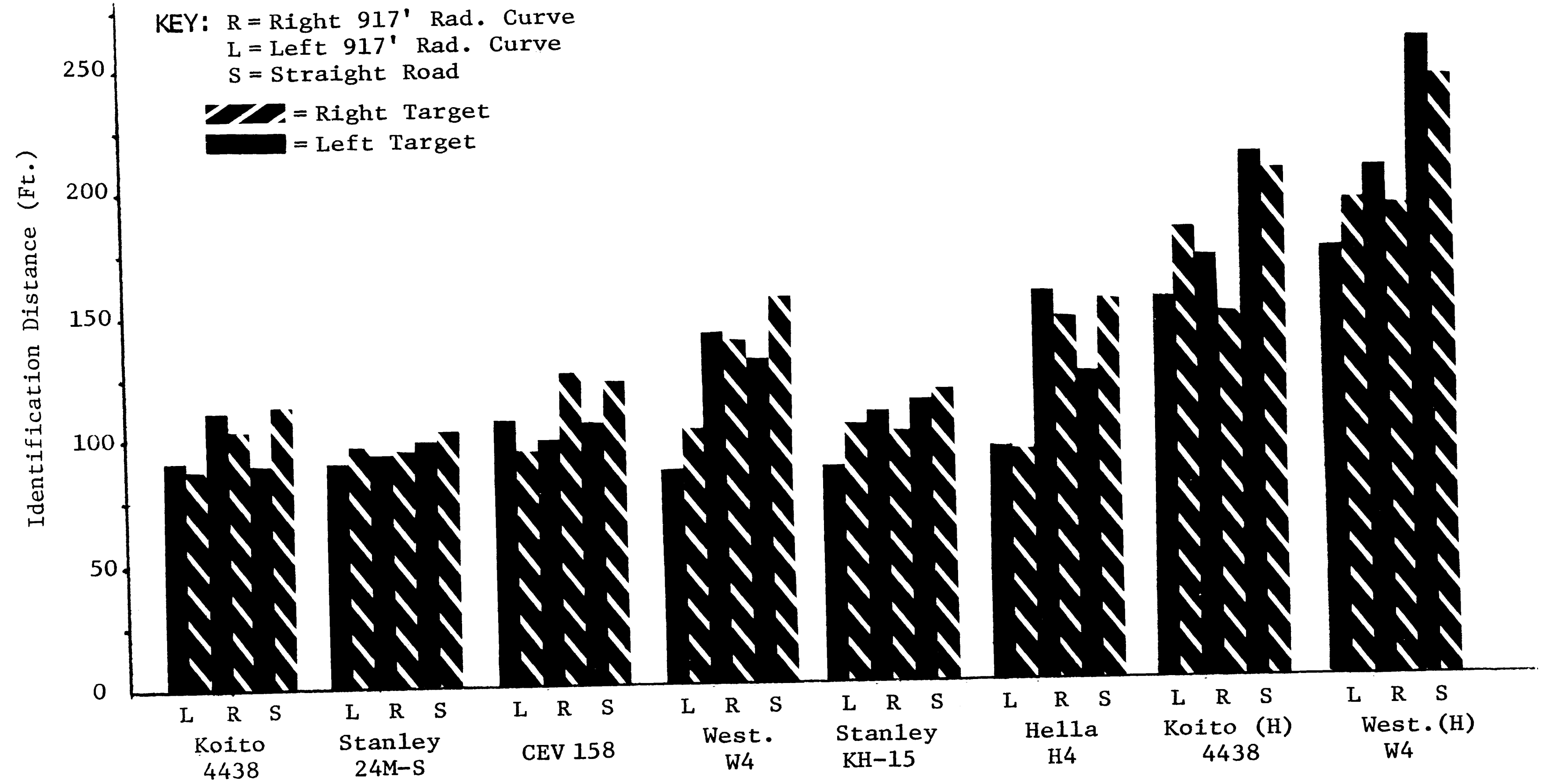


Figure 33. Mean no-glare identification distances of HSRI Type I targets afforded by high and low beams on right and left 917' radius curves and on a straight road, for targets on the left and right edges of the traffic lane.

high beams provided significantly greater identification distances to these targets than all other lamps. The W4 and H4 low beams also provided significantly greater distances than the 24M-S low to the right target. For the left target, the W4 low was significantly greater than the 4438 low and the W4 high was significantly greater than the 4438.

The differences in straight road identification distances are thus chiefly attributable to lamp power. This is particularly evident in Figure 32 as the W4 and 4438 high beams, the H4 and W4 low beams, and remaining lamps form three visually discernable groups.

IDENTIFICATION DISTANCES OF TYPE I TARGETS: HIGH AND LOW BEAMS, CURVED ROADS, NO GLARE CONDITION. These data were analyzed in a four factor nested analysis of variance with two replications, with factors of target side (two levels; left and right edge), headlamps (eight levels; six low and two high beams), subjects (five levels nested under curve direction), and curve direction (two levels; left and right curves).

This analysis showed significant headlamp and curve direction main effects, and significant Target Side x Curve Direction, Headlamp x Curve Direction, Target Side x Headlamp, and Target Side x Headlamp x Curve Direction interactions. Since the three way interaction contained all other significant effects, the analysis was interpreted by examining the level means of each of the factors of the three way interaction within levels of the other two factors.

Tukey (b) tests performed on differences in lamp means showed for the left curve, left target, and left curve, right target conditions, significant differences only between the two high beams and six low beams. For the right curve, left target and right curve, right target conditions, the W4 high beam was significantly greater than all others, and the 4438 high, W4 low, and H4 low beams were significantly greater than the 4438, 24M-S and KH-15 low beams. Additionally, in the right curve, right target condition, the 4438 high, W4 low, and H4 low beams provided significantly greater identification distances than the 4438 low beam. Figure 33 shows mean identification distances for all lamps, to left and right side targets, for right and left curves. These differences, again, chiefly reflect differences in lamp power or maximum intensity.

Post hoc analysis of the mean identification distance to left and right side targets showed mean identification distances on the left curve to be greater for right side than left side targets for the W4 and 4438 high beams and KH-15 low beams. On the right curve, the CEV 158 low beam provided greater identification distances to the left side targets. The only consistent finding is that the 4438 high beam significantly facilitates identification of targets on the side of the road opposite the direction of the curve. No other lamp showed significant target effects for both curve directions.

The curve direction factor is a between-groups effect; subjects drove either left or right curves, but not both. Analysis of the curve direction means within levels of headlamps and target sides showed mean identification distances to be greater on right curves to left side targets with the W4, H4, and KH-15 low beams and the W4 high beam, and greater on right curves to right side targets with the CEV 158, W4, and H4 low beams. The only significantly greater distance associated with the left curve is to right side targets with the 4438 high beam. The fact that seven of the eight significant differences are associated with the right curve at both target side locations indicates that the differences of significance lay more with the subject groups than with the lamp characteristics. One would intuitively expect identification distance for some lamps, at least, to be greater for right targets on left curves and left targets on right curves. The fact that such differences were not found gives some indications that the subjects were not responding in the same manner.

IDENTIFICATION DISTANCES OF TYPE-I TARGETS: HIGH AND LOW BEAMS, CURVED ROADS, GLARE CONDITION. These data were analyzed in a four factor nested analysis of variance with no replication. The factors were: target distance from glare source (seven levels; right edge targets at 700 ft., 200 ft., 0 ft., and -400 ft. from the glare source, and left edge targets at 500 ft., 100 ft., and -200 ft. from the glare source); headlamps (eight levels; two high and six low beams); subjects (five levels, nested under curve direction);and curve direction (two levels; left and right curves). This analysis produced significant main effects of target distance and headlamps and significant Target Distance x Curve Direction, Headlamp x Curve Direction, Target Distance x Headlamp, and Target Distance x Headlamp x Curve Direction interactions. Mean identification distances for each of the eight headlamps as the glare source is approached and passed are shown for left curve, left targets in Figure 34; left curve, right targets in Figure 35; right curve, left targets in Figure 36; and right curve, right targets in Figure 37.

The significant Target Distance x Headlamp x Curve Direction interaction was examined by performing Tukey (b) tests on headlamp and left and right target distance means within levels of curve direction. For the left curve, right target condition, the W4 and 4438 high beams were found to provide significantly greater visibility distances than the six low beams, at each of the target positions. Significant reductions in identification distance as the glare source was approached were found for the W4 and 4438 high beams and for the W4, H4, and KH-15 low beams.

In the left curve, left target condition, the two high beams were, again, significantly greater at all target positions than

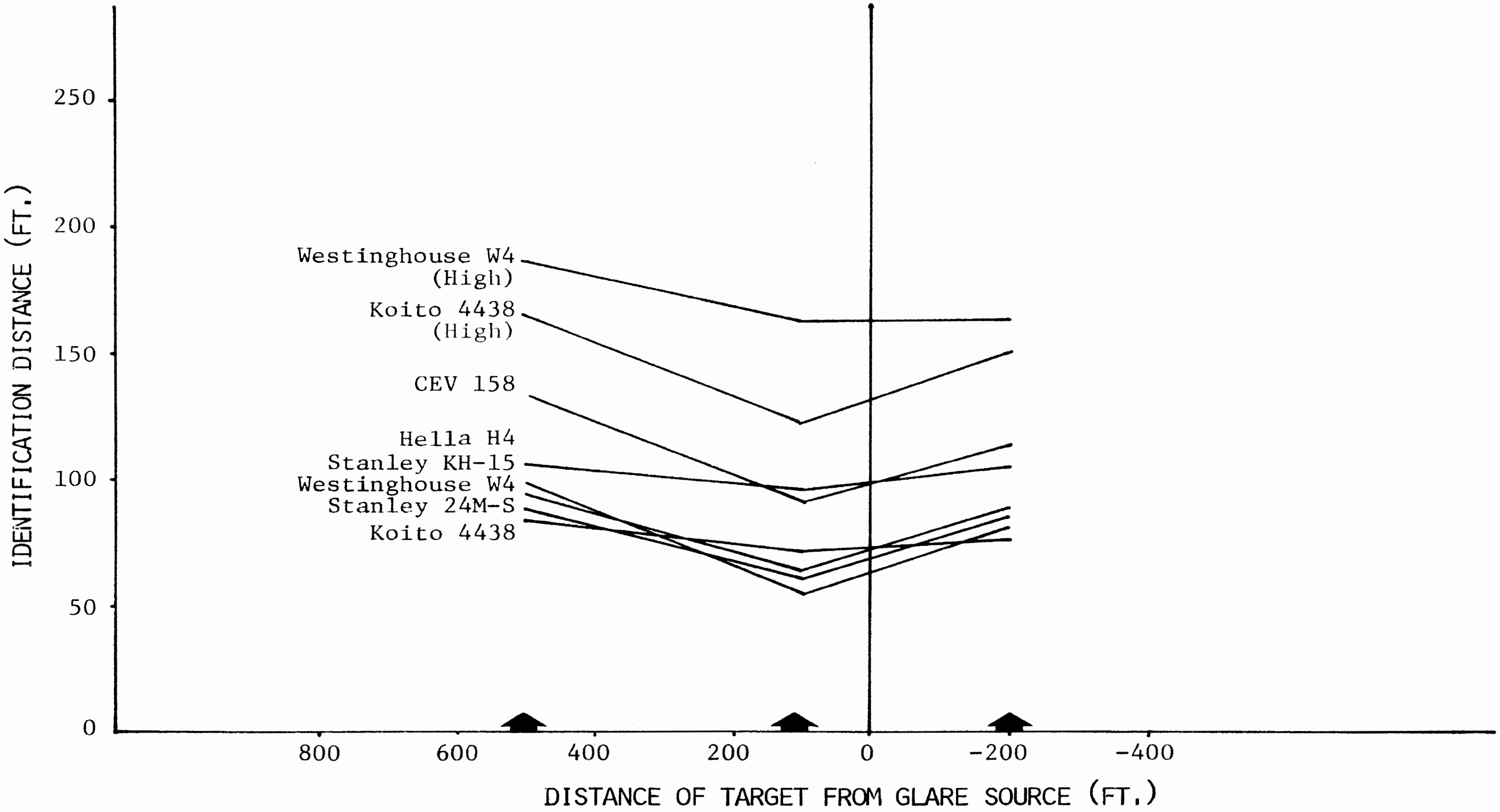


Figure 34. Mean identification distances of HSRI Type I targets afforded by high and low beams as a function of distance of target from glare source. (917' Radius left curve, target on left)

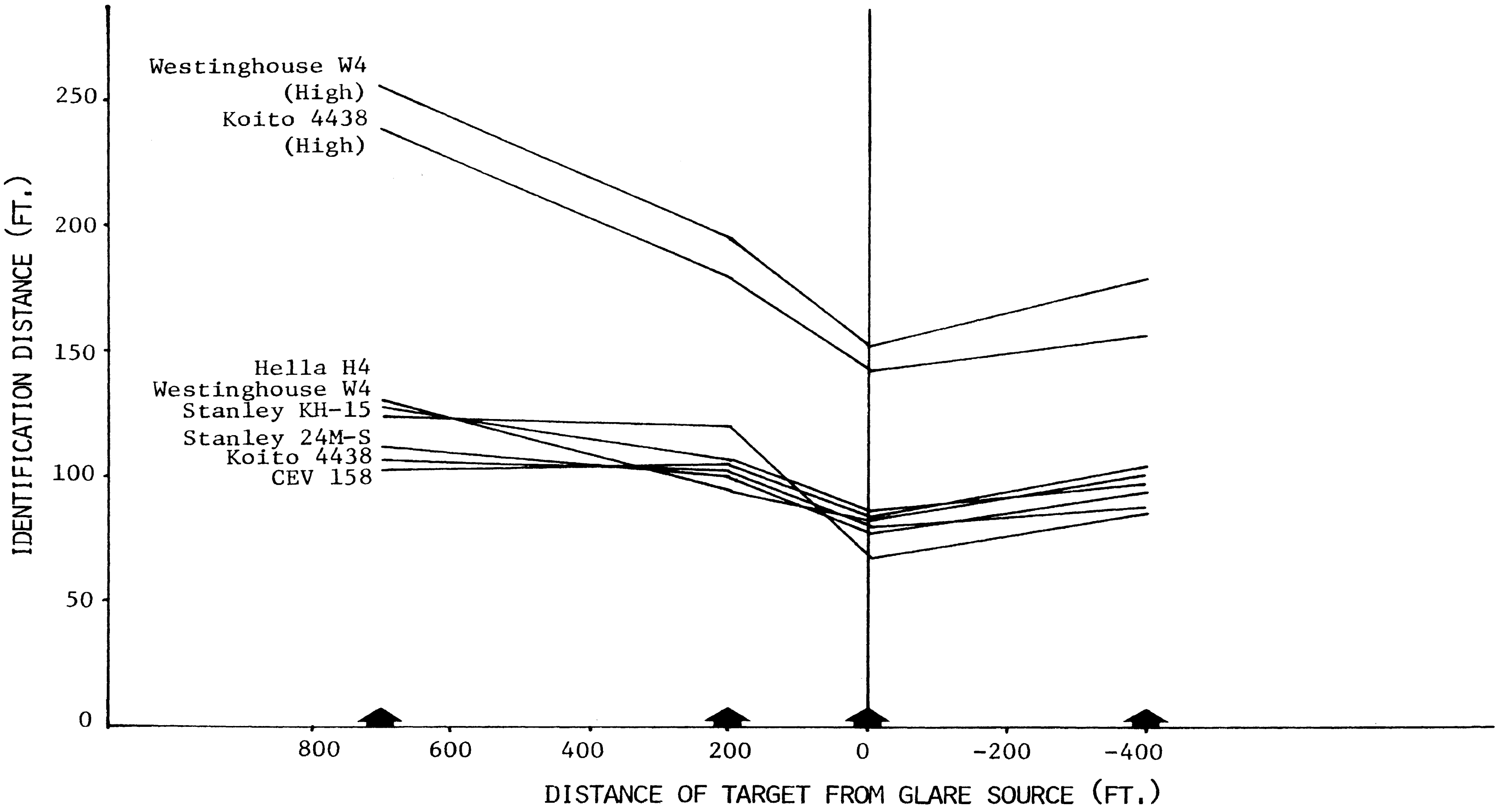


Figure 35. Mean identification distances of HSRI Type I targets afforded by high and low beams as a function of target distance from glare source. (917' Radius left curve, target on right)

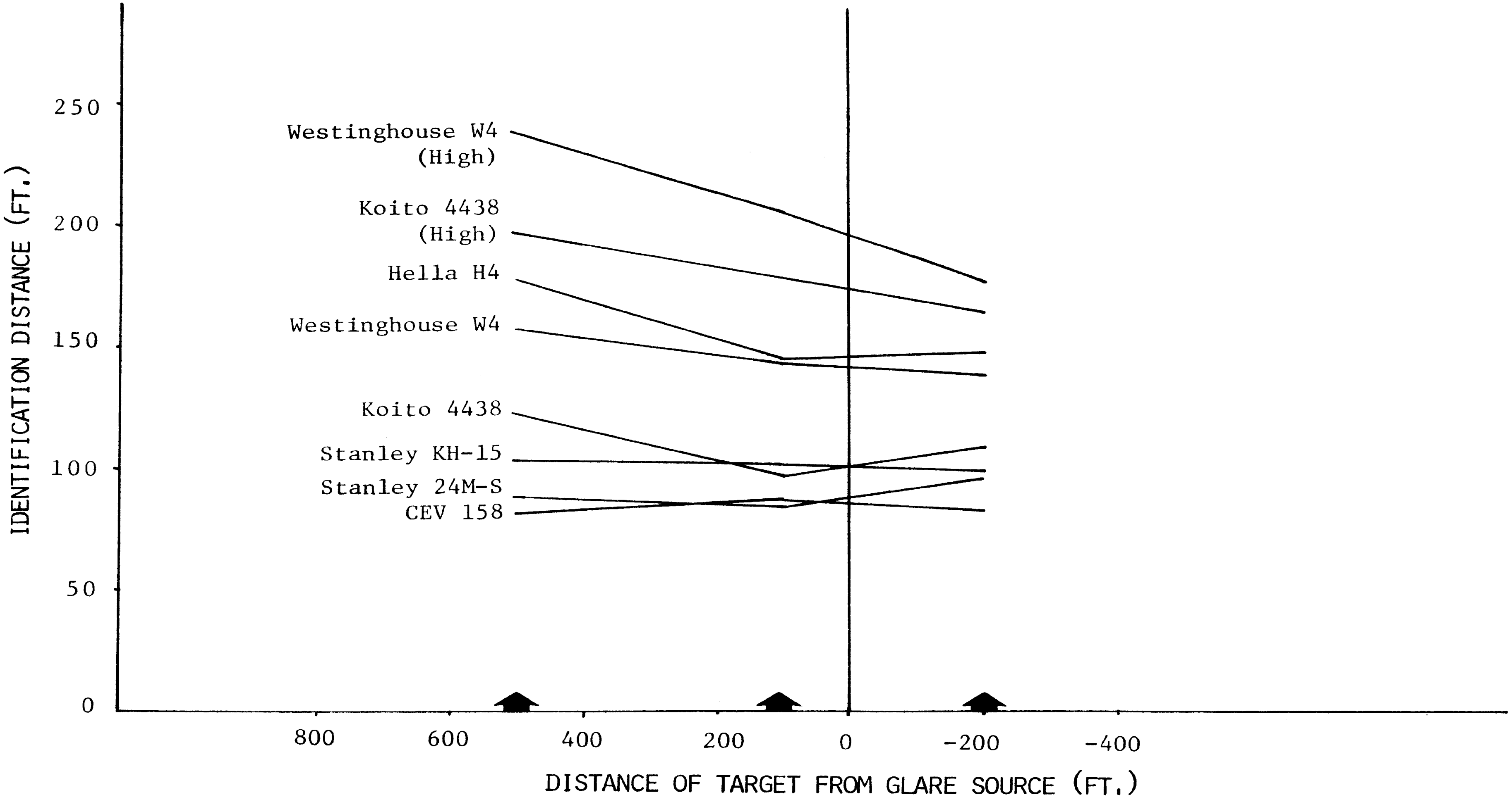


Figure 36. Mean identification distances to HSRI Type I targets afforded by high and low beams as a function of distance of target from glare source. (917' Radius right curve, target on left)

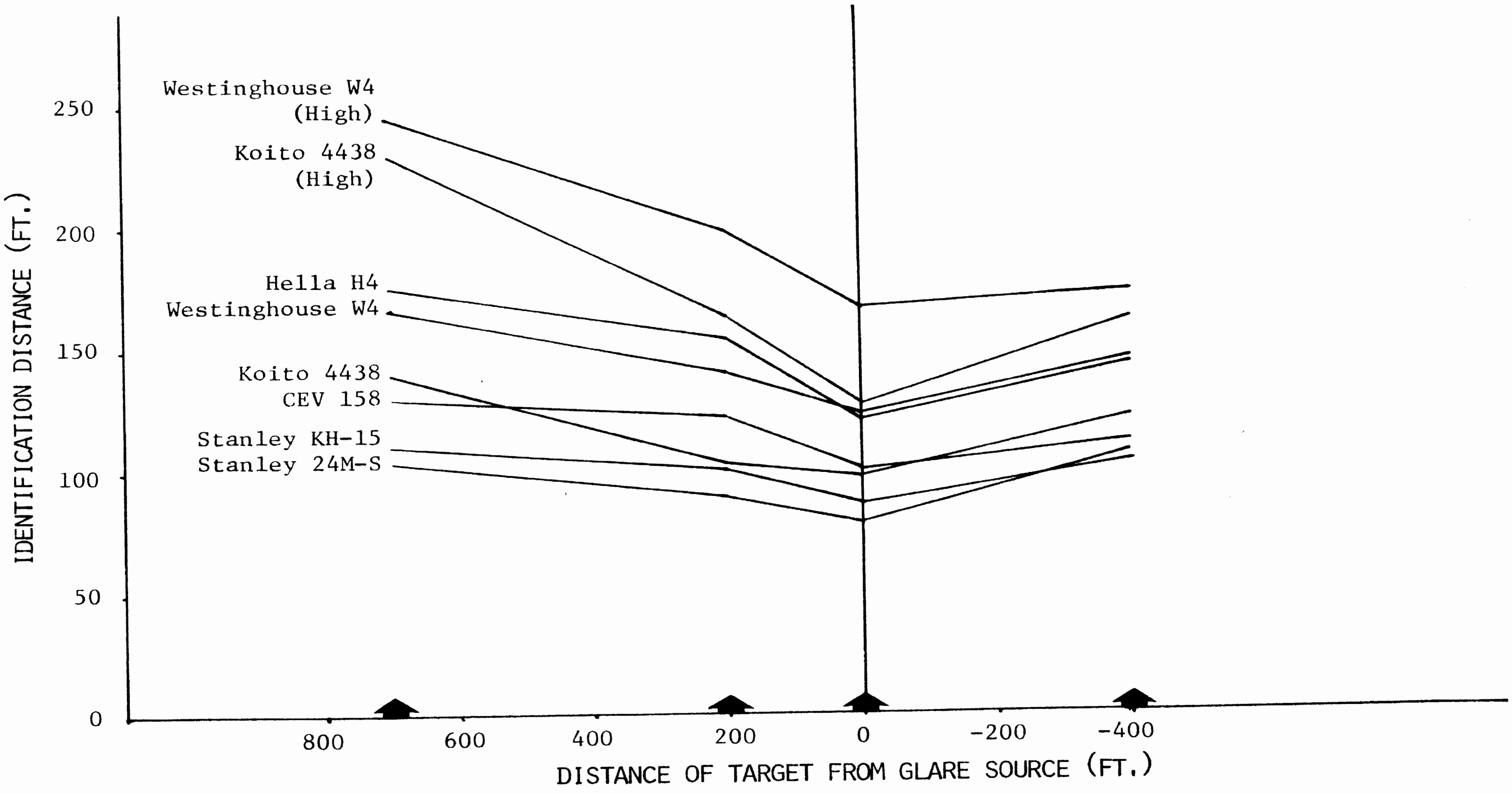


Figure 37. Mean identification distances of HSRI Type I Targets afforded by high and low beams as a function of distance of target from glare source. (917' Radius right curve, target on right)

the six low beams . In addition, the CEV 158 low beam was found to produce significantly greater mean identification distances than the 4438 and 24M-S low beams to the target 500 ft. from the glare source. No other differences were found between lamps. Identification distances for the 4438 high and CEV 158 and KH-15 low beams were significantly reduced as the glare source was approached. No significant reductions were found for the remaining lamps.

A large number of significant differences in the mean identification distance were found between lamps in the right curve, left and right target conditions. For this reason, the reader is referred to Table 17 and to Figures 36 and 37 for specific details. It can be seen from Table 17 that significantly greater performance was associated with the W4 and 4438 high beams and H4 and W4 low beams only. The W4 high beam provided significantly greater identification distances: (1) than all other lamps tested in three of the seven conditions; (2) than all low beams in two conditions; and (3) than the KH-15, 24M-S, CEV 158, and 4438 low beams in the remaining two conditions. The Koito 4438 high beam produced greater distances than the KH-15, 24M-S, CEV 158 and 4438 low beams in six of the seven right curve conditions. The H4 and W4 low beams produced significantly greater identification distances to all targets than the KH-15, 24M-S, CEV 158, and 4438 low beams and produced greater distances to most of the right targets than the 24M-S and KH-15 low beams. The 4438 high differed significantly from the H4 low in one condition and from the W4 low in two conditions. Significant reduction in identification distance of right targets was found for the W4 and 4438 high beams and W4, H4, and 4438 low beams. The only corresponding reduction in identification distance of the left targets was shown by the W4 high beam.

Table 17. Summary of significant differences in mean identification distances to HSRI Type I targets between high and low beam lamps for the 917 ft. radius right curve test conditions.

Target Position	Distance of Target from Glare Source	Significant Differences
Left	500'	W4 high > all others 4438 high > all but H4 H4, W4 lows > KH-15, 24M-S, CEV 158, 4438 lows
	100'	W4 high > all low beams 4438 high, H4, W4 lows > 4438 low, 24M-S, CEV 158, KH-15
	-200'	W4, 4438 highs, H4, W4 lows > 4438 low, 24M-S, CEV 158, KH-15
Right	700'	W4, 4438 highs > all lows H4, W4 lows > 24M-S, KH-15 H4 > CEV 158
	300'	W4 high > all others 4438 high > 4438 low, CEV 158 24M-S, KH-15 H4, W4 lows > 24M-S, KH-15 H4 > 4438 low
	0'	W4 high > all others 4438 high, H4, W4 lows > 24M-S
	-400'	W4, 4438 highs > 4438 low, 24M-S, KH-15, CEV 158 H4, W4 lows > KH-15

Again, lamp power or maximum intensity can account for most of the significant differences found. However, from inspection of Figures 34-37 and from the data presented above, it is also evident that the most powerful lamps are also the most susceptible to reductions in identification distance as a glare source is approached. This is most evident for targets on the right edge of the lane.

DETECTION DISTANCES OF PEDESTRIAN TARGETS: HIGH AND LOW BEAMS. Two pedestrian targets were placed on the straight track sections, one in a glare location, and one on the opposite side of the track with no glare. Unfortunately, these targets were not responded to by a number of subjects. Because the experimental design does not allow for missing data in analysis, the few available detection distances were not analyzed.

IDENTIFICATION DISTANCES OF TYPE-I TARGETS: MOPED LAMPS. Several separate analyses of variance were performed on these data because a complete data set was available only for the CEV 171 and Cibie 6w (4°D aim) lamps. Data were collected for the GE 4568 lamp and the Cibie 6w lamp with 0° vertical aim only for five subjects, in straight road and right curve conditions.

Statistical comparisons of identification distances afforded by the CEV 171 and Cibie 6w (4°D aim) lamp for the various test conditions were made by analyses of variance in the manner described above. The analyses showed the CEV 171 lamp to provide greater identification distances than the Cibie/Solex 6w lamp in every test condition. Mean identification distances for these lamps are shown for the straight and curved road, no glare conditions in Figure 38, for the straight road approaching glare condition in Figure 39, and for the left curve, left target; left curve, right target; right curve, left target; and right curve, right target, approaching glare conditions in Figures 40, 41, 42, and 43 respectively. Although neither lamp showed

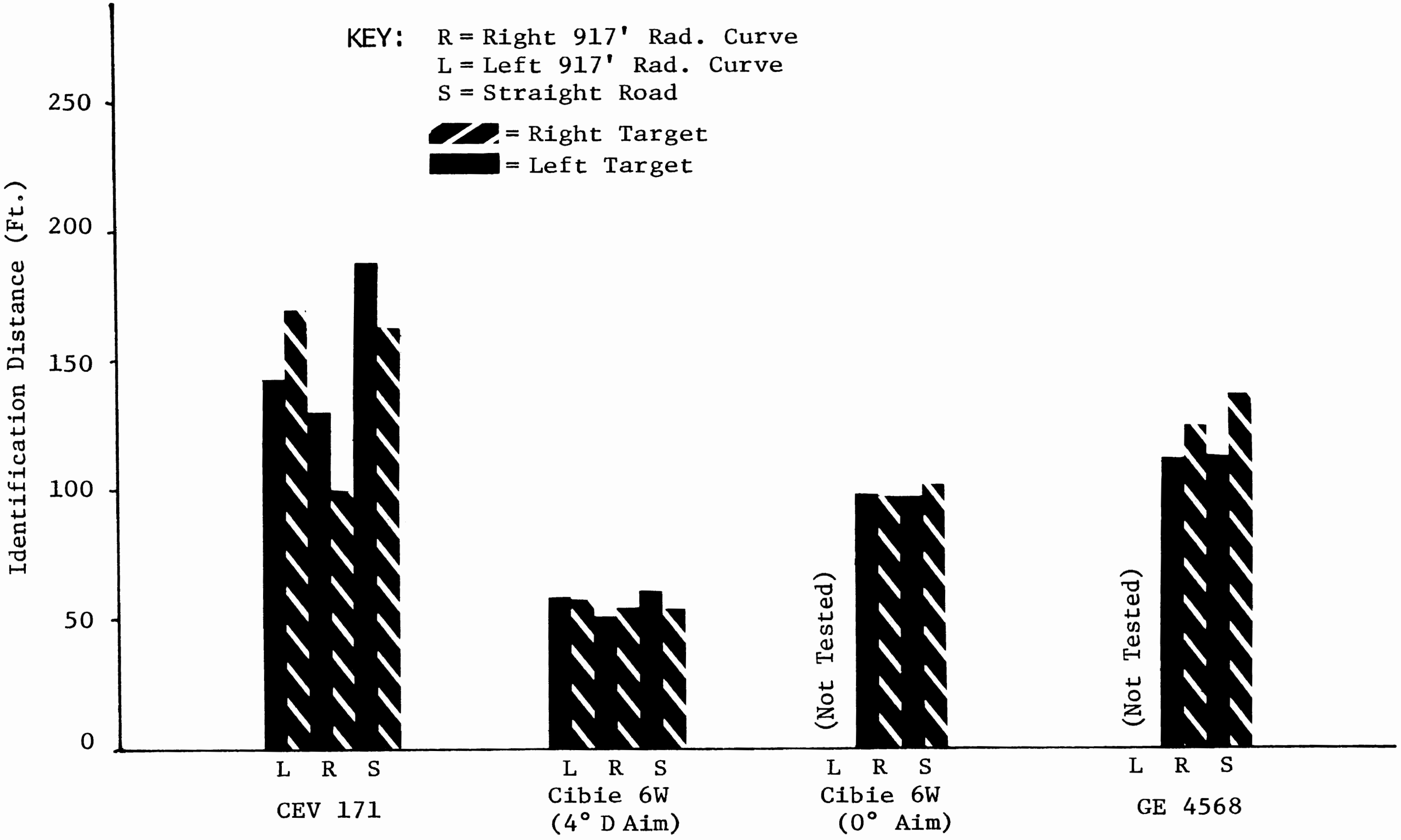


Figure 38. Mean no-glare identification distances of HSRI Type I targets afforded by single-beam moped headlamps on left and right 917' radius curves and on a straight road, for targets at the left and right edges of the traffic lane.

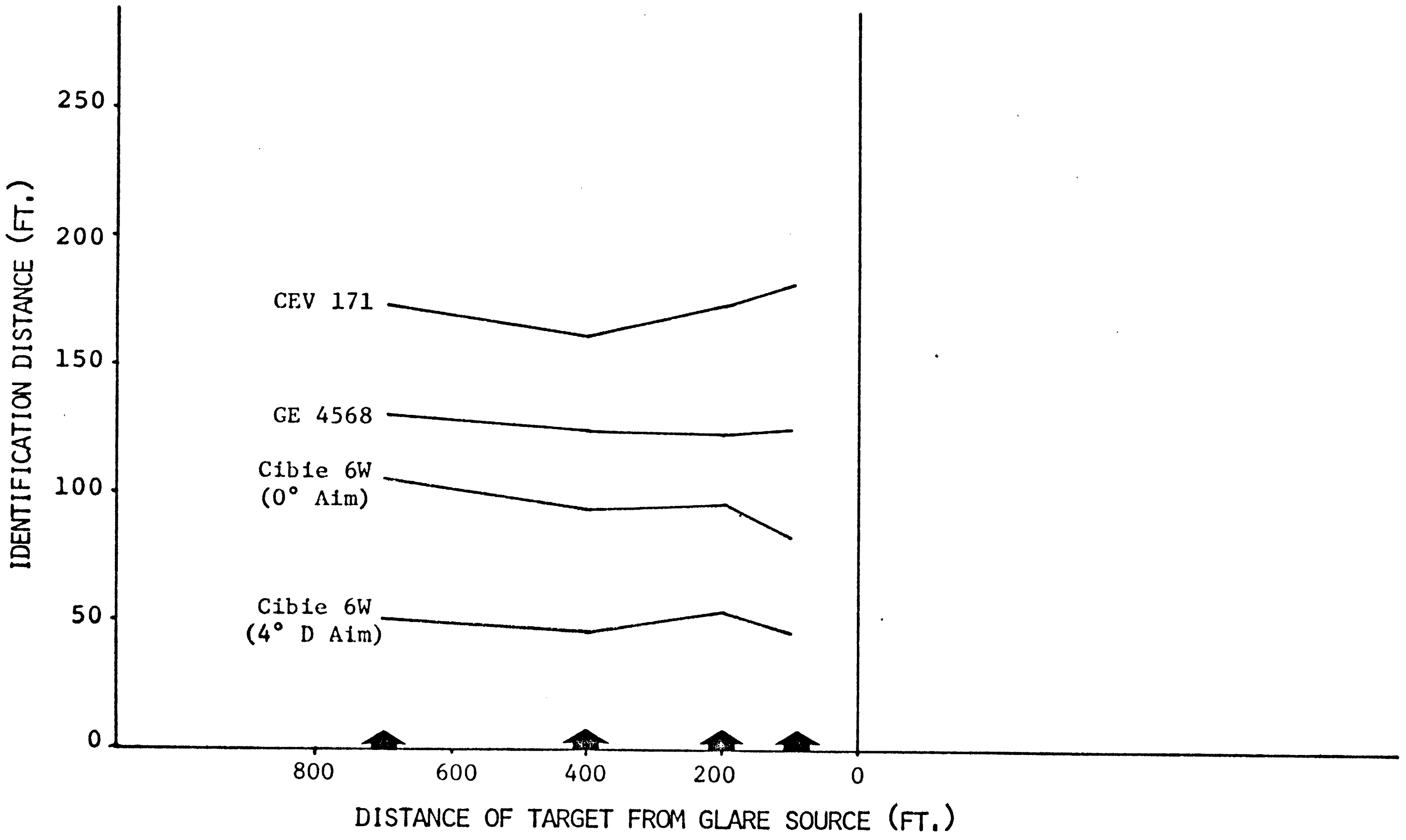


Figure 39. Mean identification distances of HSRI Type I targets afforded by single beam moped headlamps as a function of distance of target from glare source (Straight road, target on right).

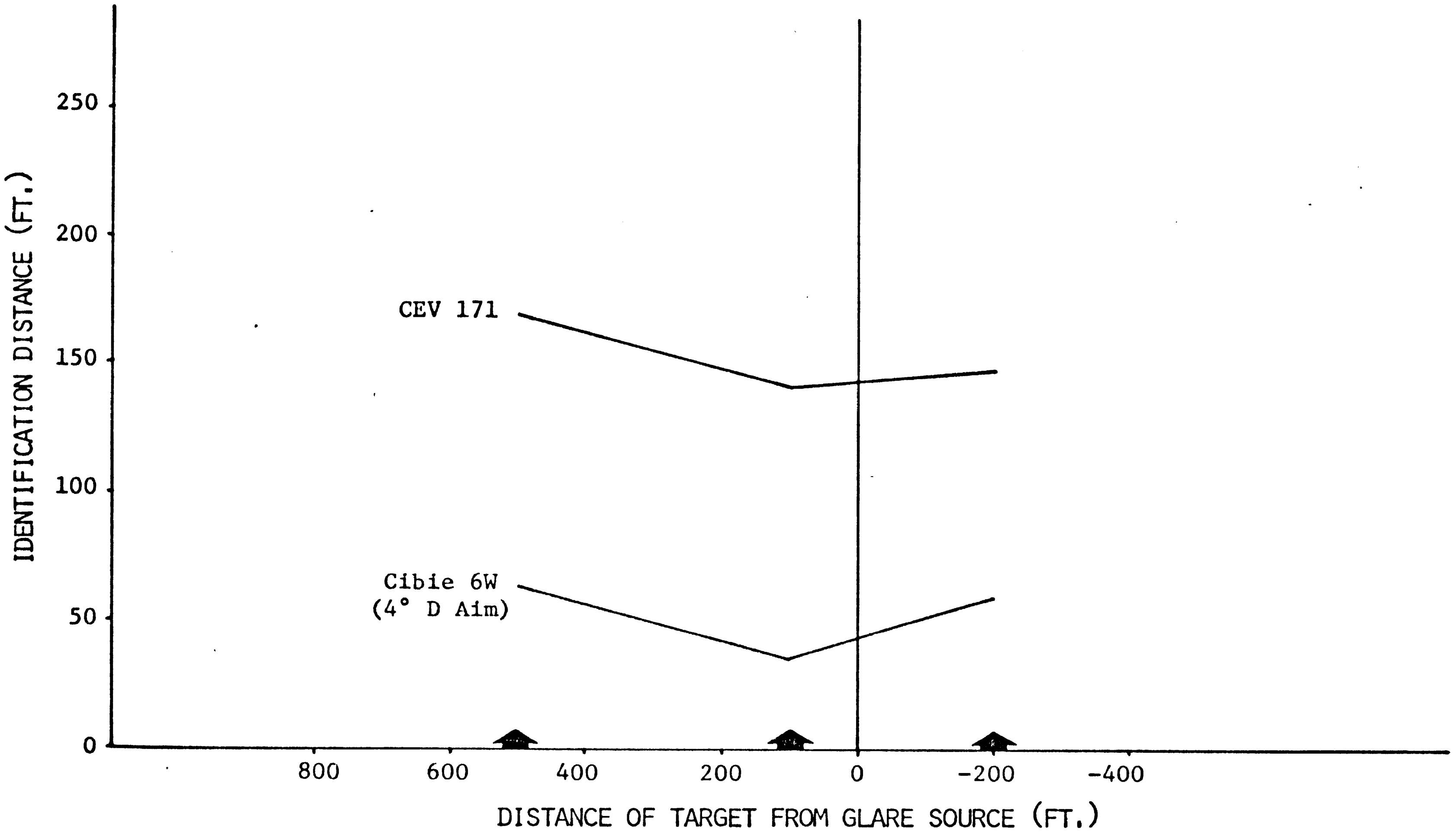


Figure 40. Mean identification distances of HSRI Type I targets afforded by single beam moped headlamps as a function of distance of target from glare source (917' Radius left curve, target on left).

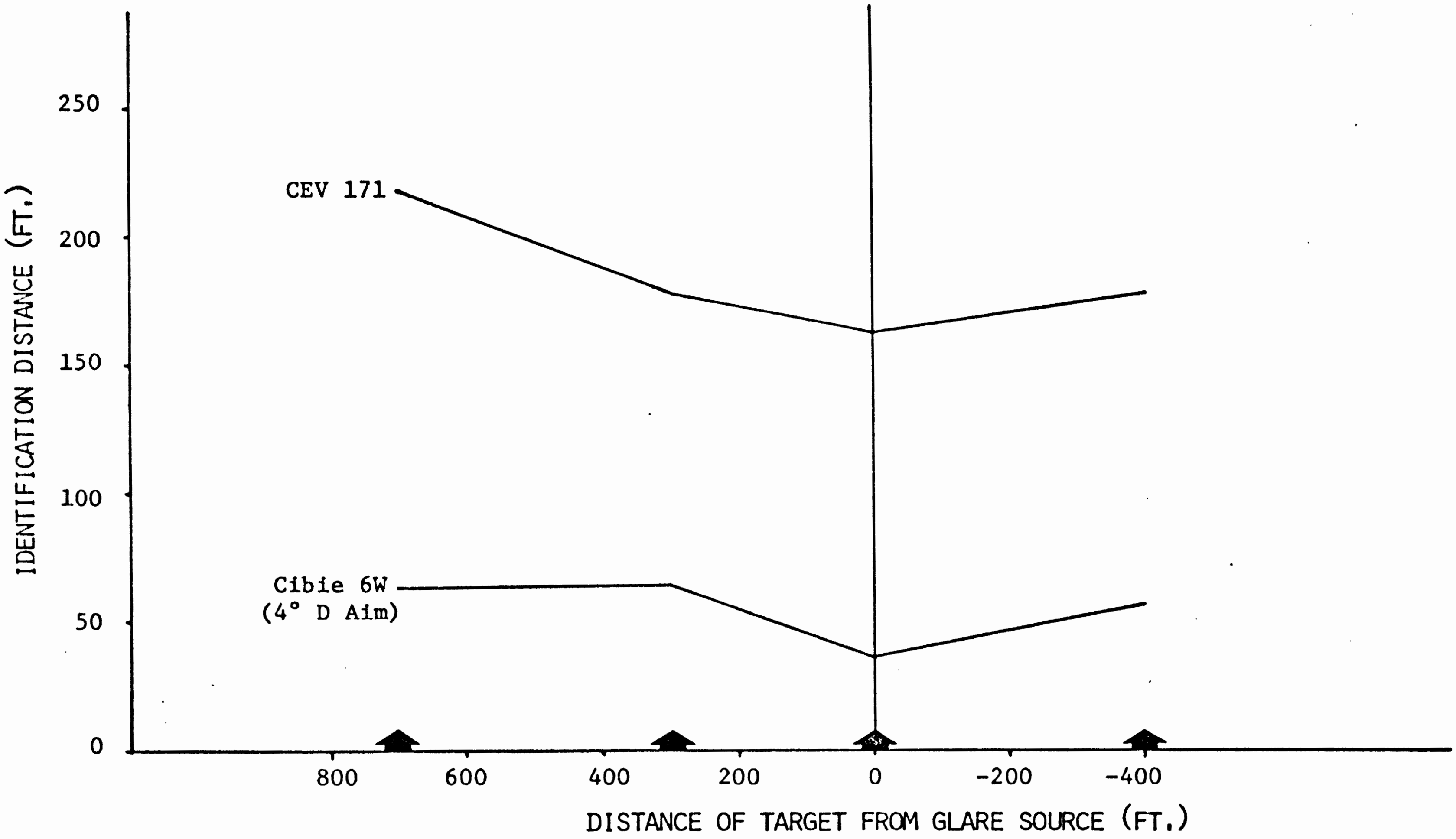


Figure 41. Mean identification distances to HSRI Type I targets afforded by single beam moped headlamps as a function of distance of target from glare source (917 Radius left curve, target on right).

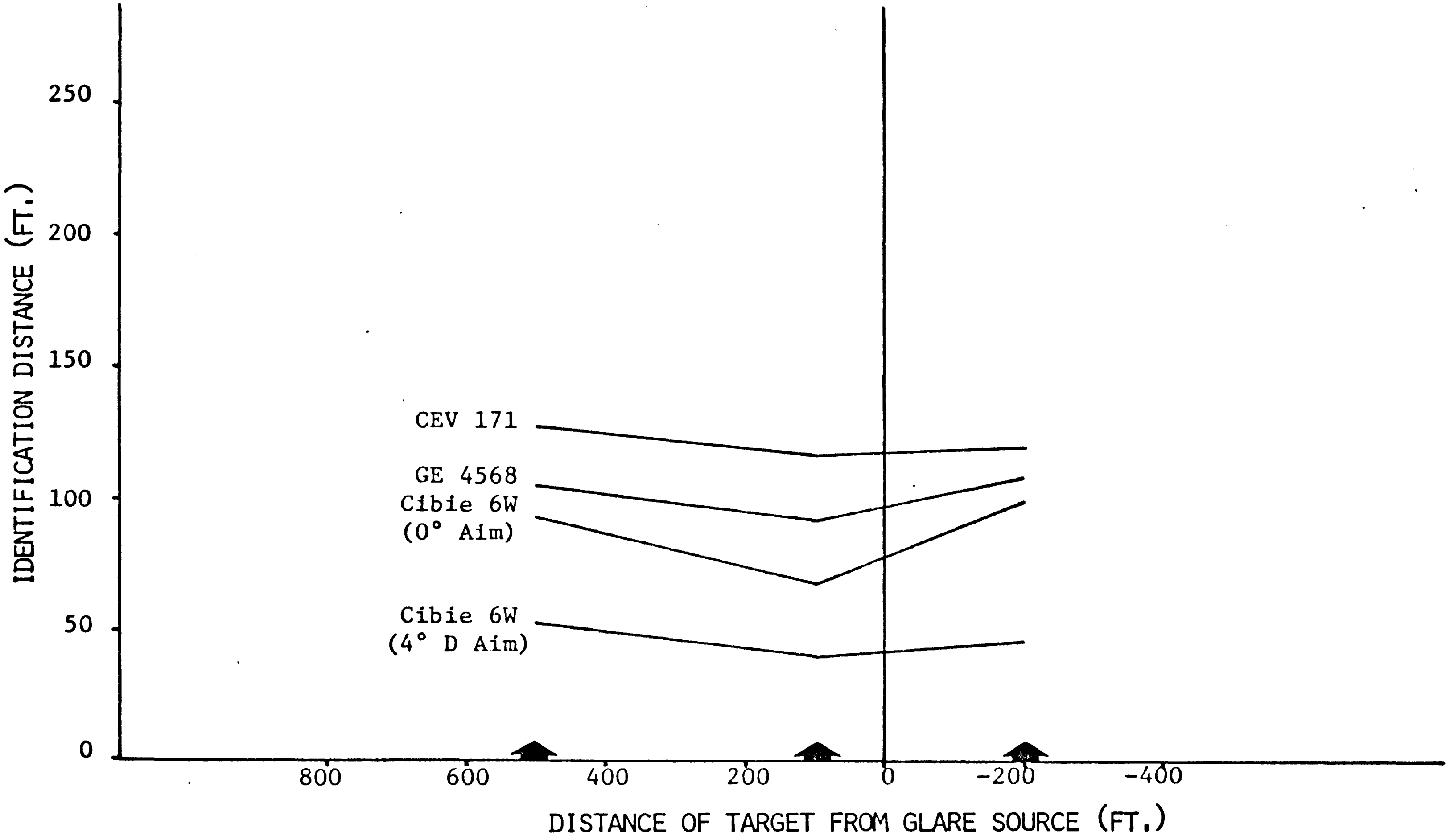


Figure 42. Mean identification distances to HSRI Type I targets afforded by single beam moped headlamps as a function of distance of target from glare source (917' Radius right curve, target on left).

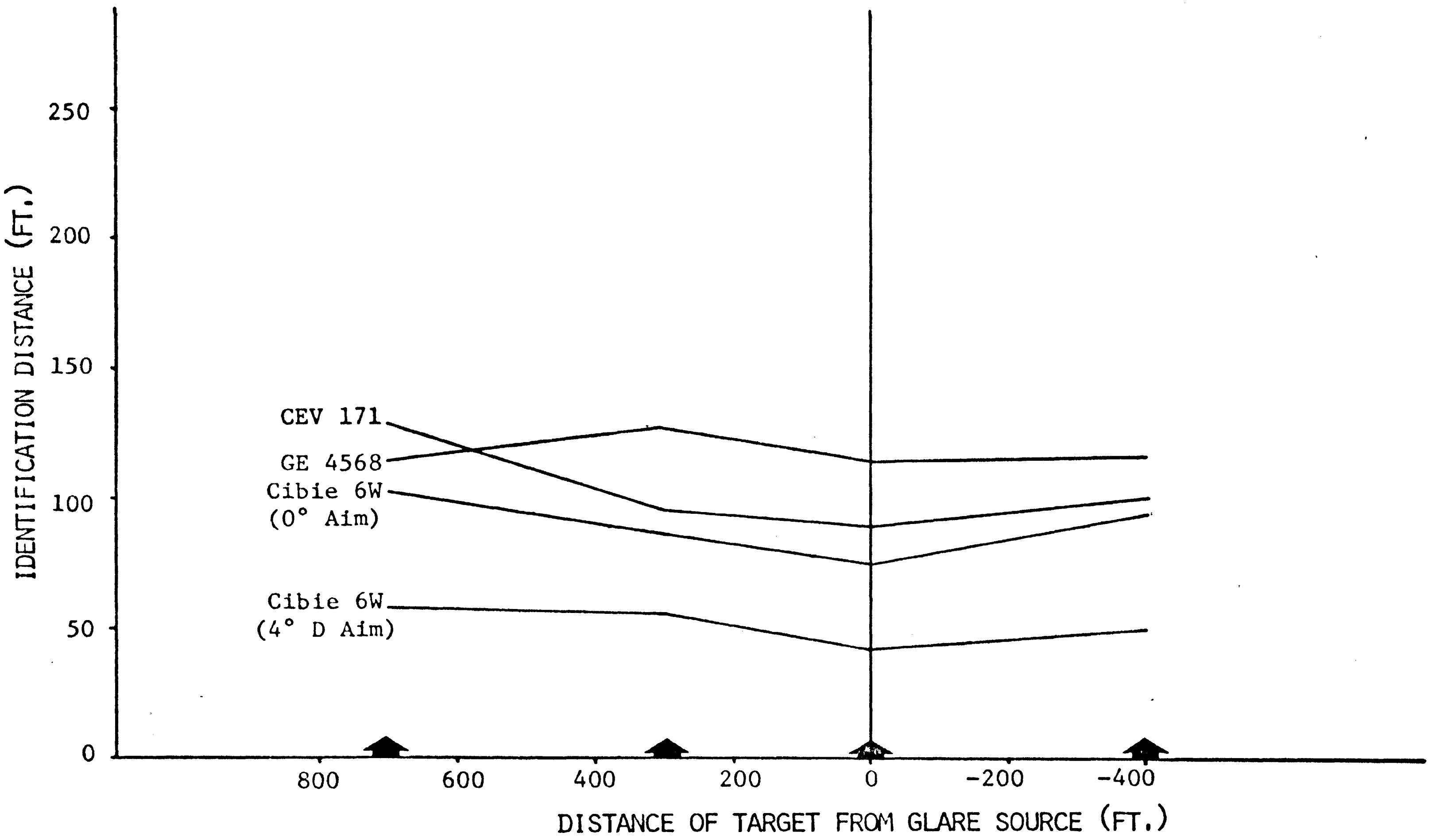


Figure 43. Mean identification distances to HSRI Type I targets afforded by single beam moped headlamps as a function of target distance from glare source (917' Radius right curve, target on right).

significantly reduced identification distances as the glare source was approached on the straight road (Figure 39), identification distances to right targets on both left and right curves were significantly reduced for the CEV 171 lamp as the glare source was approached (Figures 41 and 43). No corresponding effect was found for the 6w lamp in these conditions.

Analysis of the data from five subjects for identification distances afforded by the CEV 171, GE 4568, and Cibie 6w lamp at 0°, and 4°D aims was conducted in the same fashion as the earlier analyses, except for the curved road tests for which only right curve data were available. These analyses showed the same relationship as shown earlier between identification distances provided by the CEV 171 and 6w (4°D aim) lamps, but also showed that identification distances for the 6w lamp were significantly improved by the increase in vertical aim to 0°. The effective identification distances for this lamp were doubled, in most cases, by this change in aim (Figures 38, 39, 42, and 43). The subjects, however, complained that although the targets were visible at a greater distance, little or no illumination was put on the road surface, making the driving task quite disconcerting.

In the straight road glare tests, the CEV 171 provided significantly greater identification distances than the 4568, Cibie 6w (0°D aim), and Cibie 6w (4°D aim); the 4568 provided greater distances than the 6w lamp at both aims, and the 6w lamp at 0° aim provided significantly greater identification distances than the same lamp with 4°D aim (Figure 30). The same finding is true for the straight road no glare condition (Figure 38). In the right curve no glare condition, the CEV 171 provided significantly greater identification distances than the three other lamps to the left target, and the CEV 171, 4568, and Cibie 6w 0° aim lamps provided greater distances to the right target than the 6w lamp with 4°D aim. The identification distances associated with the GE 4568 lamp to the right target in this condition were also significantly greater than those associated with the 6w lamp at 0° aim and the CEV 171 lamp (Figure 38). In the right curve glare tests, the most pervasive finding was that all lamps provided significantly greater visibility distances to both left (Figure 40) and right (Figure 41) targets than the 6w lamp with 4° aim. The CEV 171 lamp also provided greater distances than the 6w 0° aim lamp to left targets at 500 ft. and 100 ft., and to the right target at 0 ft. The CEV 171 lamp again showed significantly reduced identification distances to the right edge targets as the glare source was approached. None of the other lamps showed this effect.

DETECTION DISTANCES OF PEDESTRIAN TARGETS: MOPED LAMPS. Only the pedestrian target in the straight road, no glare condition was responded to by all subjects. Analysis of the data for this target showed the CEV 171 and GE 4568 lamps to provide significantly greater detection distances than the 6 w lamp at 0° and 4°D aim.

ANALYSIS OF GLARE RATINGS: HIGH BEAMS, LOW BEAMS, AND MOPED LAMPS. Figure 44 shows mean glare ratings of the 10 subjects for each of the lamps used in the experiment. A two-way analysis of variance with factors of headlamps and subjects performed on these ratings showed a significant headlamp main effect. A Tukey (b) test performed on the mean glare rating indicated the mean glare ratings assigned to the W4 and 4438 high beams to be lower (more glaring) than all other lamps. The Cibie 6w (4°D aim) was rated significantly less glaring than all other lamps. No other significant differences were found.

SPEED MAINTENANCE. Mean speeds and speed standard deviations were calculated for each test trial made on the 60 cc and 350 cc motorcycles. These data were independently

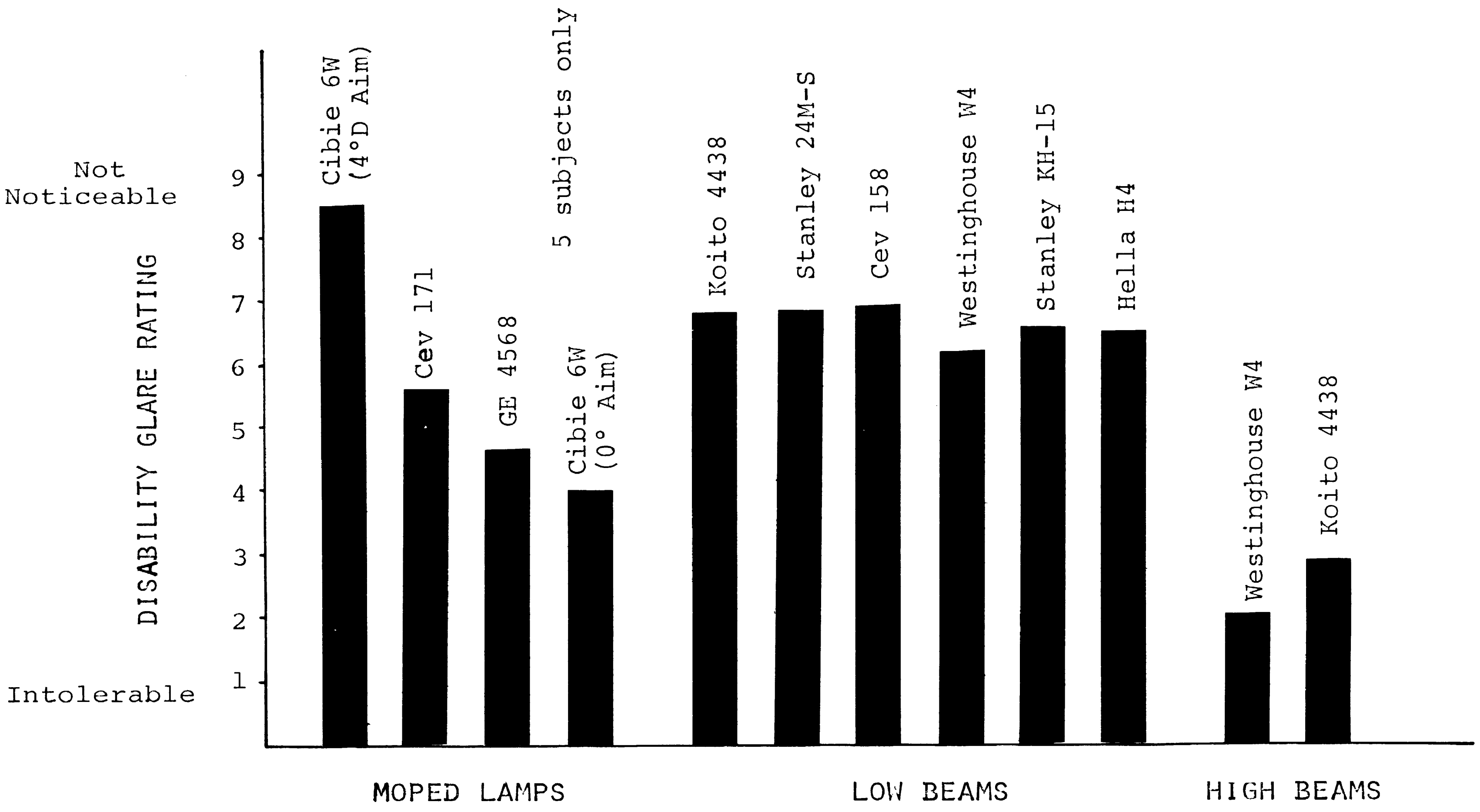


Figure 44. Mean Disability glare ratings of 10 subjects for high beams, low beams and moped headlamps.

subjected to two-factor analyses of variance with factors of headlamps and subjects. No significant effects were found in the speed standard deviation analysis, indicating that the subjects did not differentially attend to the speed maintenance task between headlamps. A significant headlamp main effect was found in the mean speed analysis, and a Tukey (b) test was performed on the mean speeds associated with headlamps. The results of the Tukey test indicated that mean speeds associated with headlamps tested on the 60 cc motorcycle were significantly lower (28 vs. 29.6 ft./sec.) than those associated with headlamps tested on the 350 cc motorcycle. This difference is attributed to differences in speedometer calibration between the two motorcycles.

ROAD SURFACE TARGET AVOIDANCE. The analog signal corresponding to the roll angle of the motorcycle was read out on a chart recorder and the road surface target avoidance maneuvers were located with reference to the target indicator pulses recorded with these data. Physical measurements were then made from the strip chart of the maximum roll angle generated during these maneuvers. The roll rate associated with each maneuver was determined by measuring the slope of the straight line portion of the roll angle signal as the maneuver was made, and multiplying it by the scale factor appropriate to the chart recorder calibration.

The maximum roll angle and roll rate data were analyzed in eight analyses of variance, treating separately the data collected on the moped, 60 cc and 350 cc motorcycles at the 30 mph test speed and on the 350 cc motorcycle at the 45 mph test speed. Each analysis was performed with two factors: road geometry - glare condition (three levels; straight road, glare; straight road, no-glare; and curved road, no-glare) and headlamps (two to five levels, depending upon the number of lamps evaluated in the test condition). Because a number of road surface targets were not detected in each of the test conditions, subjects were treated as replications in the analyses, to allow use of an unweighted means (missing data) analysis design. There was no evidence that target misses were associated with particular headlamps; i.e., the distribution of misses among headlamps was random.

MAXIMUM ROLL ANGLE ANALYSES. Significant headlamp main effects were found only in the moped and 350 cc motorcycle, 30 mph test speed analyses. Post hoc comparisons of mean maximum roll angle by headlamps, performed by Tukey (b) tests, showed the mean maximum roll angles associated with the CEV 171 headlamp (4.3°) to be smaller ($p < .05$) than those associated with the Cibie 6w (4°D aim) lamp (6.7°) on the moped, and showed mean maximum roll angles associated with the KH-15 low beam (6.9°) to be significantly greater ($p < .01$) than those associated with the 4438 high beam (4.7°) and the W4 high beam (4.2°) on the 350 cc motorcycle at the 30 mph test speed. No other significant differences between headlamps were found, nor were any differences found between the road geometry - glare conditions. Figure 45 illustrates the mean maximum roll angles associated with each of the headlamps.

ROLL RATE ANALYSES. No significant differences were found between headlamps or road geometry - glare conditions in any of the analyses. Mean roll rates associated with the various headlamps are shown in Figure 46.

The few differences that were found in these analyses were, again, directly attributable to differences in the maximum intensities of power ratings of the lamps employed.

DISCUSSION

The dynamic evaluations of visibility afforded by the various headlamps examined in this experiment have served to confirm what is intuitively obvious; that visibility at distance

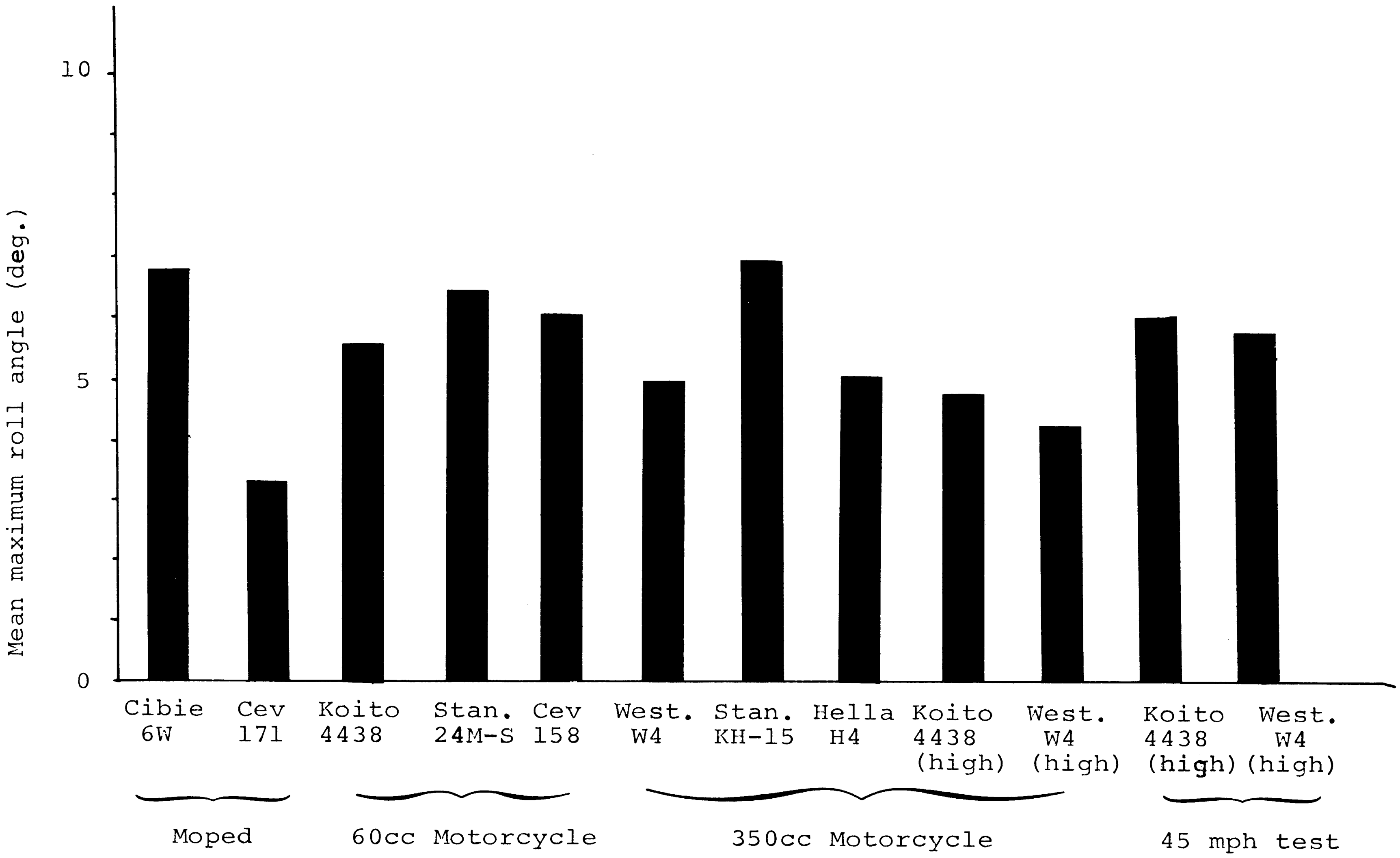


Figure 45. Mean maximum roll angles generated in the object avoidance maneuver for high beams, low beams, and Moped headlamps.

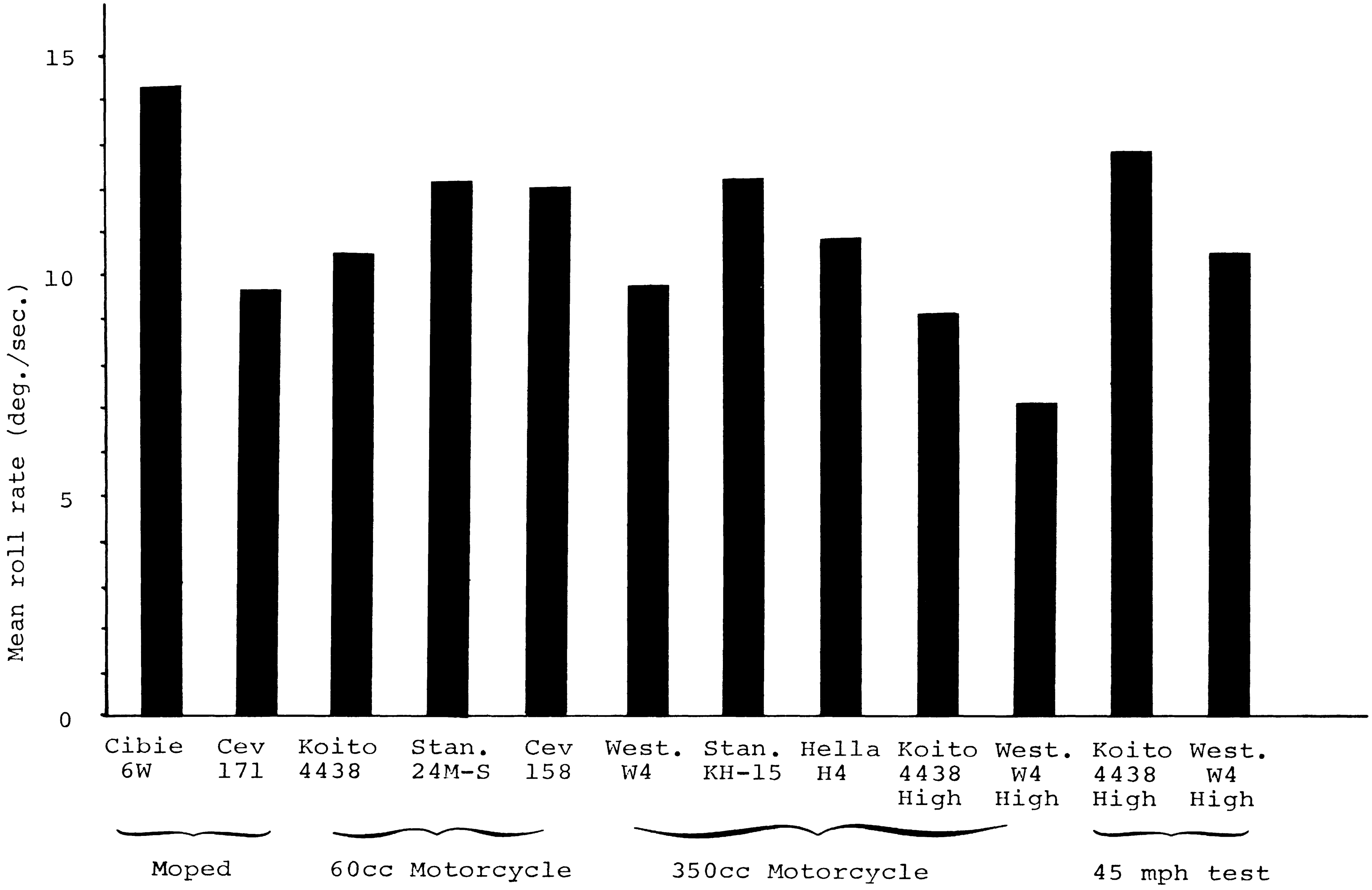


Figure 46. Mean roll rates generated in the object avoidance maneuver for high beams, low beams, and Moped headlamps.

is a function of the intensity directed down the road, and that differences in visibility can directly affect the severity of control maneuvers which are common in motorcycle driving. The fact that no consistant differences in identification distance were found among the three low beam pattern types examined does not mean that low beam pattern is irrelevant, but simply indicates that all three types can provide relatively comparable identification distances if aimed equivalently. Lamp aim is undoubtedly of much greater importance to down-the-road visibility than specific beam patterns, as evidenced by the dramatic difference in identification distances afforded by the 6w moped lamp at two levels of aim.

There is little doubt that most, if not all, of the low beam lamps tested could provide identification distances approaching those provided by the high beams, if simply aimed high enough. The two sharp cutoff lamps evaluated in this study (Hella H4 and CEV 158) were, in fact, aimed 1° to 2° high (respective to their high beams) and if aimed on high beam as per SAE J584, would have undoubtedly provided shorter identification distances than described earlier. In the subjective beam pattern evaluation, both of these lamps, aimed on low beam as above, provided acceptable visibility, the H4 more so because of its higher overall intensity. On high beam, however, subjects complained that the CEV 158 was aimed too high, and should be aimed down for adequate performance. The H4 high beam, although also aimed too high, provided such great intensity that no complaints were made. The CEV 158 could thus not provide acceptable illumination on both beams with the same lamp aim, but the H4 lamp, because of its considerable higher intensity, could. Attention must thus be given to the relationship between high and low beams of lamps of more moderate power requirements, as well as to the specific design of each beam.

INTEGRATION OF RESEARCH FINDINGS AND RECOMMENDATIONS

The various studies described in this report have served to illustrate a number of problem areas specific to motorcycle headlighting, and have provided a basis upon which photometric standards for the various classes of motorcycles can be formulated. Specific recommendations concerning motorcycle headlighting are listed below.

STANDARDIZATION OF LAMP DIMENSIONAL SPECIFICATIONS

The surveys of the state-of-the-art of motorcycle headlighting have shown that little standardization exists in the design of motorcycle headlamps. Currently supplied and available lamps differ markedly in their physical dimensions, mounting and wiring configurations, power requirements, and beam patterns. This lack of standardization severely limits the available sources of replacement headlamps and is a possible impediment to the replacement by motorcyclists of headlamps with beam outages. Considering that eighteen percent of the motorcycles examined in the in-service motorcycle headlamp aim survey described here were found to be operating with a beam outage (more than double the 8% found in random motor vehicle inspections conducted by the Michigan State Police in 1974), every possible measure should be taken to encourage replacement of burned out lamps. The first recommendation is thus that dimensional specifications for motorcycle headlamps (similar to SAE J571c) be instituted.

IMPROVEMENT OF HEADLAMP AIMABILITY

Another problem specific to motorcycle headlighting is that of initially setting and subsequently maintaining headlamp aim. The in-service motorcycle headlamp aim survey found that motorcyclists, on the whole, are unable or unwilling to accurately aim their headlamps. The variation in headlamp aim in a sample of 90 motorcycles was found to greatly exceed that found in a similar sample of automobiles. Improper headlamp aim not only affects the motorcyclists nighttime visibility, but can affect the visibility of oncoming drivers because of increased glare. It has also been shown that the weight of a passenger can change vertical aim as much as 1.5%. It is desirable, therefore, to make vertical motorcycle headlamp aiming easy to do accurately. A number of approaches to the problem are possible. A factory calibrated, gravity sensitive vertical aim indicator located in the headlamp bucket could display an indicator light to the driver that shows that the headlamp bucket and thus the headlamp are vertically misaimed. The driver could then vertically adjust the headlamp on a level road until the indicator went off. A system such as this not only indicates incorrect aim, but gives the driver a means to correct the problem. Unfortunately, such a device would probably be expensive and difficult to initially calibrate. Another method of improving headlamp aimability is to design the headlamp beam with a distinctive feature that is obvious to the driver and directly indicates vertical aim. Sharp cutoff lamps have such a feature (the sharp cutoff on the low beam) and can be aimed fairly accurately on a level road by placing the sharp cutoff at some selected distance down the road, or at least below the eye level of oncoming drivers. A beam that would be even easier to aim could have a distinctive hotspot located perhaps 8° below the H-V axis. Given the specific headlamp height, a distance (e.g. 20 ft.) could be marked off on a level road, the motorcycle placed at one end, and the lamp aimed so that the hotspot or other distinctive feature strikes the road at the appropriate distance.

Other more complex systems for maintaining headlamp aim have been suggested by other researchers. Alphen (1974) describes a dynamic hydraulic headlamp leveling system for correcting vertical lamp misaim due to differential suspension loading created by acceleration and/or the weight of a passenger. He also describes an electromechanical system which rotates the headlamp or filament to correct rotational lamp misaim when the motorcycle banks in turns. A considerably simpler system which could give the driver some control over static vertical misaim due to the weight of a passenger might feature a handle fixed to the headlamp bucket which would allow the headlamp to be rotated about its lateral axis through 1/2° detents.

The second recommendation is that considerable effort be dedicated to the development of a motorcycle headlamp aiming system which allows vertical headlamp aim to be easily and accurately set, but is resistant to inadvertant or accidental misaim. Such a system is necessary to insure that headlamps which allow improved nighttime visibility are used properly; improved headlamps will provide limited benefits and may create glare problems for oncoming drivers if misaimed.

INSURANCE OF ELECTRICAL SYSTEM DESIGN VOLTAGE MAINTENANCE

Several motorcyclists participating in the in-service motorcycle headlamp aim survey complained of headlamp failures which they attributed to insufficient voltage regulation, i.e. overpowering of the lamp. In addition, it was found that in the case of the 350 cc motorcycle used in several of the preceding studies, design voltage was not applied to the headlamp unless the battery was fully charged. This motorcycle did not receive continuous use and was typically operated, when not being used in an experimental procedure, at moderately low speeds, with its original equipment headlamp on. Since several states require daytime headlamp use to increase motorcycle conspicuity, and since many motorcyclists apparently voluntarily follow this procedure in states which have no such legislation (e.g., 69% of the motorcyclists participating in the in-service motorcycle headlamp aim survey reported such behavior although it is not required by state or local law), the problem of underpowering headlamps during nighttime operation may present an additional problem to the improvement of nighttime visibility. For these reasons, the third recommendation is that a strong standard concerning the maintenance of design voltage be developed and instituted. Clearly, photometric motorcycle standards for headlamps are of little value if in practice, the headlamp is operated at less than design voltage, or if it has been put out of commisiion by applying overvoltage.

Although the issue of motorcycle conspicuity has not been addressed by this research program, some relief to the problem of maintaining a fully charged battery while operating a headlamp in daylight may be gained by the use of a low power (10w to 20w) auxilliary headlamp which would provide intensity chiefly above the horizontal axis of the lamp, an area which is generally dealt with only by high beams. This auxilliary lamp, while chiefly intended to maximize daytime conspicuity while requiring limited power, could also be selectively used at night to provide improved illumination for large motorcycle roll angle cornering maneuvers.

PHOTOMETRIC STANDARDS FOR LOW BEAM MOTORCYCLE HEADLAMPS.

The remaining studies described in this report have enabled the collection of a great deal of objective and subjective data which together provide a base upon which photometric standards for low beam headlamps for various categories of motorcycles can be formed. The subjective study and survey have indicated that motorcyclists desire nighttime illumination in a broad area on and about the road ahead of them. The importance of an adequate distribution of illumination is not reflected in the present motorcycle headlighting photometric standard specified in SAE J584, which specifies four minimum test points located about the vertical lamp axis at 2° down. The subjective beam pattern evaluation study and the results of the in-service motorcycle headlamp aim study - nighttime visibility questionnaire suggest that additional minimum photometric test points should be added to the procedure specified in SAE J584, to insure adequate down-the-road illumination, and adequate illumination in the immediate foreground. Test points representative of these areas were selected in the section of this report dealing with the subjective evaluation study, and have enabled comparison of the photometric characteristics of the various lamps examined in terms of their subjectively desirable and undesirable features. Results of the field identification distance/object avoidance experiment give a reasonable objective account of the down-the-road intensities required for adequate nighttime visibility. On the basis of these various results the low beam headlamp photometric specifications listed in Tables 18, 19 and 20 were selected for large displacement motorcycles, small displacement motorcycles, and mopeds, respectively. These tables also show photometric values at the specified test points of representative production headlamps for which photometric data were available, and indicate test points of lamps which do not meet the minimum selected values. The minimum values shown were selected by comparing the photometric values of lamps with undesirable characteristics as determined in the subjective study with lamps which did not display undesirable characteristics, or were rated "adequate". The 1° down test point values were generated on the basis of the field identification distance/object avoidance results, by selecting photometric values which represent the minimum intensities produced by the lamps tested on the 60 cc and 350 cc motorcycles as they were designed to be aimed. It should be noted that 2° down test points bias intensities toward the right, reflecting the findings of the eye fixation study and the operator generated aim study which indicated that the right edge of the traffic lane is of considerable importance for vision.

Table 18. Recommended minimum photometric specifications for low beam headlamps for large displacement motorcycles and photometric values of representative production headlamps (Photometric values in cd/100).

Test Point	Min. Cd. (× 100)	60W	55W	50W			40W					35W		
		W4	H4	4458	6014	6014X	4438	KH-15	158	1201	MNP-69	24M-S	23M-S	0740
1D,V	(20)	74	100	88	44	66	51	53	12★	15★	6★	21	20	23
1D,2L	(15)	31	68	24	17	14★	20	29	7★	13★	5★	10★	17	13★
1D,2R	(15)	208	186	118	19	144	63	37	20	16	6★	21	18	18
2D,6L	(15)	32	68	31	22	16	27	15	32	17	10★	14★	24	12★
2D,3L	(30)	48	81	45	34	28★	50	46	36	34	19★	34	39	24★
2D,3R	(40)	382	125	172	274	357	171	64	41	42	28★	45	44	42
2D,6R	(15)	211	100	83	132	99	65	15	36	14★	14★	16	25	17
5D,V	(20)	29	39	46	44	99	31	125	57	118	35	84	71	92

★ Indicates photometric values which do not meet recommended minimums.

Table 19. Recommended minimum photometric specifications for low beam headlamps for small displacement motorcycles and photometric values of representative production headlamps (Photometric values in cd/100).

Test Point	Min Cd. (× 100)	35W			30W	25W							20W	15W	
		24M-S	23M-S	0740	4020	9M-S	1087	4568	16M-S	1047	0730	1108	171	31877	10N-S
1D,V	(15)	21	20	23	34	34	28	54	30	17	34	34	104	50	13★
1D,2L	(10)	10	17	13	17	23	20	54	24	13	28	20	94	23	12
1D,2R	(10)	21	18	18	85	24	23	56	24	15	25	26	92	36	11
2D,6L	(15)	14★	24	12★	12★	10★	13★	41	16	12★	26	17	32	8★	11★
2D,3L	(30)	34	39	24★	21★	28★	36	44	37	36	61	28★	70	30	25
2D,3R	(40)	45	44	42	117	46	50	44	50	42	58	55	61	59	24★
2D,6L	(15)	16	25	17	73	13★	16	42	17	12★	24	21	32	16	13★
5D,V	(20)	84	71	92	13★	43	37	3★	23	40	30	42	24	3★	34

★ **Indicates photometric values which do not meet recommended minimums.**

Table 20. Recommended minimum photometric specifications for single beam headlamps for mopeds and photometric values of representative production headlamps (photometric values in cd/100).

Test Point	Min Cd. (×100)	25W	20W	15W		6W	
		4568	171	31877	10N-S	Cibie	CEV
2D,6L	(10)	15	32	4★	11	4	6
2D,3L	(15)	17	70	12★	25	6	6
2D,3R	(15)	17	61	23	24	6 ★	7 ★
2D,6R	(10)	15	32	6★	13	3	6
5D,V	(10)	14	24	11	34	1	1

★ Indicates photometric values which do not meet recommended minimums.

These recommended low beam photometric values are intended to be measured as specified by SAE J584, with the high beam hotspot centered laterally and directed 0.4° below the horizontal axis of the lamp. Some of the lamps listed in Tables 18 and 19 which do not meet the minimum recommended intensities, would meet them, if the vertical separation between high and low beams was not so great. The Stanley 1201, CEV 158, and Lucas MNP-69 lamps are examples. It should also be noted that the 2° down and 5° down test points are common to all three motorcycle categories, as the areas on and about the road represented by these test points are of considerable importance to all motorcycle drivers, regardless of motorcycle speed capability. The minimum photometric values recommended for large and small displacement motorcycles are the same at these test points, but the photometric values for small displacement motorcycles are lower at the 1° down test points, reflecting their lower speed capabilities and reduced distance visibility requirements. For the single beam moped lamps, the 1° down test points have been omitted entirely, and the remaining test points reflect reduced intensities, compared to the larger motorcycles. The single beam moped lamps should be aimed, during photometric tests and in use, to optimize intensities at the specified test points, rather than to any other criteria. The photometric values for the lamps listed in Table 20 represent such aim.

Although this project has not provided an in-depth analysis of the issue of glare created by motorcycle headlamps, it is felt that the maximum low beam photometric test points specified in SAE J584 could be safely increased to the low beam maximum specified in SAE J579b (sealed beam headlamp units for motor vehicles).

These minimum recommended photometric values are not intended to represent the characteristics of "optimum" low beams, but represent minimum requirements for use. It would possibly be desirable for all motorcycles capable of being driven at high speeds to be equipped with low beam lamps which produce intensities such as those generated by the Westinghouse W4 and Hella H4 headlamps. Unfortunately, because of the difficulty motorcyclists seem to have in aiming lamps, the problems these lamps could create in terms of glare to oncoming drivers when misaimed, and the fact that higher intensity lamps can be more drastically misaimed while still providing some useful illumination, leads to the conclusion that advances in headlamp aiming technology are necessary before such a requirement could realistically be made.

RECOMMENDED ADDITIONAL RESEARCH

It is felt that substantial additional research on several motorcycle headlighting topics is desirable to:

1. Examine glare acceptance levels. It would be possible to equip high speed motorcycles with more powerful headlamps if the glare produced by misaim or normal operation was not overly

objectionable or debilitating to oncoming drivers.

2. Determine optimum beam patterns for large roll angle cornering maneuvers. Research in this area would best be conducted with the glare acceptance research noted above, as areas in the beam pattern which would provide illumination down the road during large roll angle maneuvers are areas which would create glare to oncoming drivers in straight line driving. An analitical computer model could be used to a great extent in this research.

3. Further develop the operator generated aim procedure employed in this project. Additional operator generated aim research could examine the reliability of the technique, and could examine operator generated aim as a function of beam pattern, road type, road topography, and ambient vertical illumination.

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APPENDICIES

APPENDIX A

Table 1a. MOTORCYCLE AND MOPED HEADLAMPS ACQUIRED IN THE HEADLAMP USAGE SURVEY

Production/Experimental Motorcycle Headlamps

General Electric Co.

4020	(30/30w)
4420	(30/30w)
6014x	(75/50w)

Guide Lamp

4431	(50/40w)
4458	(60/50w)

Stanley Electric Co.

10N-S	(15/15w)
9M-S	(35/25w)
16M-S	(35/25w)
23M-S	(50/35w)
0740	(35/35w)
1047	(35/25w)
0730	(35/25w)
1068	(15/15w)
1087	(35/25w)
1108	(35/25w)
1201	(50/40w)
KH-15	(50/40w)
24M-S	(50/35w)

Cibie

6670062	(H4)	(60/55w)

Westinghouse

W4	(80/60w)
6014	(60/50w)
4000	(50/30w)
W1	(30/30w)

CEV

172	(20/20w)
158	(35/35w)

Koito Manufacturing

4438	(50/40w)
71755	(25/25w)
71754	(35/35w)
71761	(25/25w)
71760	(25/25w)
31827	(15/15w)

Lucas

700	(35/35w)
H4	(60/55w)
MNP-69	(45/40w)

Tung-Sol

4456	(30/30w)
4020	(30/30w)
4420	(30/30w)

* * * *

Moped Headlamps

CEV

6w	
15w	
171	(20w)

General Electric Co.

4568	(25w)

Cibie-Solex

6w
15w

Traizet Luxor

6w
15w
21w

Soubitex-Solex

6w
15w

APPENDIX B

CHARACTERISTICS OF THE MOTORCYCLES AND MOTORCYCLISTS SURVEYED IN THE IN-SERVICE AIM STUDY

APPENDIX B

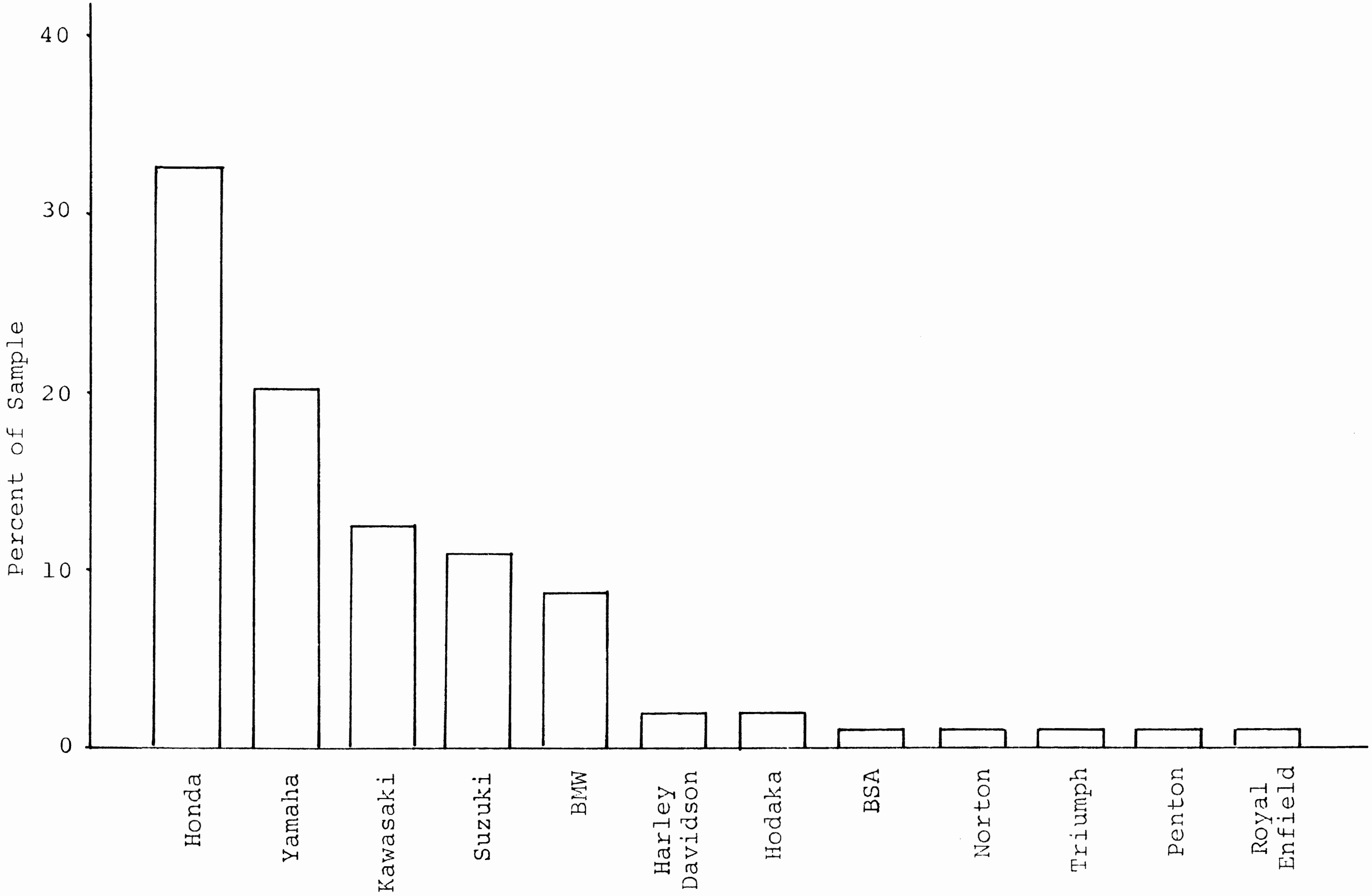


Figure 1b. Manufacturers of the 90 motorcycles examined in the in-service motorcycle headlamp aim study.

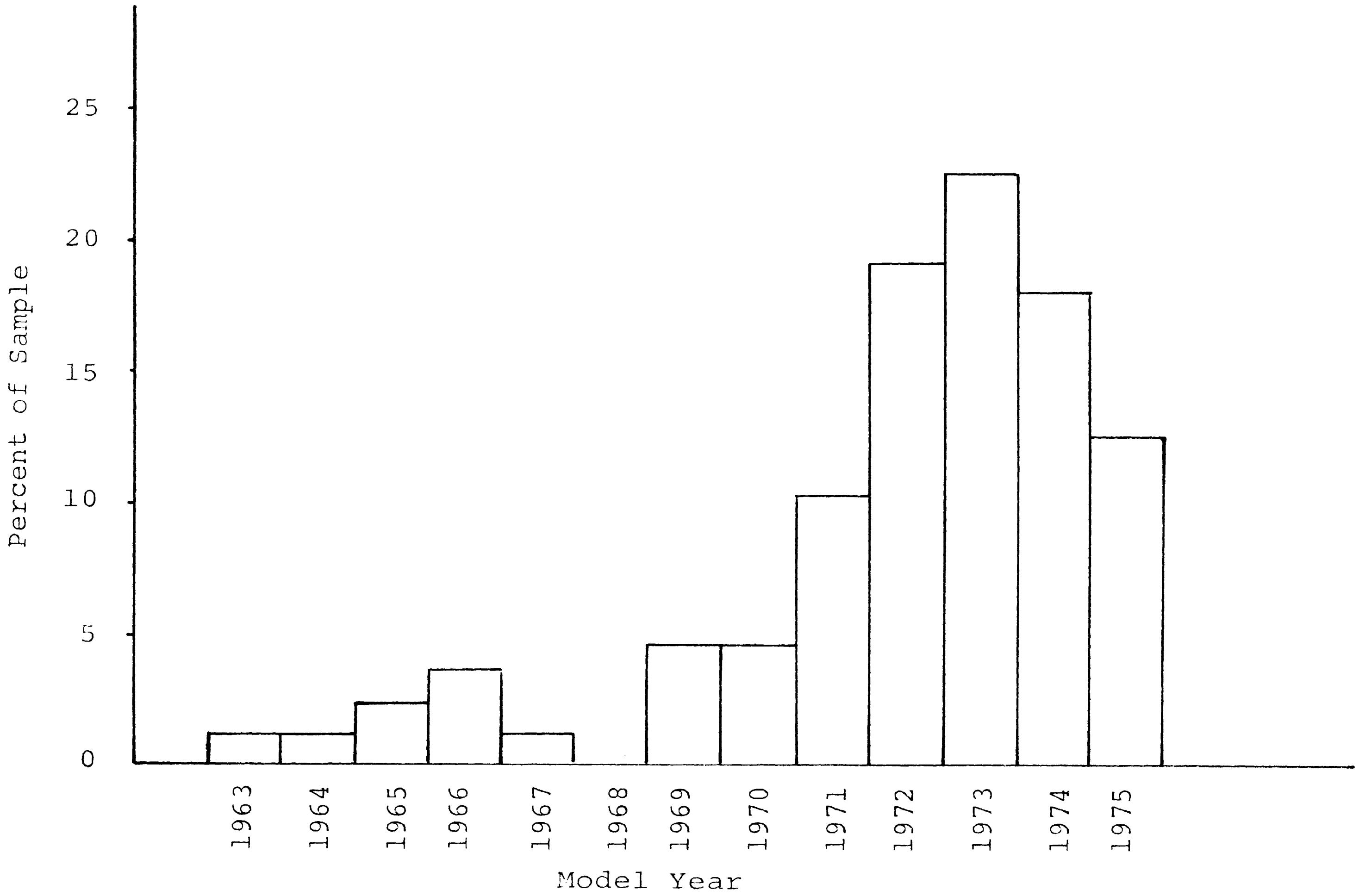


Figure 2b. Model years of the 90 motorcycles examined in the in-service motorcycle headlamp aim study.

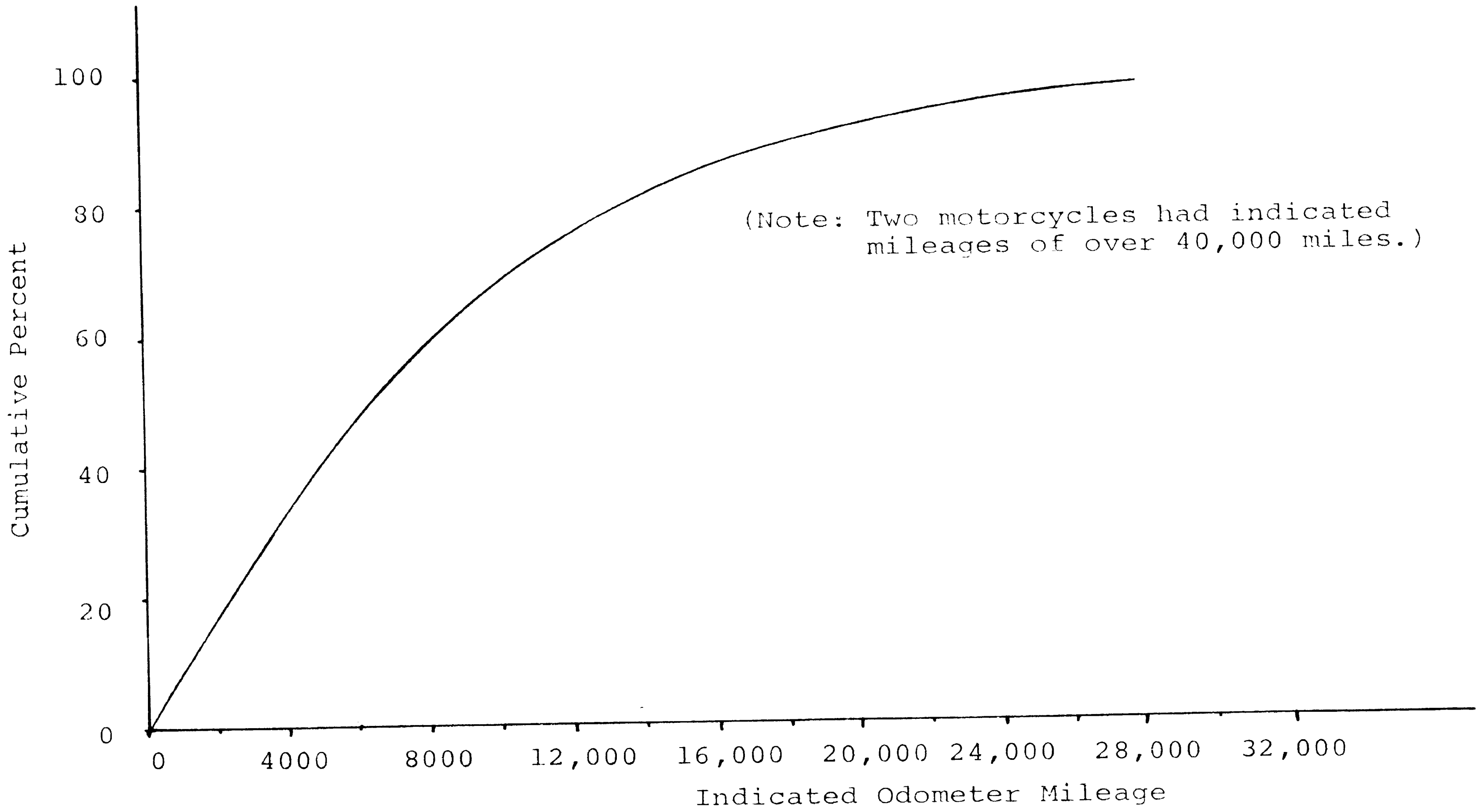


Figure 3b. Total indicated odometer mileage of the 90 motorcycles examined in the in-service motorcycle headlamp aim study.

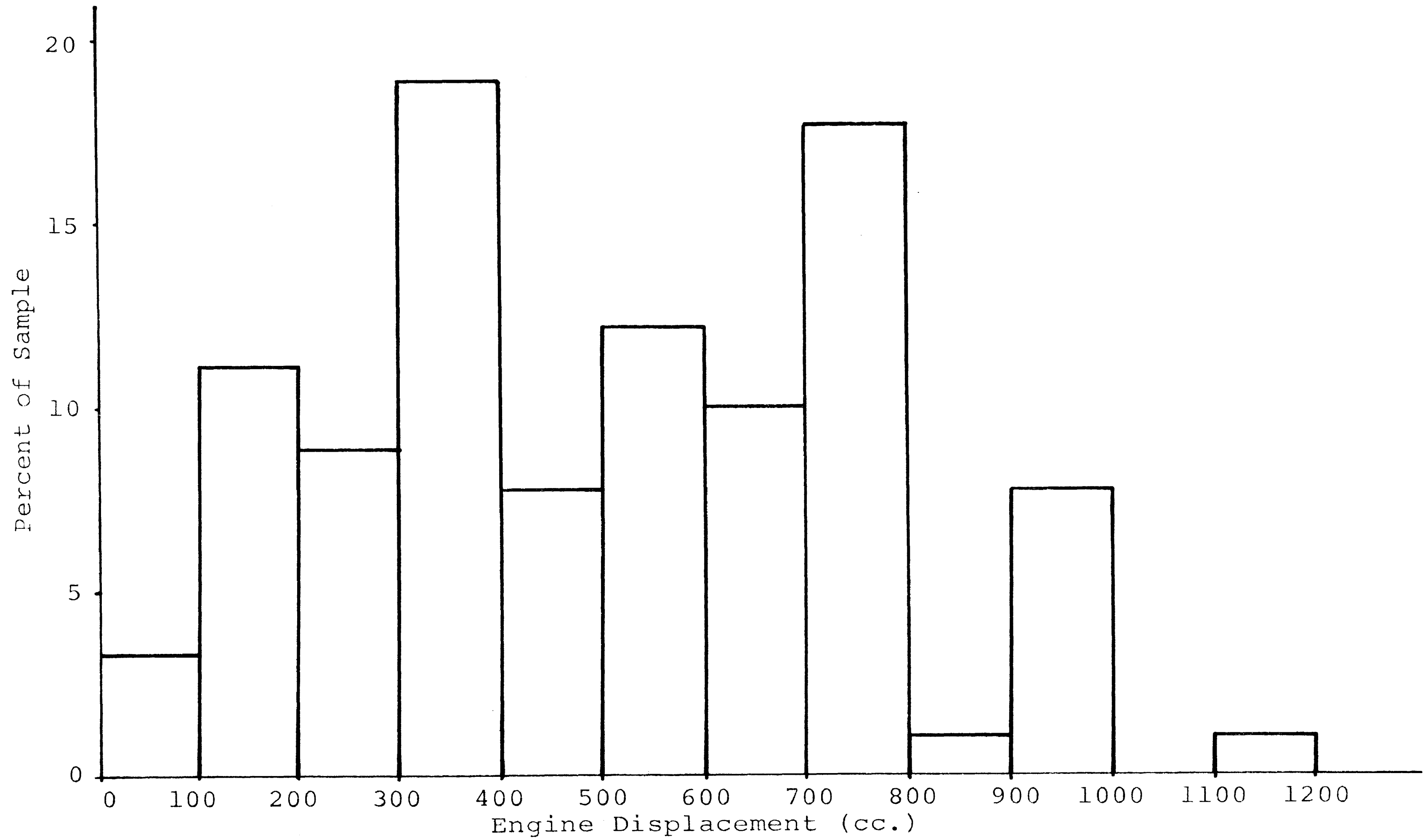


Figure 4b. Engine displacements of the 90 motorcycles examined in the in-service motorcycle headlamp aim study.

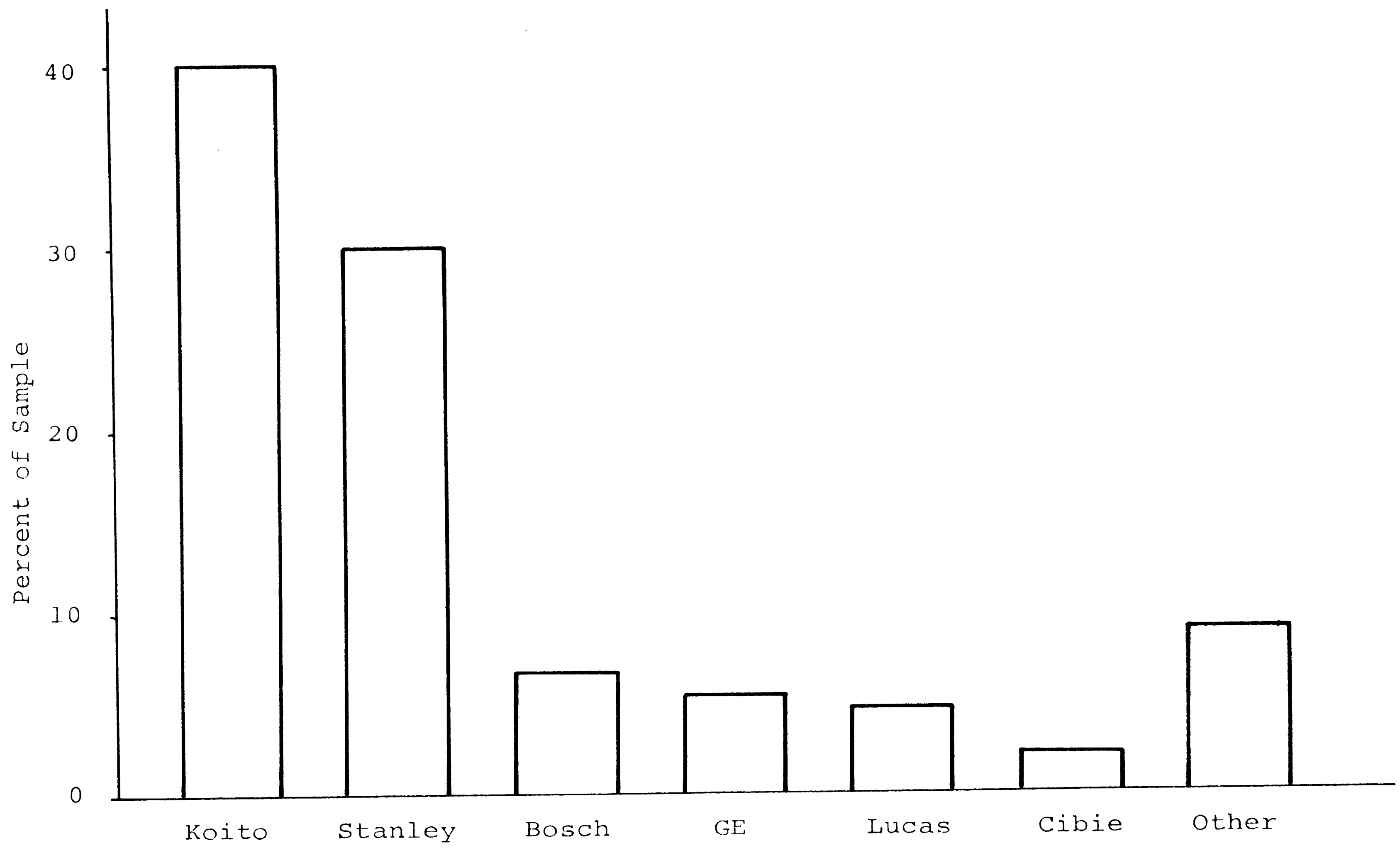


Figure 5b. Manufacturers of headlamps found on the 90 motorcycles examined in the in-service motorcycle headlamp aim study.

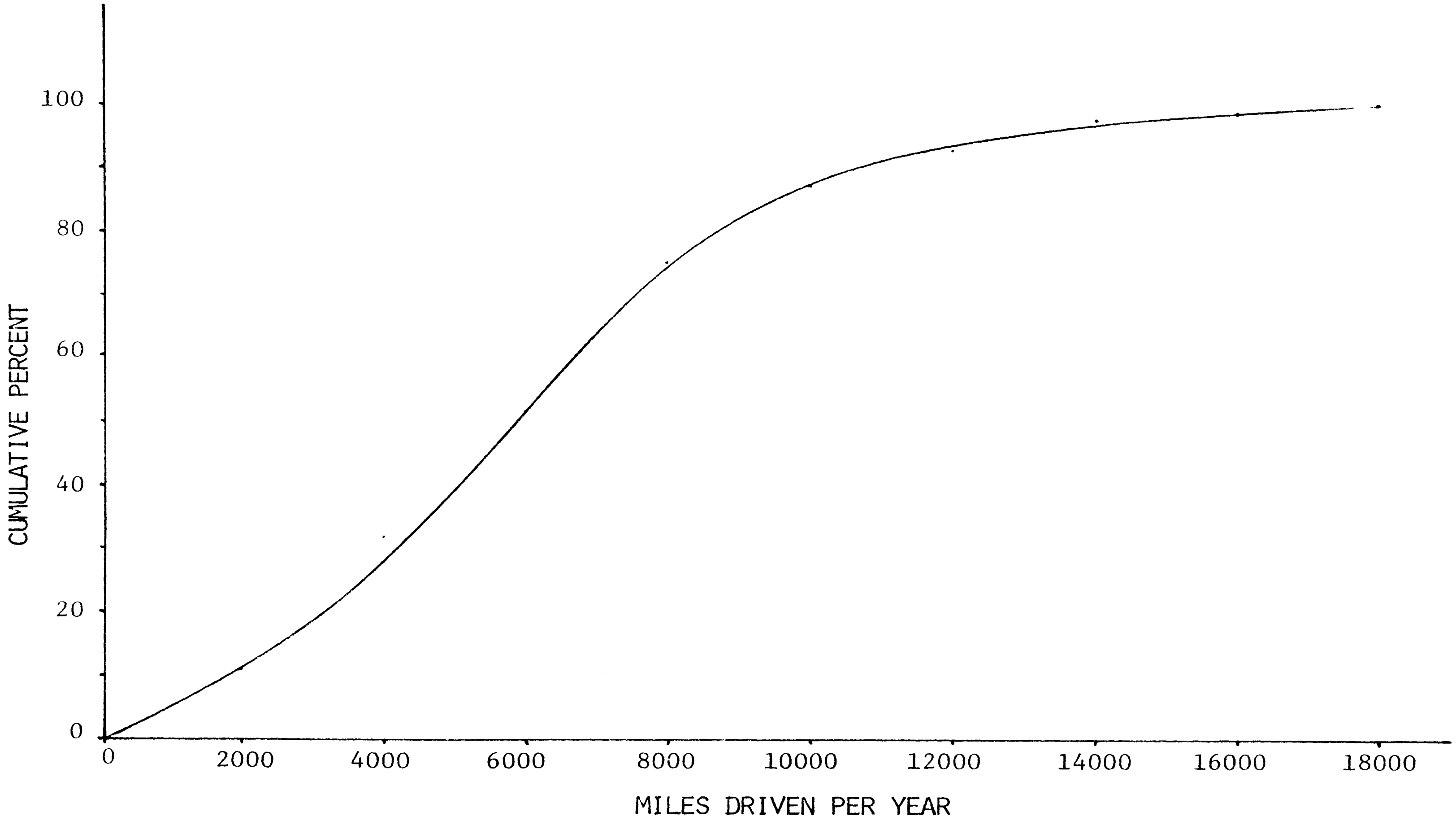


Figure 6b. Cumulative percentage distribution of estimated yearly motorcycle driving mileage of subjects in the in-service aim survey.

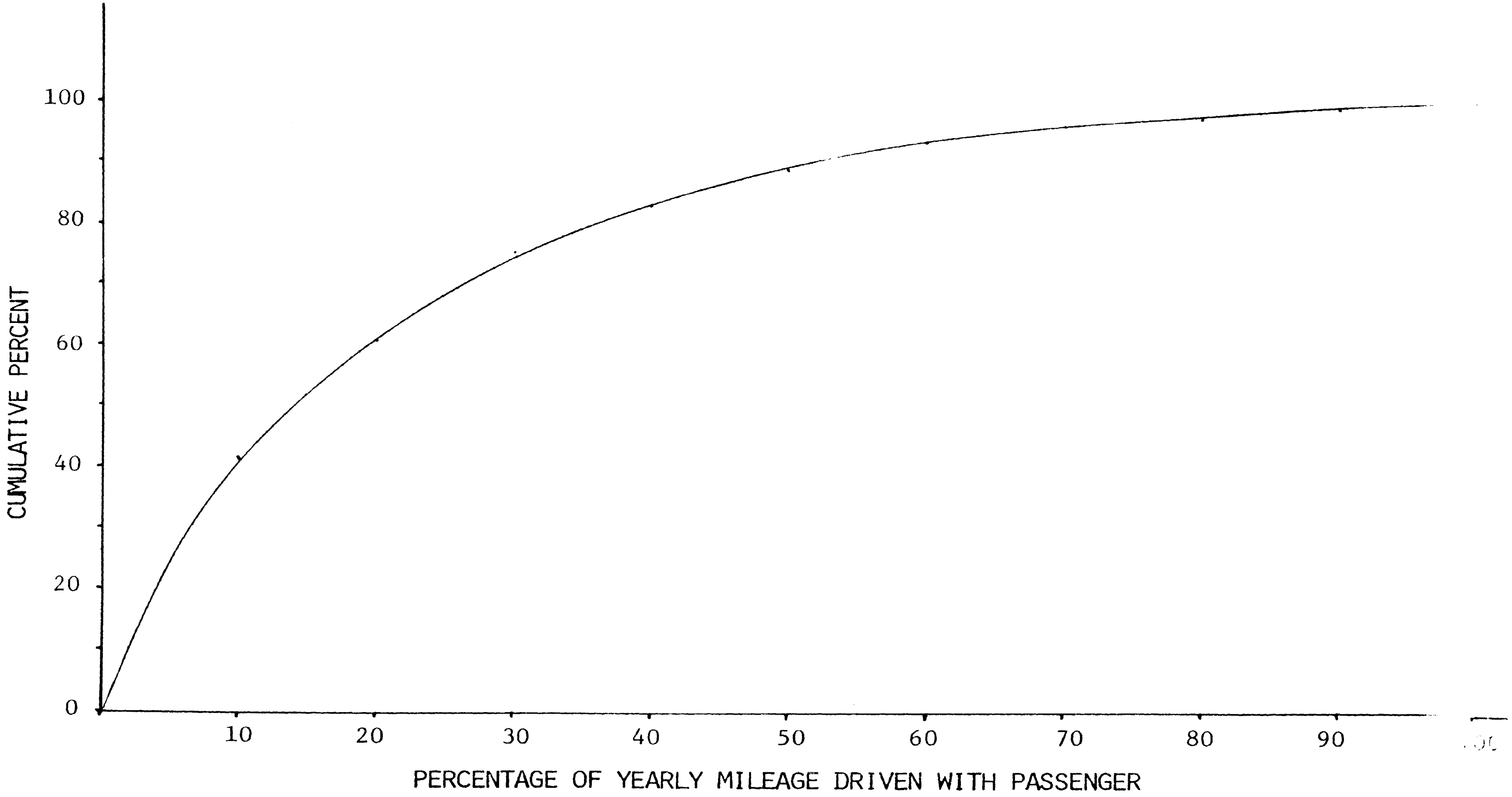


Figure 7b. Cumulative percentage distribution of percentage of yearly mileage drive with a passenger by subjects in the in-service aim survey.

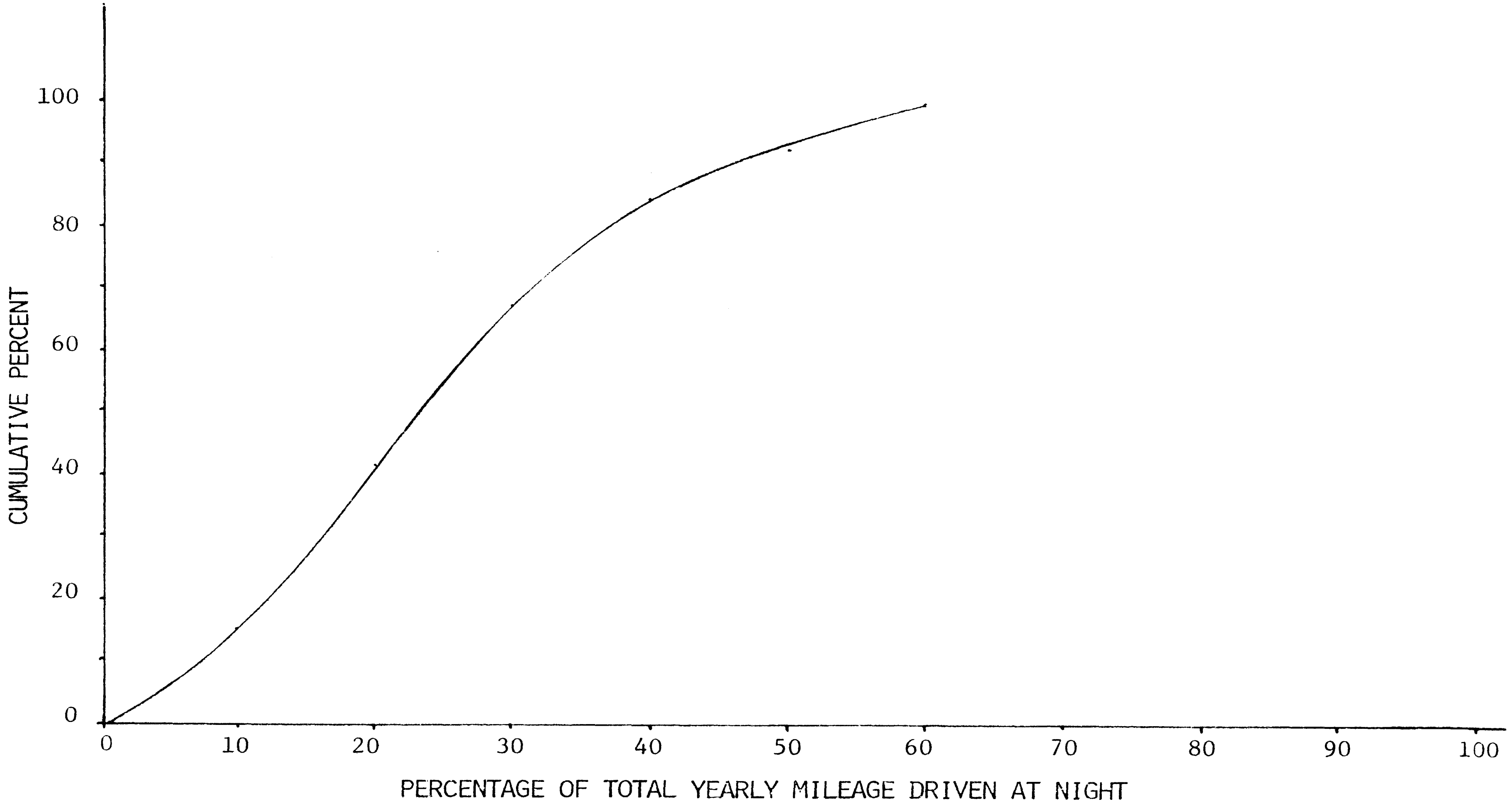


Figure 8b. Cumulative percentage distribution of percentage of yearly mileage driven at night by subjects in the in-service aim survey.

APPENDIX C

MOTORCYCLE INSTRUMENTATION

The motorcycle instrumentation consisted of two independent systems: a headlamp intensity control system and a data acquisition system. The headlamp intensity control system provided a tightly regulated adjustable voltage for powering 6 volt and 12 volt headlamps. The data acquisition provided a means of recording subject responses, distance travelled, target locations, and motorcycle roll angle. These systems are described in detail below.

HEADLAMP CONTROL SYSTEM

Figure 1c is a block diagram of the headlamp control system. In order to have sufficient overvoltage for operation of the lamp voltage regulator, two batteries were required: a 12 volt and a 6 volt, each with a capacity of about 15 amp-hours. A "center off" toggle switch provided selection of 12 volts (nominal) input to the lamp driver for operating 6 volt lamps and 18 volts input to the lamp driver for operating 12 volt lamps. A 12 volt to ±18 volt regulated DC to DC converter supplied power for operation of the lamp driver/voltage regulator circuit and a regulated reference voltage for the lamp intensity adjustment potentiometers. The output of the lamp driver/voltage regulator was a line and load regulated voltage equal to the voltage set at the wiper of the intensity adjustment pots. Overall lamp voltage regulation was about 0.1%.

DATA ACQUISITION SYSTEM

A block diagram of the data acquisition system is shown in Figure 2c. The components shown to the left of the vertical darkened line, including the tape recorders, were carried on the motorcycle. The components to the right of the line are laboratory equipment used in reproducing and reducing the data.

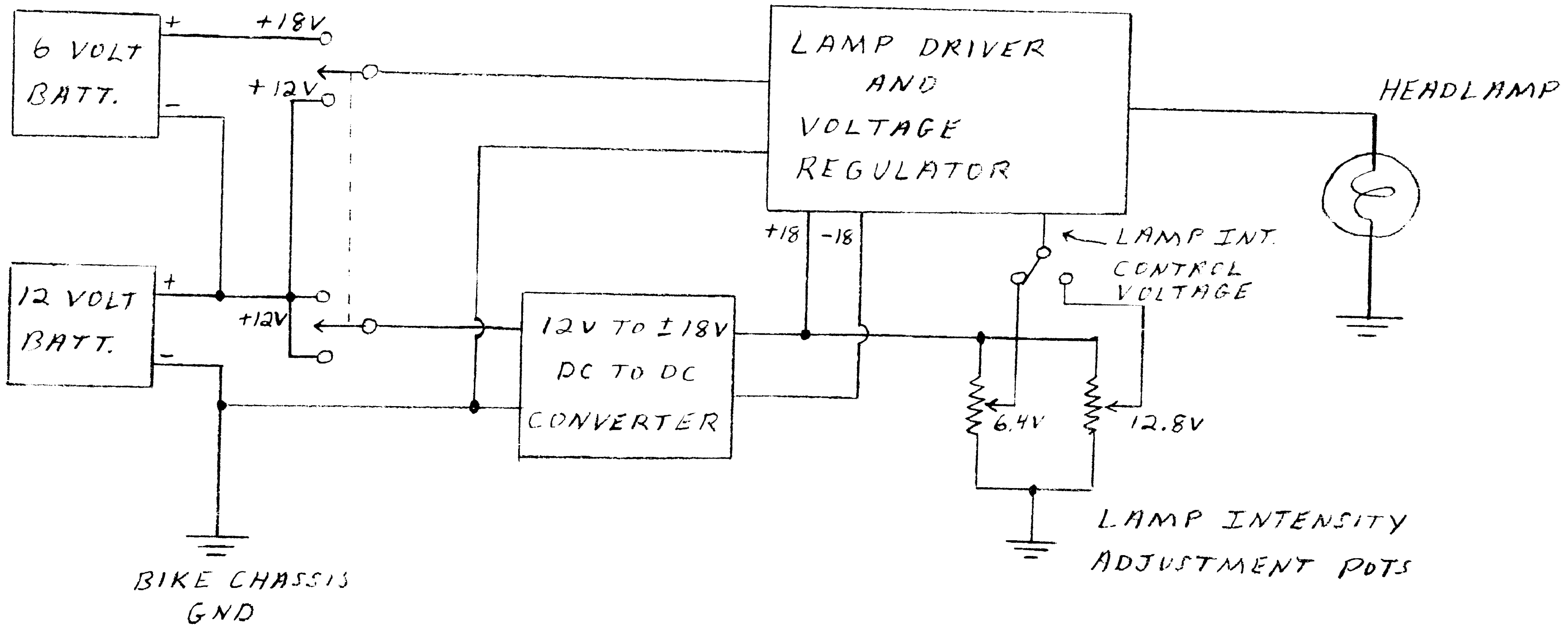


Figure 1c. Block diagram of the headlamp intensity control system.

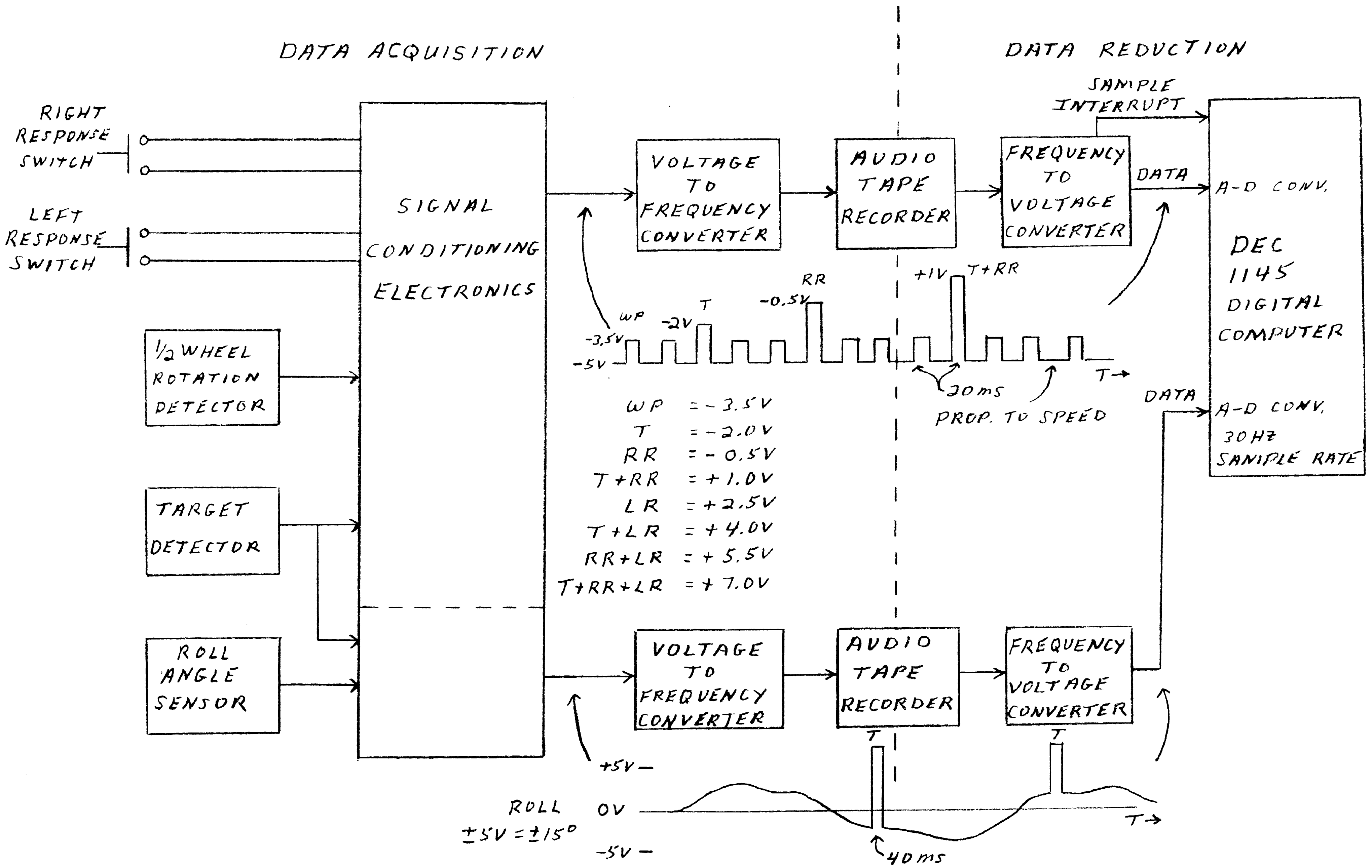


Figure 2c. Block diagram of the identification distance/roll angle data acquisition system.

RECORDERS

In order to have a light weight portable data recorder suitable for use on motorcycles, two Panasonic Type RQ-212DS audio cassette recorders were used. Data was recorded by frequency modulating a 3.5 KHZ audio tone with a frequency deviation of ±2.5 KHZ. Since data was obtained from the signal conditioning electronics coded in voltage amplitude, a linear voltage to frequency converter was used to generate the frequency modulated signal for recording. The recording bandwidth achieved was about 40 HZ giving a pulse response time (to 10% of final value) of about 1.0 milliseconds.

DATA SENSORS

The data sensors were two subject response switches, a wheel rotation detector, a target detector and a roll angle sensor.

The subject response switches were normally-open push-button switches mounted on the motorcycle handlebars so that the driver could easily and quickly activate them without removing his hands from the handle grips.

A proximity detector (Electro-Motion Associates Model 55501) was mounted on the motorcycle frame near the front wheel to detect wheel rotation and thus give a measure of distance traveled. The proximity detector produced a short pulse when each of two metal tabs attached 180 degrees apart on the wheel passed. Thus, two pulses per wheel revolution were obtained or one pulse per about three feet traveled, the exact value depending on the rolling radius of the wheel.

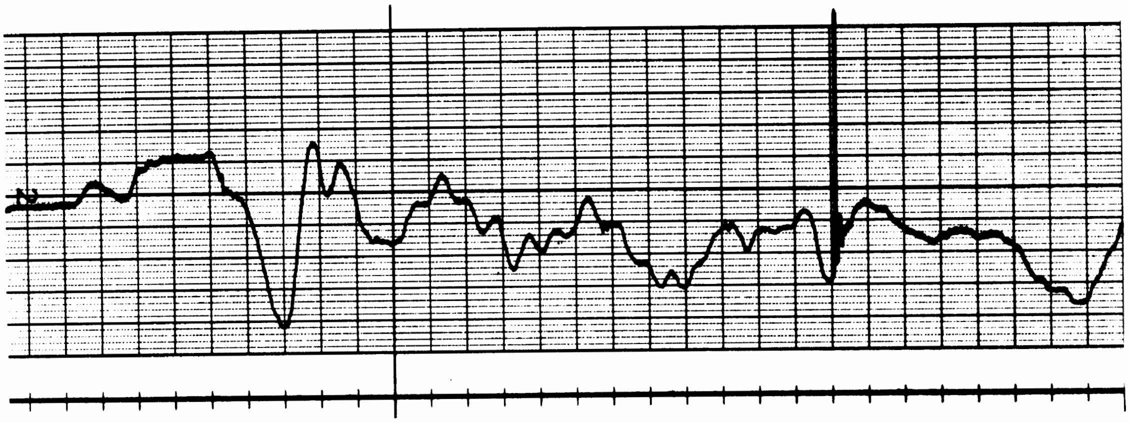
The target detector produced a single output pulse each time the motorcycle passed a retroreflective target placed along the path of the motorcycle. It consisted simply of a narrow beam light source and a narrow viewing angle phototransistor, both aimed to the side from the motorcycle.

Roll angle was sensed by a potentiometer geared to an arm extending from the side of the motorcycle. The outboard end of this arm was supported a constant distance above the road on a model airplane pneumatic tire. Thus, as the motorcycle rolled, the wiper of the potentiometer moved to produce an output voltage proportional to roll angle.

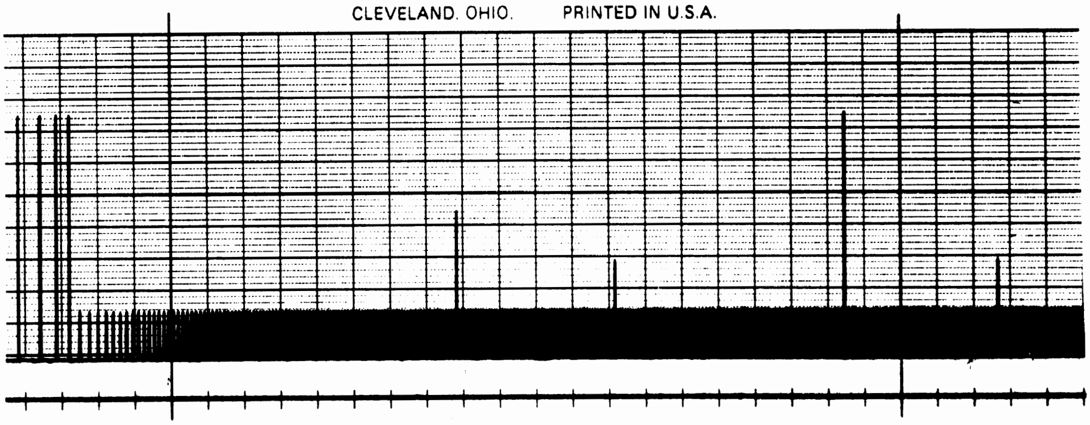
DATA RECORDING FORMAT

As indicated above, two audio tape recorders were used to record data. Roll angle and target pulses were combined and recorded on one recorder. Each time a target pulse occurred a full-scale amplitude pulse 40 milliseconds in duration was added to the roll angle data as shown at the bottom of Figure 2c. Thus, except for an occasional 40 millisecond gap, roll angle was recorded on a continuous analog signal scaled to 3 degrees per volt. Roll angle was limited to a range of ±5 volts and the target pulse was 7 volts in amplitude. Figure 3c is a sample of the reproduced roll angle and target pulse data.

Wheel pulses (2 pulses per revolution), subject responses (right response switch and left response switch), and target pulses were combined in a pulse amplitude coded scheme for recording on the second recorder. This scheme is shown at the center of Figure 2c. In the signal conditioning electronics, each wheel pulse was converted to a 20 millisecond wide pulse of variable amplitude. Each time a subject response or a target detector response occurred, the amplitude of the next wheel pulse was changed to indicate the response according to the amplitude coding shown in Figure 2c. By providing seven discrete pulse amplitude levels, all possible combinations of responses which could occur during the time interval between wheel pulses were coded. A sample of the data reproduced from this recorder is shown in Figure 4c(a) and 4c(b). In 4c(a) the amplitudes of the (right response (RR) + left response (LR)) pulse and the (T + RR + LR) pulses were limited by the strip chart recorder.



ROLL ANGLE DATA



WHEEL PULSE DATA

Figure 3c. Reproduced roll angle and wheel pulse data.

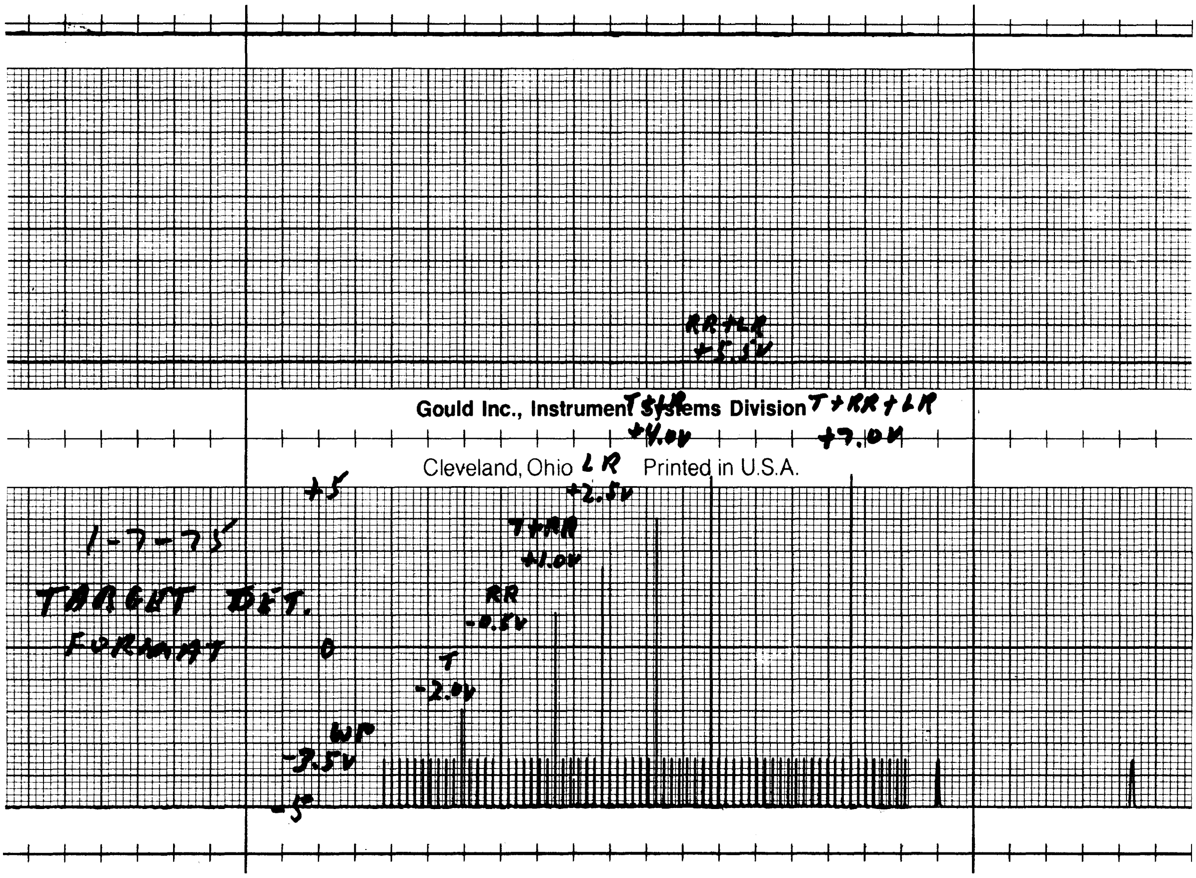


Figure 4c. (a). Wheel pulse calibration showing various pulse amplitudes.

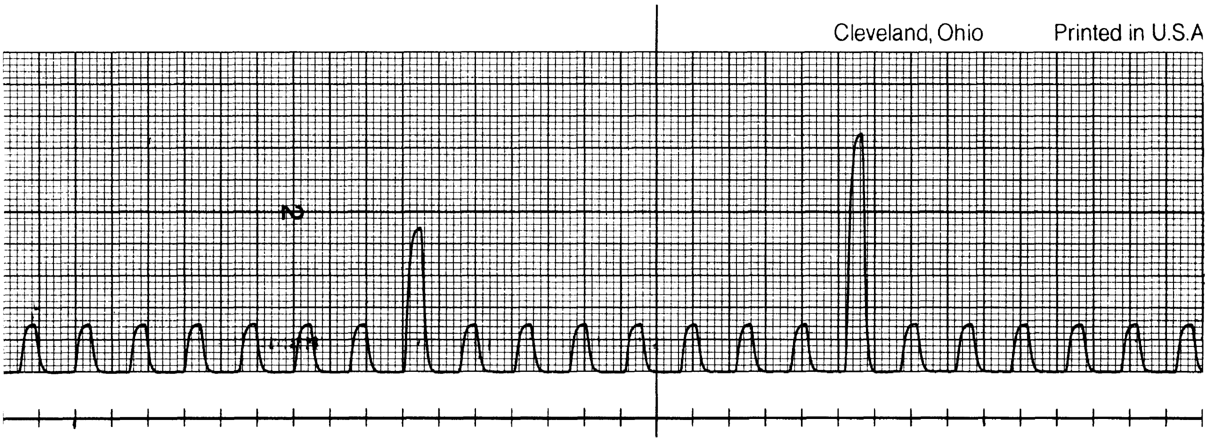


Figure 4c. (b). Time scale expansion of wheel pulse data showing pulse response time (pulse shape limited by dynamic response of strip chart recorder.)

With the data in this format it is a simple matter to determine the distance travelled by the motorcycle between responses by counting the number of wheel pulses.

DATA REDUCTION

The data reduction portion of the motorcycle instrumentation is shown to the right of the darkened line in Figure 2c. It consisted of a frequency to voltage converter to change the frequency modulated signal recorded on tape back to the original voltage amplitude coded signal, and signal, and a digital computer to digitize and store the data. In the case of the wheel pulse and response data, a computer interrupt was generated at the leading edge of each pulse and the computer sampled and digitized the pulse amplitude and stored this amplitude for subsequent data analysis. The output from the frequency to voltage converter was also recorded on a strip chart as shown in Figures 3c and 4c for visual study of the data and for manual data reduction.