SOME DAY AND NIGHT VISUAL ASPECTS OF MOTORCYCLE SAFETY

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This study includes a comparison of the daylight visibility properties of 2 fluorescent and 4 conventional pigments against representative backgrounds for clear and overcast sky conditions, representative solar altitudes, and cardinal directions. In detection and identification, fluorescents are comparable to conventional high-visibility pigments under optimum viewing conditions; however, fluorescents show a substantial improvement when illumination levels decrease toward dusk or when conditions for visibility are least advantageous. As a result, fluorescent colors are now used for certain safety appliances and devices where particularly hazardous conditions are common. Aspects of night visibility suffer from extremes of contrast, low levels of available light, and ineffectiveness of any conventional color to render objects visible at night. Visual clues are dependent on learned patterns of light sources rather than on natural information acquired from daytime driving. Transferral of visual skills from day to night is substantially inhibited by the widely differing aspects unless some "natural" visual information is preserved. The night factors and materials that tend to visually preserve natural information have long been employed for traffic signs and safety appliances. Their extension to cyclist and vehicular use is a promising means of enhancing rapid night visual comprehension. A systemized means of evaluating both the day and night aspects of the visual elements comprising the motorcycle and cyclist is presented. A perception model is reviewed as a possible means of evaluating the several aspects of the visual model.

•VISIBILITY plays an important role in motorcycle accidents. Numerous accident investigations reviewed by the authors list the motorist's not seeing the cyclist as a principal accident factor.

As explained in an Iowa Department of Public Safety Report (1), "Motorcycle drivers, when involved in a fatal accident with another type of vehicle, were considered by the investigating officer not to be at fault in about ⅓ of total violations. This may be partly due to a visibility problem; the drivers of other vehicles do not see the motorcycle." Similarly, in a Minnesota review of accident factors, Shields (2) states, "The greatest apparent hazard for the motorcycle rider is the left turning automobile at an intersection; approximately one out of four fatal accidents occurred when a car or truck was turning left in front of an almost invisible oncoming motorcycle. Passing situations involving motorcycles cause many accidents, usually fatal. These occur when an automobile driver is pulling out to pass another automobile, and fails to see an oncoming motorcycle." Poor visibility of the rider and the small frontal area are cited as apparent causes. McCracken of Liberty Mutual Insurance Company states (3), "Two out of three motorcycle accidents involve collisions with an automobile. Our accident records show that in three out of four auto-cycle collisions our insured automobile driver said he 'did not see' the oncoming cyclist in time to avoid him.... In two out of three collisions the automobile was making a left turn, crossing in front or into the path of the oncoming motorcycle." He cites poor visibility of the motorcyclist as the principal problem.

A 1968 New York study (4) of 3,546 motorcycle accidents reports 1,370 accidents at

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intersections. Of these, 352 involved vehicles traveling in opposite directions with 1 turning left, and 587 involved vehicles entering at an angle. These 2 categories accounted for nearly 70 percent of all motorcycle accidents in the state.

Janoff et al. (5), reported a significant decrease (3.8 percent) in daytime accidents in 4 states having daytime motorcycle headlight laws. But, standard taillights do not increase noticeability. The inadequacy of the taillight is undoubtedly due to insufficient intensity and size. For the motorcycle to be more noticeable, 2 shortcomings must be corrected—the small image of the motorcycle and rider and the low luminance of the colors used in the rider's outerwear and the machine finish. Studies of conspicuousness have been performed to determine the most effective combination of color and size under day and night driving conditions. Siegel and Federman (6) report that dimensions of a conspicuous surface must subtend $\frac{1}{5}$ deg of arc as perceived from the required distance. Areas in excess of $\frac{2}{5}$ deg did not increase noticeability. This yields a dimension of at least 24 sq in. for a distance of 600 ft. Breckenridge and Douglas (7) recommend a factor of 100 to 1,000 times the area required at the visual threshold, suggesting 1.4 to 14 sq ft based on known detection distances for various colors for traffic control devices. Six-hundred feet is chosen as representative of stopping distances required for the 2 head-on situations cited above.

The color chosen for maximum daytime conspicuousness should be foreign to the color makeup of the roadway and surroundings and to the color of other motor vehicles using the roadway. A distinctive color for the use of motorcyclists, which could be seen and recognized at a considerable distance both day and night, would prevent some motorcycle-motor vehicle accidents. Investigations show fluorescent yellow-orange to have greatest effect. Richards et al. (8), in an exhaustive study of wear for deer hunters, recommend "daylight fluorescent orange."

More directly related to the driving environment is a study conducted by Hanson and Dickson (9). This study, to select the most conspicuous color for traffic control signs, compared colors of known high luminance, including conventional and fluorescent pigments. Conventional pigments work by a subtractive process in which certain wavelengths of incident energy are partially absorbed and the remaining energy is reflected. Reflectance values of fluorescent pigments exceed 100 percent at a specific wavelength because energy is absorbed in the near ultraviolet and blue-green regions of the spectrum, and is reemitted in the yellow-red region, thus adding to the energy that is conventionally reflected.

Natural illumination contains greatly varying proportions of blue light for various locations, sky conditions, and times of the day. When targets are in the shade or are overcast, blue light is predominant in the distribution. When daylight visibility is poor, such as during dusk, on an overcast day, or in the shade, the fluorescent materials' ability to use the blue-rich side of the spectrum substantially improves visibility.

Table 1 gives the results of an extensive field study. The threshold distances at which the color of targets could be identified are averaged for a number of viewers and for all backgrounds, for overcast and clear days, and for all times and directions. Both fluorescent colors had better than 2 to 1 recognition ranges for distance compared to regular red.

MOTORCYCLE DISADVANTAGES

The response of the motorist to vehicle hazards is conditioned by the average vehicle encountered—its size, typical lighting, typical speeds, and placement. Motorcyclists therefore suffer certain disadvantages. The small size of the motorcycle places it below the threshold of what is expected. Because of its smaller than average silhouette and angular size, the motorcycle's speed may be misjudged. As a result, closing rates and reaction-braking times may be frequently misjudged. And, the colors of the rider's protective garments are usually of such low luminance that they offer little contrast with the surroundings, particularly those at night.

Brightness

Forbes (10) has shown that traffic signs seen "first and best" are signs with the

Table 1. Mean recognition ranges and rank order of 0.01-square foot circular targets.

Rank	Color	Recognition Range (ft) Both Days	Overcast Day	Clear Sunny Day
1	Fluorescent yellow-orange	441	438	443
2	Fluorescent red-orange	394	391	396
3	White	342	345	338
4	Yellow	315	311	319
5	International orange	242	242	242
6	Red	190	192	187

Figure 1. Silhouette area—0 degrees (head-on view).

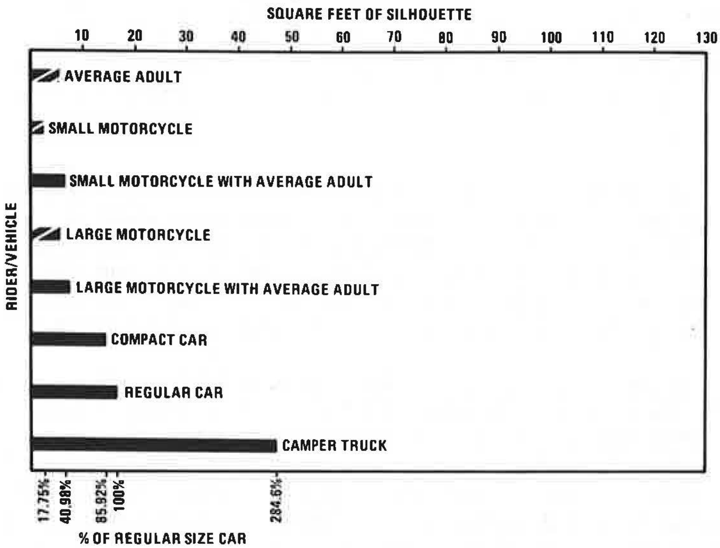
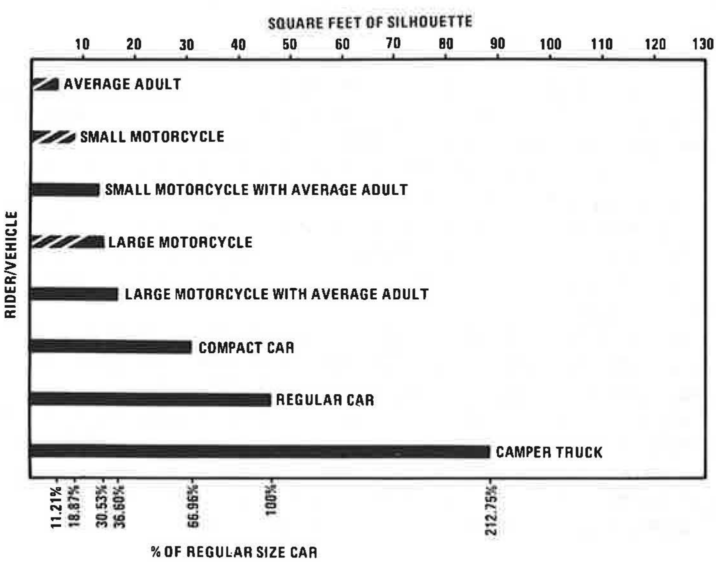


Figure 2. Silhouette area—45 degrees.



greatest brightness contrast when seen against their surroundings and large signs with brightness held constant. The perception model expresses expected recognition range as a function of percentage of contrast of the sign and surroundings multiplied by the minimum dimension of the sign in feet. The direct relationship of size and contrast that yields the expected recognition range suggests that improved brightness contrast may compensate for the motorcyclist's small size.

Visual Area—Tests

The visual area was investigated with the rider astride the machine and with the machine and rider separate. The areas were measured for a number of encounter positions—head-on, at angles, from the side, and from the rear. The visual areas were photographed with a 35-mm camera on a tripod. The center of the visible mass for each vehicle was placed at the center of the viewing field for each of the 5 angles viewed—0, 45, 90, 135, and 180 deg. The camera was positioned at $4\frac{1}{2}$ ft above the roadway surface to correspond to the average motorist's eye height. Each picture incorporated a template 5 ft in length to later project a standard-sized image. Pictures were projected onto a gridded screen to determine the area with an accuracy of ±5 percent. The analysis did not include the wheel spoke areas or background areas visible through windows.

Visual Area—Results

The results of the analyses are shown in Figures 1 through 7 and Table 2. The comparative silhouette areas presented are for a typical standard-sized automobile, a camper truck, a compact car, a large motorcycle (BMW R-60, with fairing and saddle bags) with rider, a small motorcycle (Harley Davidson TX-125) with rider, and rider and motorcycle separately. Views are at 0 deg (head-on); 45 deg (a right-angle intersection encounter); 90 and 135 deg (return from a passing lane); and 180 deg (directly behind).

Silhouette areas presented by the motorcycle and rider vary from 30 to 40 percent of the standard passenger car as shown on the composite average. The various views, shown in Figure 7, compare the silhouette areas of a standard-sized car and a small motorcycle with adult rider. There is a significant reduction in area when the encounter is at 0 or 180 deg. Analysis of the motorcycle and rider separately shows the area of the rider's helmet and clothing to be greater than that of the machine for 0- and 180-deg encounters. To improve the brightness contrast of 50 percent of the silhouette area, a minimum of 3.44 sq ft for the end view to a maximum of 7.40 sq ft for the side view would need to be treated. It would then be above the threshold values cited by Siegel et al. (6) and would be similar to the area presented by a conventional 30-in. stop sign.

NIGHT VISIBILITY

From 0 and 180 deg, the single headlight and taillight provide cues as to location, but the single light may be confused with an automobile with 1 headlight or taillight out, and the single light offers little aid in determining either distance or relative speed. It is far more difficult for a motorist to estimate a motorcycle's distance and speed at night than in the day. The daylight cues include seeing the size of the motorcycle and its movement relative to a textured background, both of which require a certain amount of ambient light. The information used in daylight is difficult to preserve at night because of single and often ambiguous point sources. For nighttime, a system of visual enhancement is required to provide these missing cues.

This problem is related to automobile headlighting. As Schwab and Hemion (11) observe, "Headlighting design is currently based on a compromise between the need for adequate illumination of the road ahead and the need to avoid 'dazzling' the eyes of the oncoming drivers with 'glare' light." The low-beam intensity and configuration "cannot possibly provide adequate lighting to enable the driver to operate his vehicle safely during many common night driving situations because of the nature of the necessary design compromises." Low-beam lights are used in more than 60 percent of all night driving in low-volume rural areas. Low-beam use increases to 90 percent when traffic volumes increase.

Figure 3. Silhouette area—90 degrees (side view).

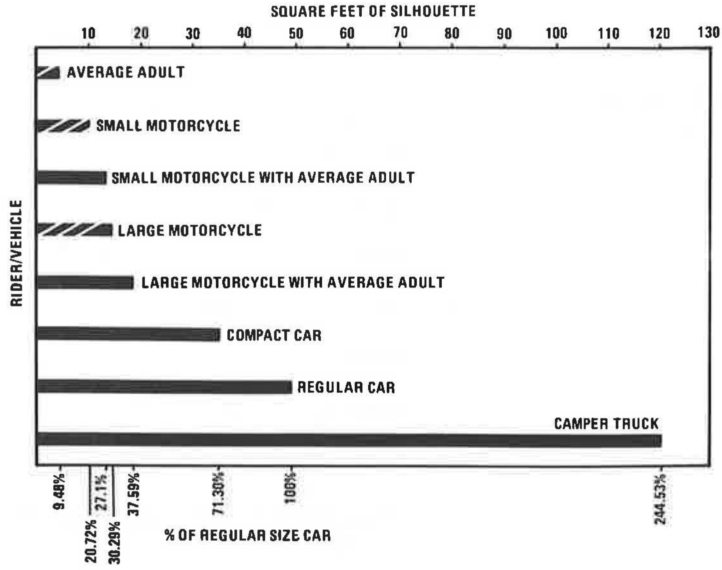


Figure 4. Silhouette area—135 degrees.

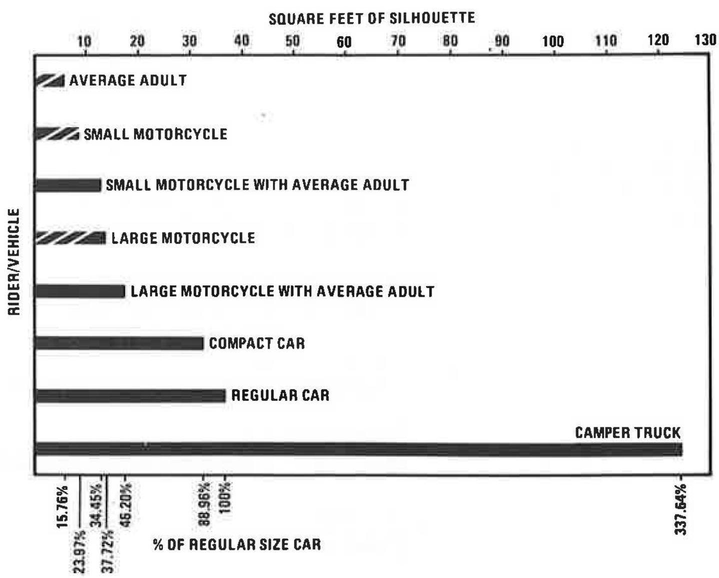
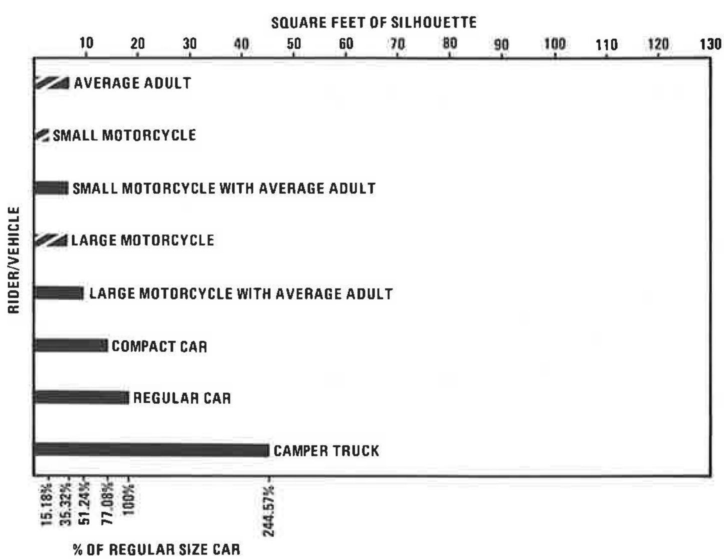


Figure 5. Silhouette area—180 degrees (rear view).



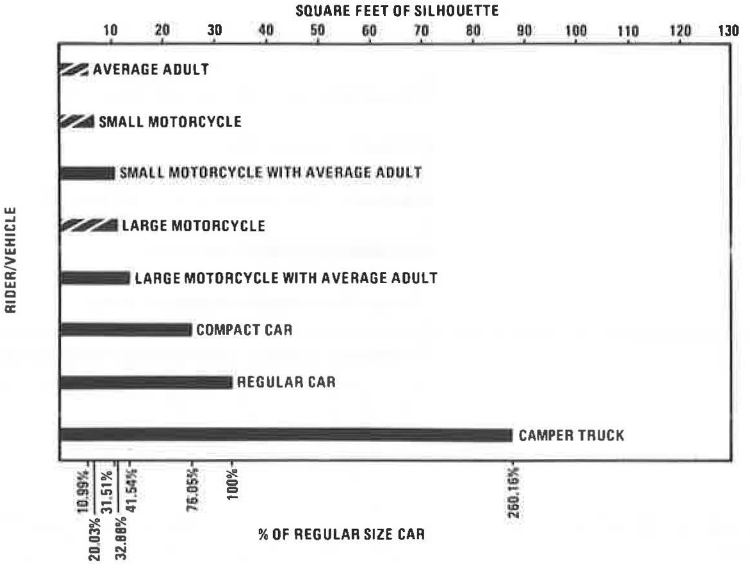


Figure 6. Silhouette area composite average.

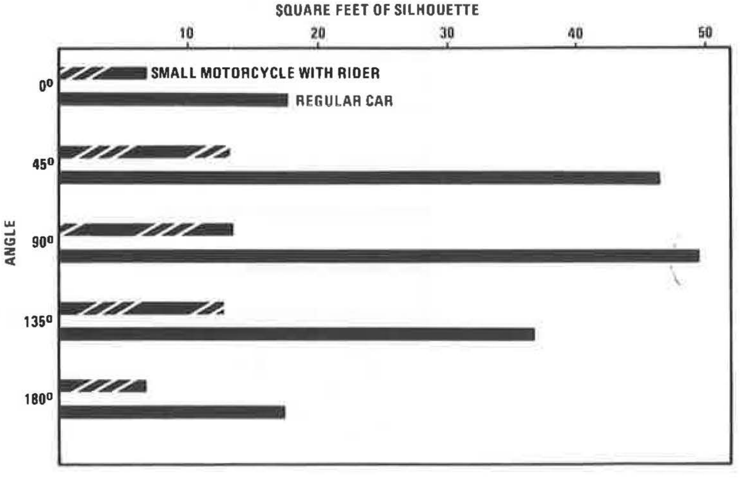


Figure 7. Comparsion of silhouette areas of small motorcycle with rider and regular car.

Table 2. Dimensions and silhouette areas for various vehicles.

Vehicle	Overall Dimensions: Height (ft)	Width (ft)	Length (ft)	Silhouette Area (sq ft): 0 Deg	45 Deg	90 Deg	135 Deg	180 Deg	Composite Average
Average adult	5.86	2.09	1.26	6.73	5.21	4.69	5.82	6.73	5.71
Small motorcycle	5.22	2.51	6.48	2.89	8.77	10.24	8.85	2.89	6.73
Small motorcycle with average adult	5.23	4.81	6.48	6.88	13.06	13.41	12.72	6.88	10.59
Large motorcycle	4.60	2.51	7.42	6.09	14.19	14.97	13.93	6.09	11.05
Large motorcycle with average adult	5.86	2.51	7.42	8.60	17.01	18.58	17.06	8.60	13.96
Compact car[a]	4.81	4.81	12.54	14.30	31.12	35.24	32.85	14.30	25.56
Regular car[b]	4.81	6.27	17.56	17.60	46.48	49.43	36.93	17.60	33.61
Camper-truck[c]	9.41	6.90	18.81	46.37	98.20	120.87	124.69	46.37	87.44

[a]Volkswagen. [b]1969 Oldsmobile. [c]9½-ft 1972 Ford pickup with camper.

Figure 8. Standard motorcycle–day and night views.

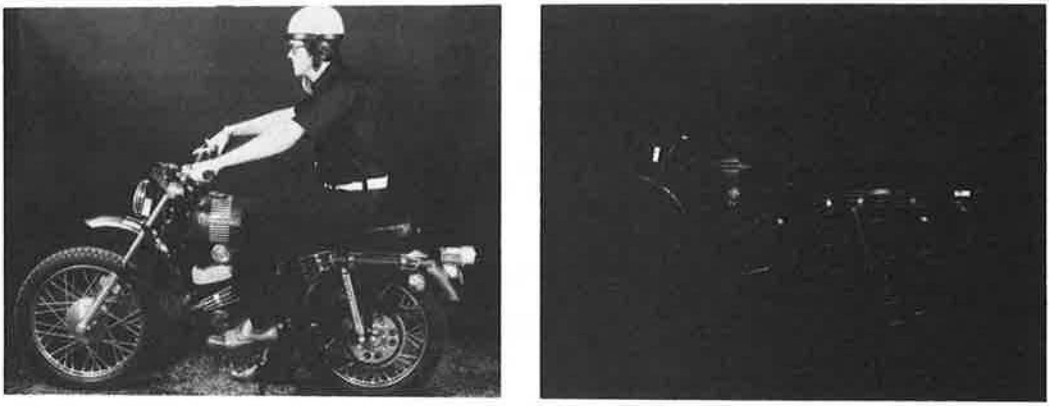


Figure 9. Retroreflective motorcycle, suit, helmet, and tires–day and night views.

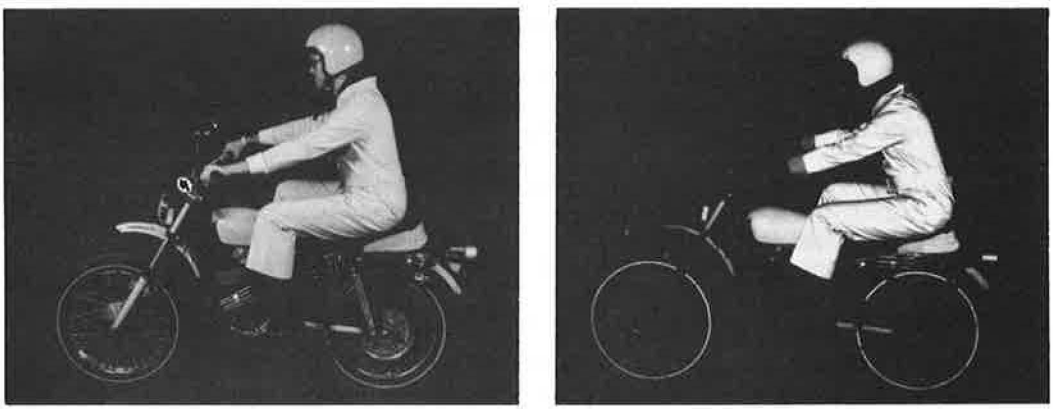


Table 3. Night luminance of standard and fully reflectorized motorcycle and rider.

Viewing Angle (deg)	Motorcycle (ft-L)	Lights (ft-L)	Retroreflective Treatment On Motorcycle (ft-L)	Helmet (ft-L)	Suit (ft-L)	Total (ft-L)
0	0.01292	39.0443	0.0003	0.0015	0.0161	39.0751
45	0.01225	0.8440	0.0083	0.0017	0.0263	0.8925
90	0.01473	0.0559	0.0106	0.0018	0.0263	0.1093
135	0.01315	0.0143	0.0038	0.0018	0.0220	0.0549
180	0.0154	0.3076	0.0025	0.0017	0.0368	0.364

Note: View is from low beams at 600 ft with motorcycle headlight and taillight on. Lamps were adjusted to standard alignment. Luminance values were obtained with a Pritchard telephotometer at driver eye position in a 1973 Oldsmobile.

Table 4. Luminance of standard and fully reflectorized motorcycle and rider.

Viewing Angle (deg)	Luminance (percent)	
	Standard	Reflectorized
0	99.97	0.03
45	95.94	4.06
90	64.65	35.35
135	50.00	50.00
180	88.75	11.25

In a study of available braking distances for night driving, Johansson and Rumar (12) found that for speeds over 30 mph braking distance exceeds the visibility distance (for European dipped headlights). They suggest reflectorizing cyclists and pedestrians to enhance their visibility. Tests conducted by Rumar (13) on the visibility of pedestrians wearing reflectorized clothing indicate a fivefold improvement in recognition distances (from 75 to 625 ft). Figures 8 and 9 show retroreflective helmet, clothing, and motorcycle surfaces, which preserve the natural information of daylight by providing the luminance, size, and shape that are frequently invisible under low beams.

A field-of-view study by Ford Motor Company (14) describes the angular span required to see and safely accommodate intersecting vehicles. A field of view of 126 deg encompasses 85 percent of the vehicles on a converging course. This yields a half-angle of 63 deg and should therefore be the entrance angle requirement for side-marker reflectors on vehicles.

At approach angles of 45, 90, and 135 deg, side-marker reflectors have luminous areas far lower than what may be required for adequate attention and recognition. The values measured by the authors are given in Tables 3 and 4, which illustrate the contributions of various components. Required seeing distances for right-angle encounters approximate 400 ft at 45 deg to either vehicle when either is traveling at 40 to 50 mph. The combination of increased visibility and shape identification, as is shown by the perception model, should result in a marked improvement in nighttime recognition.

CONCLUSIONS

The visual area of the motorcycle and rider is approximately a third that of a conventional automobile. The conventional automobile is the size of hazard to which the motorist most frequently and successfully accommodates. The more frequent failure to correctly cope with the smaller motorcycle hazard might be improved by perceptual aids employing highly visible and contrasting colors such as fluorescent orange in sufficient size to be readily seen. At night, if both motorcycle and operator were reflectorized, depth perception would be enhanced. This increased bright area would communicate relative distance and speed better than traditional motorcycle lighting.

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