Dynamic Visual Fields*

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It is estimated that an obstruction to vision contributed to one out of every eight motor vehicle accidents. In these, vision was obscured by objects on the car in 40 percent of the cases and stationary objects such as trees and buildings in 30 percent of the cases; the remainder were other cases—some moving, some parking, and a few instances of glare. To these must be added an undetermined number of cases where, through inattention, distraction, or other cause, the visual stimulus which fell upon the eye failed to "register;" that is, it failed to be perceived and interpreted. Knowledge of man's capability for viewing in terms of extent when operating a moving vehicle, his viewing habits or patterns, and his response behavior, is essential as the basis for specifying and providing for human requirements for vehicle design, highway planning, and driver training.

● THE reports which appeared both in the 1954 and 1955 edition of Accident Facts emphasized the relative importance of visibility in vehicular safety. An obstruction to vision was considered to have contributed to one out of every eight motor vehicle accidents. In these, vision was obscured by objects on the car in about two-fifths of the cases and by stationary objects such as trees and buildings in a third of the cases. The remaining one-quarter involved obstruction to vision by moving or parked cars and in a few instances interference with vision by glare. To these must be added an undetermined number of cases where, although visual obstructions were not involved, the object which should have warned the driver failed to register in his consciousness because of inattention, distraction or other causes.

In analyzing the visual factors contributing to accidents, the visual stimulus from a potentially hazardous object (a) may not reach the eye because some opaque object on the car or on the highway blocks the image that would otherwise have fallen on the retina; (b) may not constitute an adequate stimulus because of the characteristics of the hazardous object and the limitations of man's visual equipment; (c) may not fall upon the retina because the vehicular operator is looking elsewhere during a critical period; or (d) may form an image of adequate energy on the retina but fail to register—that is, may fail to be perceived and interpreted. Visual requirements for safety, then, relate to the car, the driver, and the road.

While there is nothing new in the concept that the machine, the highway and the man may each contribute to an accident, such a classification fits in well with a method of approach to the study of accidents which is currently being used by some biologists. Since accidents constitute a mass health problem, the biologist veiws them much as he would an epidemic and considers that accidents result from interaction of the agent (the vehicle), the environment (the highway), and the host (the driver). The approach is not only useful here, but also serves to emphasize the thesis of this report: since accidents result from an interaction of three components, the prevention of accidents due to some failure of the visual warning will require the application of remedial measures to the car, the highway, and the man.

Measurement of Opaque and Transparent Areas Affecting Vision

The first consideration is the agent (the vehicle). From the driver's seat—even under optimal conditions of a clean windshield, fair weather and good illumination—the sideposts, dash, hood, top, sides and floor of the vehicle markedly limit what can be

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seen. The arrangement for visibility and the design of structures will vary from car to car. There must be some means of describing the transparent areas and the opaque obstructions as a basis for interpreting accident reports, comparing makes and models, and evaluating new and "improved" visibility provisions. Subjective evaluation can no longer be accepted where, for example, a 1956 model is judged to provide better visibility than a previous model. Simple measurement and comparison of the total glass area is unacceptable not only because of the sloping and curved windshields, but also because it fails to give the locations of the opaque structure. The procedure here has been to employ a system of measurements and calculations which provides for evaluation of visibility from within the vehicle on an absolute basis, rather than a mere subjective comparison between designs. Briefly, the procedure is to measure the angular positions of points along the boundary of the windshield and side windows as seen from the eyepoint of the driver, to determine from a graph of these data the total solid angle intercepted, and to score this with respect to the total useful visual field. The measurements are made with a goniometer (Figure 1) which the authors developed to obtain data on automobiles (Figure 2), buses, and trucks. The values are plotted on a modified polar coordinate graph paper developed by P. J. Sutro especially for this purpose (Figure 2A). The special paper gives an equal area projection such that the area of any region on the graph is proportional to the solid angle. The areas for vision shown on the plot are measured directly with a planimeter. To convert the results to solid angle (in steradians) the measured area is divided by the scale factor; in out plots there are 10 sq in. per steradian. The details of measurement and calculations are described in earlier reports (1, 2). The results for the foregoing example (Figure 2) are given in Table 1.

Evaluating and Scoring Visibility. Once the data are obtained, how are they to be interpreted? Since design for visibility is specifically directed toward fulfilling human

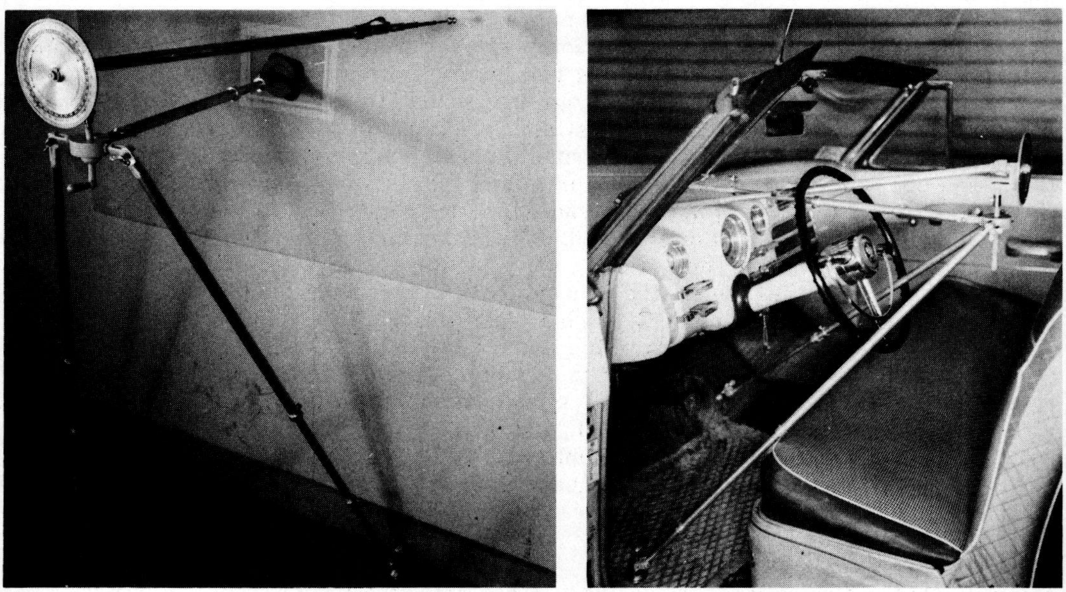

Figure 1. Vehicle goniometer showing the angle plate, the telescoping rod and supporting structure. There is also a sighting attachment for the goniometer (with crossbar and circle-dot sights and double mirror system which permits viewing at right angles to the sighting line) which can be readily attached and used in place of the telescoping rod. At right are shown details of mounting in an automobile, with the reference center of the instrument located at the eye-position of the driver.

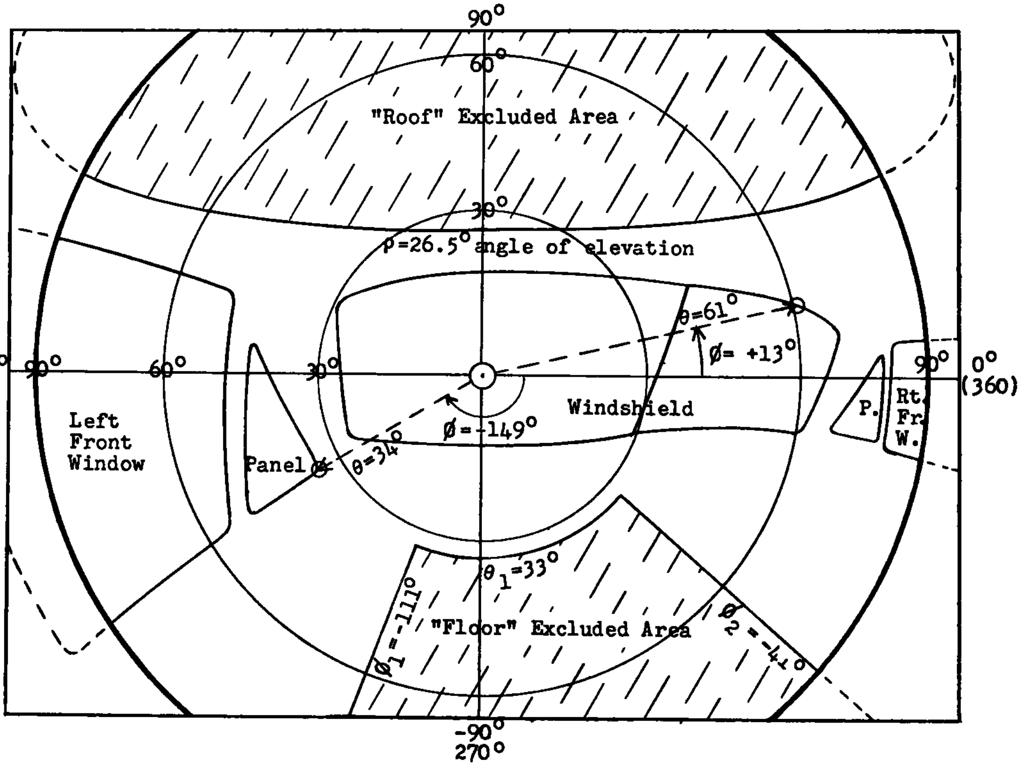

Figure 2. Diagram illustrating the location of the various windows and excluded areas plotted in Figure 2A (as an example), and showing how angle data are plotted on the special graph paper (2A)(to give an equal-area polar projection). For instance, the bottom front (b.F) corner of the left front panel is at ϕ=-149°, θ=34°. The plotted position of this point (circled) is located by moving outward along the radial line for θ=-149°(as indicated by the dashed arrow) until it crosses the circle for θ=34°.

requirements in a driving situation, the total area of visibility provided by the vehicle can be compared with the total area which man would be capable of viewing if he were sitting in space with no obstructions limiting his vision. There is, however, a practical consideration to the latter; not all of the area which man is capable of viewing constitutes a necessary or even useful area of vision for driving. A practical basis or reference value can be taken excluding certain non-essential areas (Figure 3). This is the total area which man is capable of viewing less: (a) the "floor" area directly beneath the vehicle, bounded by the four wheels (since once in this area, the object can no longer be avoided); and (b) a "roof" region overhead, above a critical angle of elevation (beyond which upward vision is not a vehicular safety factor).

The area score for a vehicle would then be the ratio of the "useful" region that can be seen from the vehicle (measured as the solid angle of the total useful area; that is, the windshield, side windows, etc.) to a reference solid angle defined as the total useful region which man could scan; that is, the solid angle of the total human visual field, excluding areas corresponding to (a) and (b).

The total solid angle, in itself, is no true index of the effectiveness of the provisions of visibility. Not only must the area be sufficient, but certain critical areas must be completely free from obstruction, while in other important but sub-critical areas, structures up to 1.5 to 2.0 in. wide can be tolerated. The critical area is defined as the region through which is to be seen the road and its shoulders ahead of the front wheels. The sub-critical areas might be suggested, but could not be factually supported at this time. They are determined by potential collision courses with moving and with stationary objects which lie within the areas that could be viewed by man under normal conditions of operation.

Windshield Wiper Performance and Visibility. If there is rain or snow, only a small portion of the transparent area provided by design is cleared by the windshield wipers; this may be less than 30 percent of the total transparent area provided. Other glass areas to which rain or snow may not adhere and portions of the areas cleared by windshield wipers may be fogged in spite of heaters and defrosters. A "lighthouse" diagram illustrates the obstructions to vision (a) from structure and (b) from areas which are not cleared by standard wipers in a 1954 sedan (Figure 4). Photographs taken through the windshield of this car show the road and other areas as seen through the standard wiper pattern by tall, medium and short drivers (Figure 5). It is to this aspect of the vision problem that the attention of the design engineer is invited.

Man's Viewing Habits and Capabilities. Knowledge of the area which man is capable of viewing is necessary to predict whether a design change will be of benefit. In order that the data be pertinent, what a man can see under normal conditions of driving must be considered (that is, with moderate head and eye movement) rather than the visual fields determined by usual clinical examination where the head is fixed, one eye is closed, and the eye under test is focused on a fixation point directly ahead. A reasonable set of conditions for moderate head and eye movements would be with the head moving 45 deg to the left and right and 30 deg up and down, and the eyes moving 15 deg

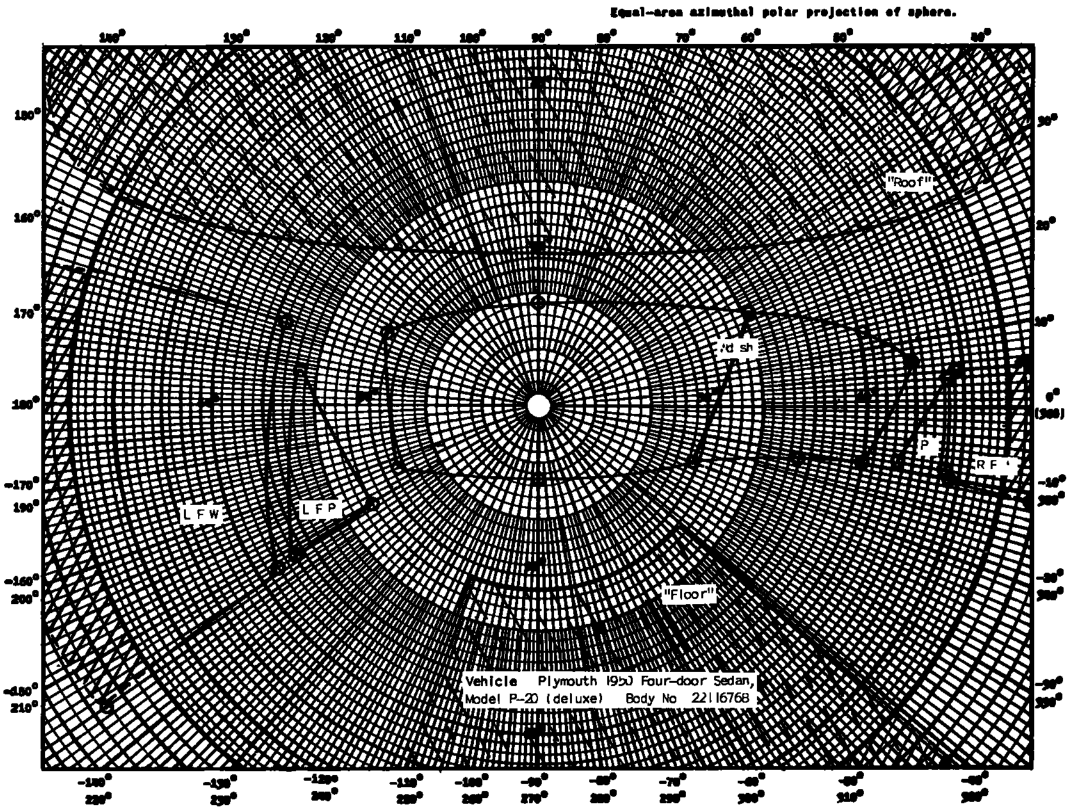

Figure 2A. Forward hemisphere - Plymouth P-20 sedan. Equal-area polar plot of windshield and side windows, as well as excluded areas (dashed shading), for the front half ($\theta \leq 90°$) of the vehicle-as seen from the driver's eye-point. On the special graph paper, the co-latitude θ is plotted radially (scale non-linear), and the azimuth angle ϕ counter-clockwise. The pole at the center is the forward horizontal line of sight (the prime axis) and the region outside the heavy circle ($\theta = 90°$) is in the rear hemisphere.

TABLE 1

RESULTS ON PLYMOUTH SEDAN

Plymouth 1950 Four-Door Sedan (deluxe), Model P-20.

Scores calculated from windshield-window and reference solid angles, which are given in steradians (Ω) and in percent of sphere ($\Omega/4\pi$) and broken down into component parts "Front half" refers to values for forward hemisphere alone (where $\theta \leq 90°$), "entire car" to sum of results for both hemispheres. Thus the differences between these two columns are the results for the rear hemisphere ($\theta \geq 90°$) for all tabulated quantities except the (final) score

Window or Area		Entire Car Ω (sterad)	Entire Car ($\Omega/4\pi$) %	Front Half Ω (sterad)	Front Half ($\Omega/4\pi$) %
Excluded area (solid angle)	"roof"	3 480	(27 7)	1.740	(13 8)
	"floor"	2.052	(16 3)	1 031	(8.2)
	Total: Ω_{ex}	5 532	(44 0)	2.771	(22 1)
Reference solid angle $\Omega_{rf} = 4\pi(\text{or } 2\pi) - \Omega_{ex}$ ≠		7.03+	(56 0)	3.51	(27.9)
Windshield (total)		0.737	(5 86)	0 737	(5 86)
Left front panel		.078	(0 62)	078	(0.62)
Left front window		.906	(7.21)	.580	(4.62)
Right front panel		.023	(0.18)	023	(0.18)
Right front window		.098	(0.78)	058	(0.46)
Left back window + panel		.212	(1.69)	-	-
Right back window + panel		104	(0.83)	-	-
Rear-view window		114	(0.91)	-	-
	Total Ω_w	2.27	(18.1)	1 48-	(11 7)
Score. Ω_w/Ω_{rf}		32 3%		42 0%	

≠ Ω_{rf} is found by subtracting the forward hemisphere Ω_{ex} from 2π for the "front half," or the whole Ω_{ex} from 4π for the "entire car"

Note $\Omega/4\pi$ (in percent of sphere) merely expresses Ω in other units

to the right, left, up, and down from a central position in the orbit. According to the data of Hall and Greenbaum (3), under such conditions a man may see 155 deg to the left and right, about 90 deg up and 112 deg down. Peripheral limits which could be viewed simultaneously with both eyes would be out to 105 deg left and right; the 50 deg beyond that which can be viewed monocularly is important for gaining information warning of the presence of objects, especially those in motion. Detailed data are shown in Table 2. The corresponding total solid angle viewed has been calculated, with the results given in Table 3. This shows that under conditions of moderate head and eye movement, the solid angle of the visual field is 9.48 steradians or about 75 percent of a sphere. Closed cars may not provide total transparent areas which are even one-third of this value, so that apparently man's capabilities are not likely to limit the benefits he might gain from designs which may appear in the next few years.

Collision Pathways and Stopping Distances. T. W. Forbes wrote in 1951: "Ever notice, when driving, that another vehicle was tending to maintain a fixed

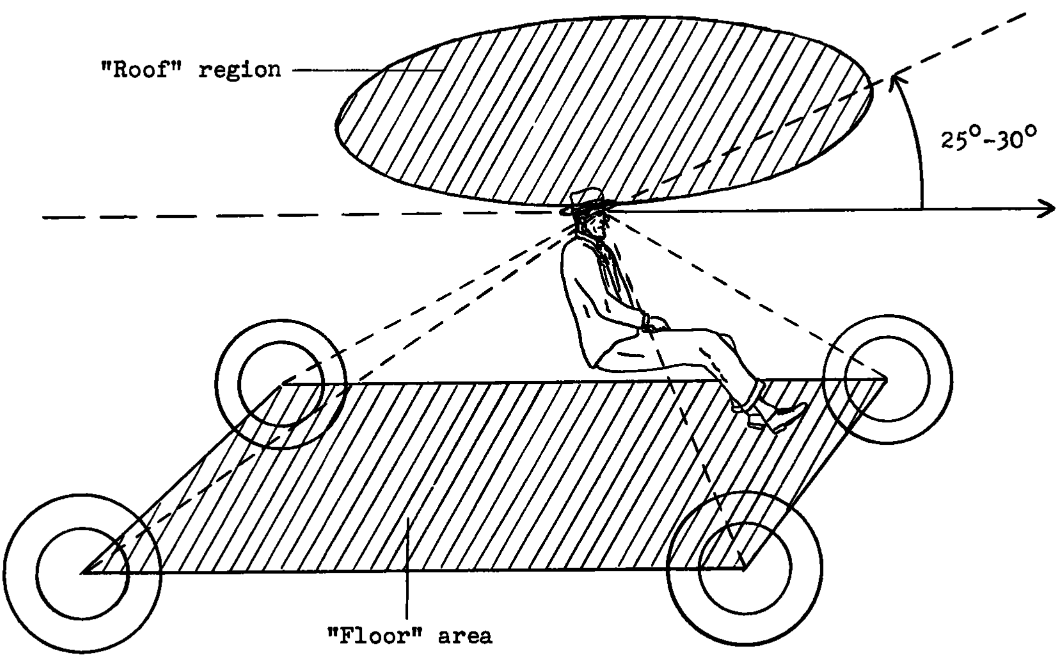

Figure 3. Regions which do not contribute to the areas of vision useful for vehicular operation (shaded areas) are excluded from the solid angle employed in scoring vehicles.

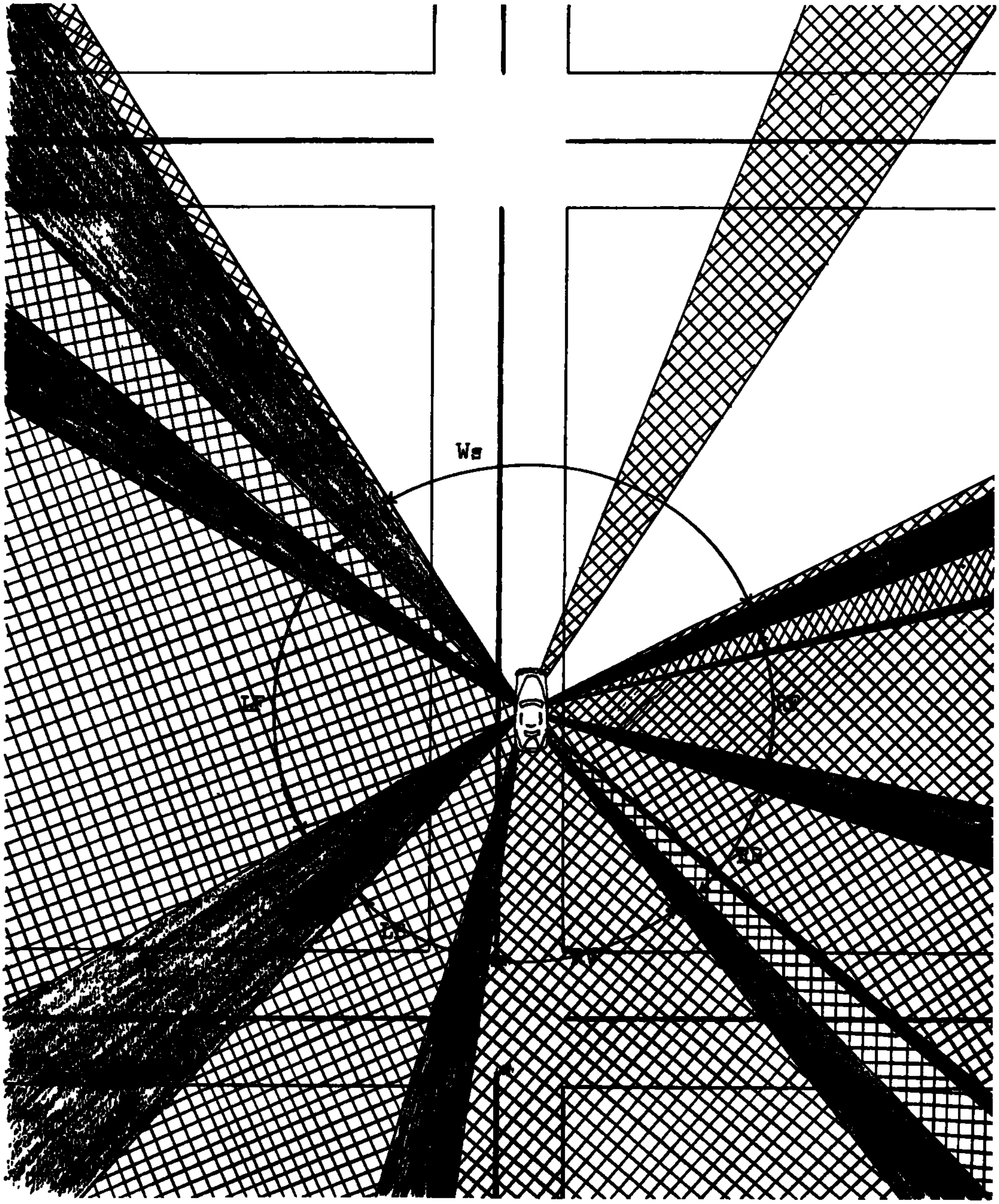

Figure 4. Automobile visibility in the horizontal plane: standard wiper pattern. Diagram illustrating angles of view cleared by standard windshield wipers on a typical passenger car (1954 Ford sedan) at the eye-level of a median-height driver, in contrast to total windshield and window angles. This is the pattern seen in Figure 5(b), produced with extra-length (12 in.), fixed-angle blades on the conventional equipment supplied with the car. Legend: Unshaded sectors—cleared by windshield wipers, shaded sectors-other window areas (not wiped), blackened sectors—blocked by permanent obstructions. Ws—windshield, RV—rear-view window, LF/RF-left/right front window and panel, LB/RB—left/right back side-window and panel.

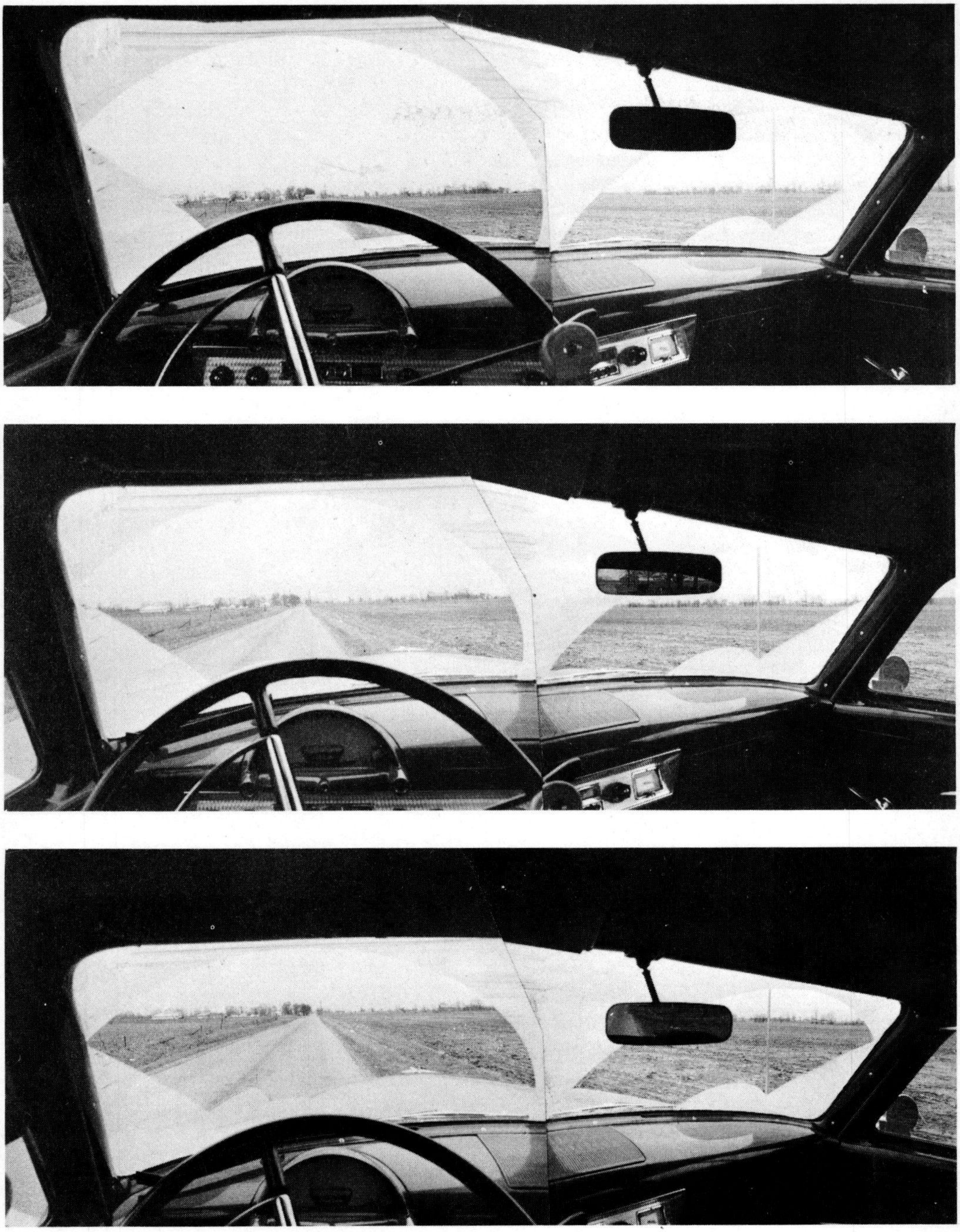

Figure 5. Standard windshield-wiper pattern on a 1954 Ford sedan, using extra-length blades (12 in.instead of 11 in.) on the conventional equipment supplied with the automobile, where the wipers point to the center when parked flush with bottom of windshield. The three pictures show the outside areas seen through the pattern as in actual operation by drivers of various heights from very short to very tall. Note the marked improvement from (a)-(b), and in (a) the vehicle on the road ahead largely concealed by the wheel.

position as seen past the corner post of your windshield? In air and sea navigation this condition is called constant bearing, and navigators know that it indicates a collision course" (4). This serves to emphasize another environmental factor in the problem of visibility and safety. Thus, whenever courses are such that an outside object continues in the same angular position (the operator's eye is taken as the reference point) while its distance grows less, a collision will follow unless action is taken to alter the situation, such as changing the speed and/or direction from the collision course. While this holds for any course and speed relationship, its converse is not necessarily true unless speeds are constant—that is, an approaching vehicle on a collision pathway will necessarily remain in the same angular position from the subject vehicle only if the speeds of both do not change. The authors have employed this special case as their

TABLE 2

FIELD ANGLES OF HUMAN VISION

Condition of Movement Permitted	Type of Field	Horizontal Limits (Temporal) Ambinocular Field (each side)	Horizontal Limits (Nasal) Binocular Field (each side)	Vertical Limits Field Angle Up	Vertical Limits Field Angle Down
(a) Head and eyes moderate movements, assumed as	Range of fixation	60°		45°	
Eyes 15 deg right or left, 15 deg up or down	Eye deviation (assumed)	15°	15°	15°	15°
	Peripheral field from point of fixation	95	(45)	46	67
Head 45 deg right or left, 30 deg up or down	Net (peripheral) field from central fixation	110	60 [c]	61	82
	Head rotation (assumed)	45	45	30 [a]	30 [a]
	Total peripheral field (from central body line)	155	105	91	112 [b]
(b) Head fixed, Eyes fixed (central)	Field of peripheral vision (central fixation)	95	60	46	67

[a] Estimated by the authors on the basis of tests on a single subject

[b] Ignoring obstruction of body (and/or knees if seated) This obstruction would probably impose maximum field of 90 deg (or less, seated) directly downward, however, this would not apply at either side, where the potentiality of seeing further downward if the body were transparent extends the total area of the visual field markedly.

[c] Maximum possible peripheral field (equal to that achieved with maximum eye deviation) This is limited by the anatomy of the structures around the eye (nose, cheeks, brows, etc.) The figures in brackets on the line preceding each occurrence of this note are calculated values, chosen to result in the maximum limit thus indicated.

All data except as noted are from Hall and Greenbaum (3).

The ambinocular field is defined here as the total area which can be seen with two eyes, but not in all parts by both at once. At the sides, it includes uniocular regions visible to the right eye but not the left, and vice versa. It is bounded only by the temporal field-limit of each eye.

The term "binocular" is here restricted to the narrower, more central region which can be seen by both eyes simultaneously (stereoscopic vision). It is bounded by the nasal field-limits of the eyes. In other words, the binocular field is the area where the individual (monoculate) fields of the eyes overlap each other, while the ambinocular field comprises in addition the marginal regions visible to only one eye.

TABLE 3

SOLID ANGLES OF HUMAN VISUAL FIELDS

		Solid Angle of Total Field: Ambinocular Angle (sterads)	Ambinocular % of 4π (= % of sphere)	Binocular Angle (sterads)	Binocular % of 4π (= % of sphere)	Unobstructed Solid Angle Seated: Ambinocular Angle (sterads)	Ambinocular % of 4π (= % of sphere)	Binocular Angle (sterads)	Binocular % of 4π (= % of sphere)
(a) Head and Eyes moderate movements	Range of fixation	2.40	19.1	2.40	19 1	2.40	19 1	2 40	19.1
(as indicated in Table 1)	Total peripheral field	9.48	75.4	7 70	61.3	8.88	70 7	7.10	56 5
(b) Head fixed, Eyes fixed (central)	Peripheral field (total)	4.38	34.9	2 97	23 6	4 30	34.2	2 89	23.0

Table 2. The solid angles intercepted by the fields of human vision, calculated from the field limits of Table 1.

The "solid angle of the total field" (as tabulated) includes any visible areas of the body (but not the head). That is, the "external" field visible beyond the body is less than this "total field" value by whatever solid angle is obstructed by the position of the body

The "unobstructed solid angle" has been corrected for the obstruction of the body when seated From the "total field" value was subtracted the solid angle intercepted (from the eye-point) by a region extending from hip to hip sideways, and from the knees to the downward limit of the vertical field (when this extends past the knees)

For a standing position, the "unobstructed" field would be intermediate between the values given

Anthropometric data from Randall et al. (7) were used to find the body angles from which the body obstruction corrections were calculated.

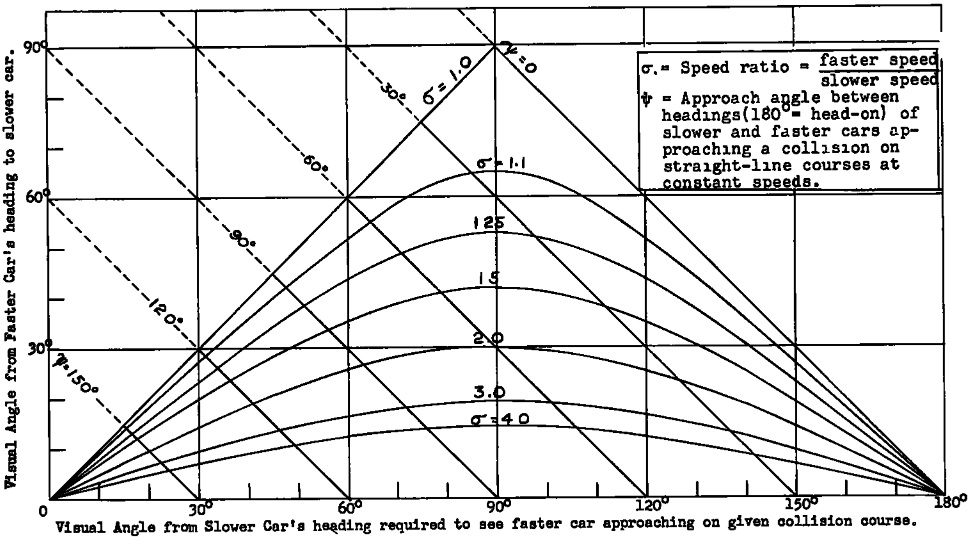

Figure 6. Collision pathways of vehicles. The graph shows the required horizontal visual angles (measured around from the forward line of motion) required by the driver of each vehicle in order to see the other when approaching on a course which will result in collision if both continue in straight lines at constant speeds. (The angle from the faster car is never over 90°.) The graph is entered with the values of approach angle and speed ratio which specify the relative (collision) courses of the two vehicles; the visual angles are then read from the axes opposite the point thus located on the chart.

initial approach to the problem and have carried out a theoretical analysis of all straight-line collision courses with constant speeds, so that the angular position of each vehicle from the other remains constant (5). The results are shown in Figure 6 which gives the values of these angular positions for surface vehicles, for various speed relationships and angles of approach between the two headings (the horizontal visual angle required from each vehicle in order that its driver can see the other approaching the collision). The faster driver never needs to see more than 90 deg to right or left, although the slower one often does; for this reason, primary attention is focused on the slower vehicle. This approach could be extended to curved courses of various types.

A driver not only must see a vehicle approaching on a collision course but also must see it in time to stop completely before reaching the pathway intersection, since only thus can he surely avoid collision—regardless of what the other vehicle does. In contrast, should he rely on merely changing speed (or direction), the other driver may inadvertently match his actions and remain on a collision course. For this reason, Figure 7 was prepared to show the distances required for each vehicle to reach a full stop after the driver decides to do so, together with the range of variation resulting from differences in reaction time prior to actual application of the brakes. This chart is based upon the data shown in the following table:

Reaction Time for Braking Range = 0 20 to 1 00 seconds, maximum normal value allowable = 0 75 seconds
Reaction Distance = Speed x reaction time
Braking Distance is that required for car to stop after brakes are put on
Stopping Distance (total) = Reaction distance + braking distance

The resulting data are

Speed (V) mph	Reaction Range ft	Distance, Max. Norm ft	Braking Distance ft	Stopping Range ft	Distance, Max Norm ft
10	3 - 15	11	5½	8½- 20	16½
20	6 - 29	22	22	28 - 51½	44
30	9 - 44	33	50	59 - 94	83
40	12 - 59	44	89	101 - 148	133
50	15 - 73	55	139	154 - 212	194
60	18 - 88	66	200	218 - 288	266
70	21 - 103	77	272	293 - 375	349
80	23 - 117	88	356	379 - 473	444

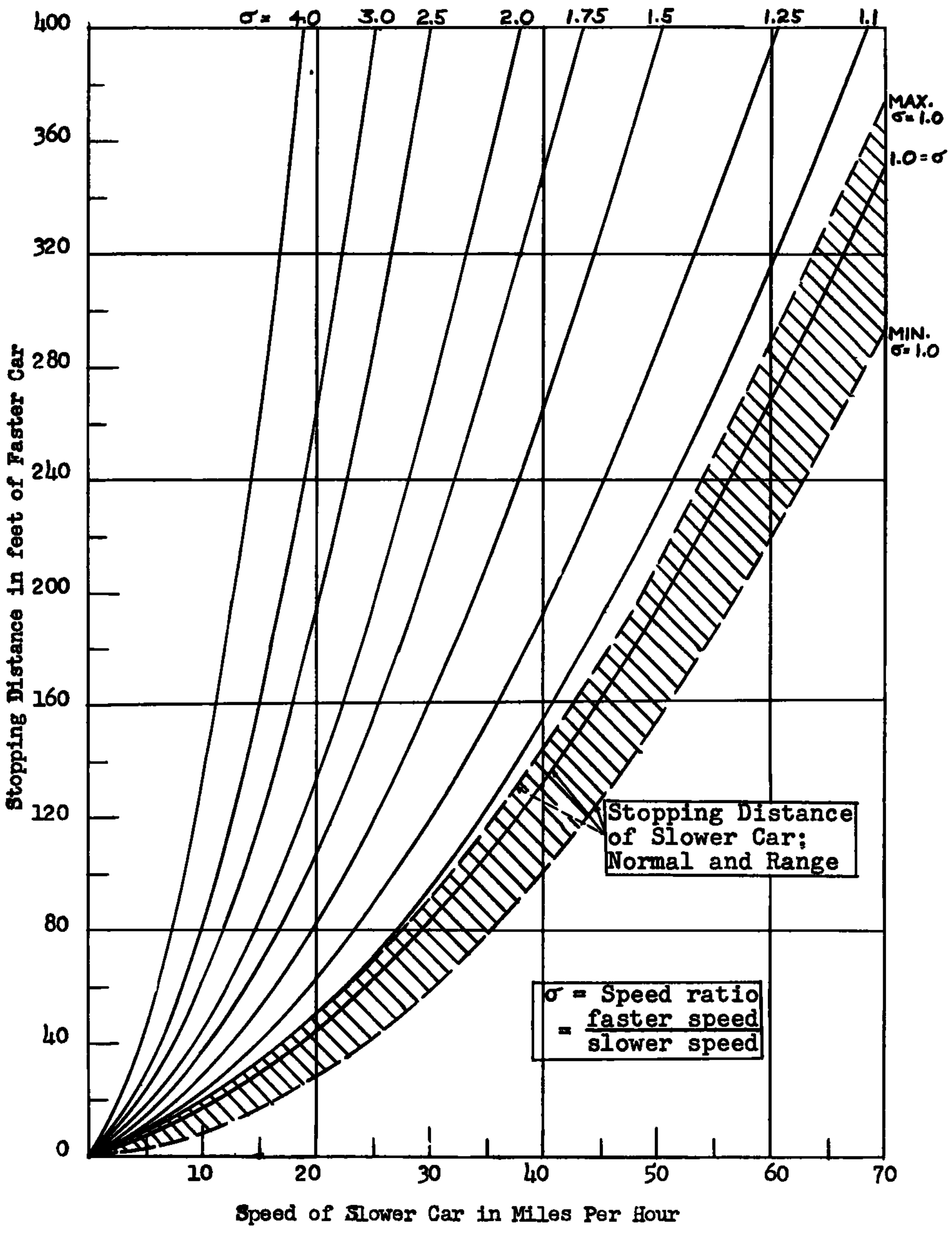

Figure 7. Stopping distance of automobiles (reaction distance plus braking distance). A dry road is assumed, with brakes and tires in good condition. The curves for speed ratio 1.0 (shaded area) give required stopping distance (at left) for a car in terms of its speed (bottom axis), including maximum and minimum values (dashed lines) for the reaction-time range from 0.20 to 1.00 seconds as well as for the greatest allowable normal time of 0.75 seconds. For the other curves, enter graph at the bottom with the slower speed and go up to the curve for the speed ratio given, across at left, read this normal stopping distance for the faster car (with the same range as the equal distance on the 1.0 curve).

The analyses can have immediate practical applications in addition to their utility for evaluating visibility provisions. The results are pertinent to the study of situations at intersections for the removal or correction of fixed visual obstructions and to the determination of local speed regulations and traffic signs. This aspect of the problem should be treated by both automobile design and highway engineers. The collision "predictor" charts may also be used in classroom instruction in driver training.

The Human Factor: Clear Seeing and Attention. "What are the necessary characteristics of a potentially hazardous object in order for it to constitute an adequate visual stimulus?" Consideration of some limiting factors in man's visual equipment is involved. The human eye is a most remarkable and sensitive instrument with the ability to distinguish separations of lines subtending a visual angle of 1 minute or less. It may function with some degree of effectiveness over a range of stimulus energy of about ten billion to one. It may also detect flicker in frequencies of 50 to 60 cycles per second if the light intensities are sufficiently high. There are, however, definite limitations to seeing. Fundamental variables which must be above certain limiting values if an object is to be recognized are as follows:

1. The visual size, or the visual angle subtended by the object or some critical detail of it. This is generally expressed in minutes of (visual) arc, because an object decreases in visual size with increasing distance. Under optimal conditions, a visual size subtending an angle of one minute or less can be distinguished.
2. The contrast between the object and its background (the ratio of the difference in the brightness of the object to the brightness of the background). This is expressed as percent brightness contrast.
3. The level to which the object is illuminated (its absolute, or photometric, brightness).
4. The time the retina is exposed to the image of the object.

Luckiesh and Moss (6) show the relationship of visual angle, contrast percent and background brightness for various combinations of these factors which result in "clear seeing" and "no seeing."

The contrast and object brightness are two factors which can be influenced for safety by selection of color, characteristics of the surfaces, or use of an additional energy source, such as lights. At some future time, there may be installed an automatic "forward" anti-collision light which will remain on at all times when the car is moving forward. A significant number of drivers now utilize this means of increasing visibility to oncoming cars by manual operation of headlights during daylight hours when passing on the highway at moderate or high speeds.

The driver can and must make a contribution to the visual aspects of safety. He should know generally the limitations imposed on normal human visual capabilities; in the event he suffers from a visual defect, he should be acutely aware of the effects of this additional restriction. This invites the attention of not only the design engineers, but also those who can apply measures to influence man—by traffic control, disciplinary measures, driver medical examination and driver education.

As for the other aspects of the visual problems in safety (those having to do with the vehicular operator looking elsewhere) and adequate visual images which fail to register, the responsibility is almost if not entirely that of the psychologist, the physiologist, the biophysicist and the biochemist. There is little the engineer can do except provide technical consultation to assist in the biological research and, perhaps, advise, on the basis of experience in traffic control problems, as to the value of disciplinary action in specific traffic situations.

What can the biologist do? Working with the engineer, he can provide detailed descriptions of man's visual capabilities and specify human requirements in the driving situation which should be met by the automotive and the highway designer. Working with those engaged in driver training, he can provide information on the inter-relation of the four important variables in vision as a basis for a continuous development and improvement in driving methods and practices. Working with the driver, the physician and the research biologist must determine physical (including mental) fitness and must instruct man in at least the elements of the physiology of vision. For example, a driver should know the time required for the eye to accommodate to see a near object after looking at a distant object, or the greater time to shift his focus from a near to a far distance; the limits of his ability to judge the relative position of two cars or other objects at a distance; and the influence of twilight, glare, fatigue and age on vision.

So much for what the biologist can do by working with others. The biologist's most important responsibility in vehicular safety, which is his alone, is that of studying the problem of attention. How can a driver be kept looking about and paying attention, so that an image of the potentially hazardous object will fall on the retina and will be perceived and appropriate action initiated?

There are at least five major factors which may be considered briefly in connection with attention (7). These, and many others, must be the subject of intensive research investigation if a sufficient knowledge of the mechanisms involved to prevent accidents due to lapses of attention is to be attained.

1. Free and Controlled Attention. In free attention there is the question of which of a number of objects will "catch the eye" and elicit a response. In controlled attention there is a specific response to a set of stimuli alike in nature. While potentially hazardous objects may be sufficiently "alike in nature" to insure that controlled attention benefits safety, can the role of free attention in avoiding accidents be evaluated?

2. Shifting and Fluctuating Attention. While an object or group of objects may receive an individual's attention for a period, his attention is likely to fluctuate in degree or to shift from one object to another. To what degree is safety dependent upon time factors for "seeing" and for shifting the gaze, and to what degree on the probability of bringing the hazardous object into view through shifting and fluctuation?

3. Distraction. An involuntary interruption of controlled attention or a shifting of it is implied. A priori, it might be considered as prejudicing safety, but this is not necessarily so; too great a pre-occupation with the highway without breaks in the monotony of the environment has been considered as conducive to accidents.

4. Divided Attention. This implies a voluntary attempt to do two things at once; it would appear to be one variety of controlled attention, where conscious direction is applied alternately to the several tasks. Quite possibly the psychologists would not agree with this concept, but it would seem that this divided attention may involve motor acts, such as movement of the limbs which are initiated voluntarily but controlled to some extent by the peripheral nerve-muscle mechanisms, or sensory perception and interpretation, such as alternately judging the cars forward and in the rear view mirror in attempting to avoid a "chain reaction" smashup.

5. Span of Attention. This involves the ability to remember or take account of all objects presented at a glance and make an effective response. This is a spatial rather than a temporal phenomenon.

Accidents are determined by the interaction of the man, the machine, and the environment. Success in accident prevention depends on the engineers and the biological scientists working together to discharge the responsibilities of their respective fields.

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