Eye Scanning Rules for Drivers: How Do They Compare with Actual Observed Eye Scanning Behavior?

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The U.S. driver education and training literature was reviewed to identify rules and recommendations with regard to driver eye scanning behavior and strategies, where drivers ought to fixate their eyes when driving, specifically when driving through a curve. In addition, driver eye scanning behavior was recorded and analyzed for nine drivers driving through right curves with radii of 73.15 m (240 ft) (unlighted Interstate entrance and exit ramps, 270-degree turns) at night with low beams. An instrumented car with a corneal reflection technique television eye scanning system was used. Each driver made a number of runs through the curves at an average speed of 41.8 km/hr (26 mph), and the driver eye fixation sequences were analyzed for three to eight runs per driver, yielding 51 analyzed runs. Of most importance for the eye fixation sequence analysis were the eye fixation positions on the curves ahead of the car. Besides the eye fixation sequences analyzed in this study, previously analyzed spatial and temporal eye scanning data from the same subjects were used to compare the eye scanning rules with the actual observed eye scanning behavior. Matrices and histograms were established to indicate the conditional frequencies for forward- and backward-progressing eye fixation sequences, given a previous type of eye fixation sequence. The results showed that the expected number of consecutive forward eye fixations (including forward-ending eye fixations) is 1.89, while that of backward eye fixations (including backward-ending eye fixations) is 1.26. The results of the exploratory study indicate that drivers use both forward and backward eye fixation sequences and that there appears to exist no predictable, simple, systematic eye fixation sequence patterns within a driver (within a run or between runs) or between drivers when driving through a curve. Since no such sequence was discovered, it may be tentatively concluded that various eye fixation sequences and strategies provide adequate visual input for proper curve driving. Therefore, there is probably no need for very specific recommendations for objects- or sequence-oriented eye fixation for curve driving, or even for driving on a straight section of a highway.

The U.S. driver education and training literature contains a number of recommendations with regard to driver eye scanning behavior and strategies and specifically with regard to where drivers should fixate their eyes when driving. One of the earliest sets of perceptive driver training rules was provided by Smith et al., who recommended to "aim high at steering, have a wide picture, keep your eyes moving, keep yourself an out and make sure they see you" (*1*). The American Automobile Association proposed and discussed the "brief glance" technique for drivers to avoid a dangerous condition known as "captured attention" (*2*). Aaron et al. proposed and explained driver seeing habits (*3*) that were the same as the rules published previously by Smith et al (*1*). They recommended that drivers should develop a habit of scanning the entire traffic scene (about 300 degrees) and that their eyes should move from left to right in a continuous effort to assess the potential hazards.

Bishop et al. explained the techniques of "systematic seeing" and indicated that systematic seeing involves three important steps: "center on the travel path, scan and search the traffic scene, and check mirrors and instruments" (which, according to the authors, can be thought of as an extension of scanning and searching) (*4*). They explained that for centering on the travel path, one's reference point on a straight road should be in the middle of the path, and on curved roads and turns, it should be through the curve or turn to the point at which the vehicle will be when the turn is complete; the same rules should be followed when driving at night (*4*). Some of the other recommendations given by Bishop et al. are to "scan and search the scene by looking far ahead and near and on both sides of your vehicle, look away from your visual reference point." They also proposed several ways to make the best use of vision for centering and scanning: "Use central vision only on pertinent events, look at each event in the traffic scene briefly, limit the number of times you look at each event in a traffic situation, avoid looking at former events and keep all previous information in mind." Night vision and the factors affecting it were further discussed, and it was recommended that drivers should scan the darkened areas when driving at night. To lessen the likelihood of being blinded temporarily by the glare of oncoming headlights, they recommended that one "look at the edge of the pavement ahead of your car until the oncoming vehicle has passed."

In another publication Davis et al. discussed two basic seeing rules that should be made a habit: "Center on a target 12 seconds ahead, and keep your eyes scanning and searching" (*5*). The authors explained that "the eyes should move from the target 12 seconds ahead to the left and to the right, they should then move to the rear view mirrors, then to the instrumented panel, and finally they should move back to the target ahead" and recommended to reduce the speed and stay in the lane. Johnson et al. specifically discussed driving on two-lane highways and curves (*6*). The authors proposed taking these steps when approaching a curve: "Take quick glances across the curve to identify oncoming traffic, maintain proper lane position by glancing ahead at your intended path of travel, evaluate the sharpness of the curve, slow down to a suitable

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speed before entering the curve, accelerate gently after entering the curve, and once around the curve, resume a safe speed." They also explained an "orderly visual search pattern," which is a process of searching critical areas in a regular sequence. Moreover, they recommended that drivers should develop the technique of "selective seeing," a process of selecting and identifying only those events and clues that pertain to a driving task.

On looking at the rules and recommendations found in the U.S. driver education and training literature, it appears that most of these recommendations do not make any distinction between driving through a curve or a straight section of a highway, between daytime and nighttime driving, and between driving on the road alone or with other traffic present. Most of these recommendations, however, make general statements about where to look in the driving scene and, very important, suggest moving the eyes frequently to scan and search the traffic scene. Some of these recommendations stress the importance of short eye fixations, brief or quick glances, and limitations of the number of fixations at a specific feature in the driving scene.

Only a few previous studies reported in the literature have investigated driver eye scanning behavior on straight and curve sections of a highway. One such study by Shinar et al. concluded that "drivers rely on different visual cues, for directional and lateral control, on curves than they do on straight roads" (*7*). The authors stated that drivers, instead of paying close attention to the focus of expansion as is done on a straight road, should concentrate intermittently on the position of the roadway ahead and the road edge (or lane markings) closer to the car when on a curved road. Moreover, they concluded that "drivers start scanning curves for directional cues as they approach them and resort to direct foveal fixations of the roadway close to the car for lateral placement cues." Most of the driver eye scanning behavior studies usually provide average and standard deviations for the spatial and temporal eye scanning measures, but very few provide detailed density plots of spatial eye fixation or frequency distributions of eye fixation duration.

No studies have been found that would provide any information about the eye fixation sequences that drivers make when driving either on a straight road or through a curve. In addition, there may be problems with regard to the accuracy of the spatial and temporal eye scanning summary measures provided in some of the previous curve eye scanning studies. This is not surprising if one considers the difficulties involved in the spatial and temporal analysis of the eye fixations when driving through a curve. Since there is no fixed visual reference point in curve driving (such as the focus of expansion in straight driving), one must work with an imaginary focus of expansion as the environmental reference point. The imaginary focus of expansion in curve driving for a given eye position in the curve is defined as a point on the horizon line where a pair of imaginary straight, extended, left, and right edge lines of the driving lane meet, assuming that a driver's sagittal plane coincides with the center of the visual field and is tangential to the curve radius.

It is extremely difficult to determine accurately the correct horizontal location of the imaginary focus of expansion along the horizon on the television screen on the basis of a limited field of view of the curve perspective (given by the left and right edge lines of a driver's driving lane). Depending on the accuracy with which one determines the imaginary focus of expansion for each eye position in relationship to the perspective view of the left and right edge lines of the driving lane, the calculated mean of the horizontal eye fixation distribution can be more or less wrong. Furthermore, depending on the assumed accuracy of the perspective view of the curve as it is seen by the drivers, the results and statements with regard to the horizontal overall average of the eye fixations may not be accurate. Figure 1 shows the correct perspective views for curves with two different radii of curvature. It should be noted that because a driver's eyes are located at a certain distance above the pavement of the flat road, the edge lines of the driving lane in the curve do not touch the horizon line as indicated incorrectly in figures published by some authors.

If one would know, with a reasonable degree of accuracy, the spatial and temporal eye scanning behavior characteristics and the eye fixation sequences of fairly experienced drivers (assuming that experienced drivers have developed adequate, sufficient, and possibly near-optimal eye scanning sequence patterns), one should be able to evaluate the validity of the driver eye scanning behavior rules and recommendations found in the U.S. driver education and training literature and, if warranted, propose new rules. It was the purpose of this study to determine in an objective and quantitative manner the type of eye fixation sequence (EFS) patterns that drivers exhibit in terms of fixating successively farther away, or closer toward

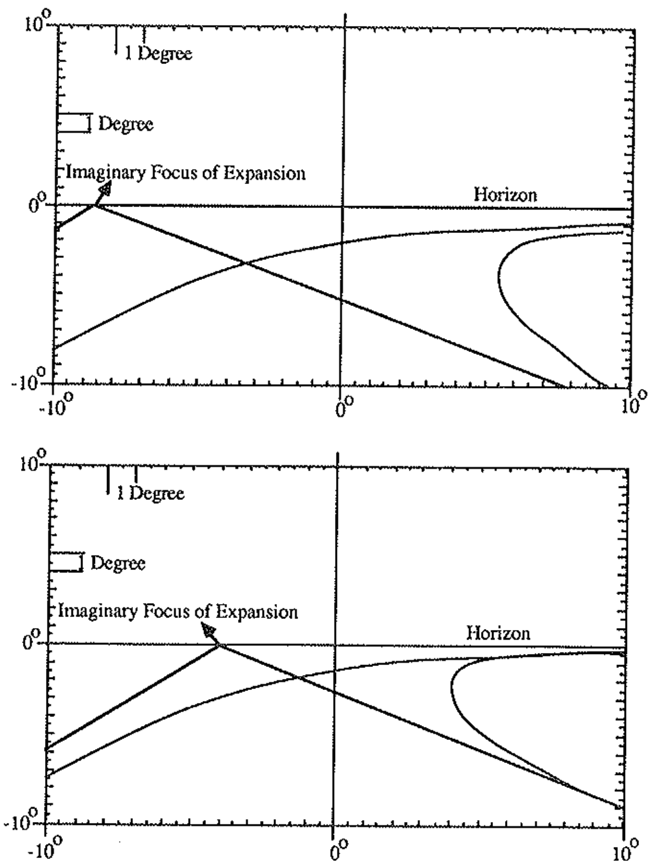

FIGURE 1 Perspective views of typical right curves: *top*, radius = 200 ft; *bottom*, radius = 1,000 ft.

the car when driving through a curve, and compare them with the rules and recommendations given in the driver education and training literature.

DATA ANALYSIS

The curve eye scanning behavior data used in this analysis were collected as part of a study conducted by Zwahlen (*8*). Driver eye scanning and performance data were collected at night for Interstate highway entrance and exit ramps (270-degree right curves, both dry and wet pavement) with radii of 73.2 m (240 ft) and widths of 4.9 m (16 ft). An instrumented car (VW 412, automatic transmission, four doors, 4000 low beams) with an in-car television eye scanning recording system, a lane trucker, and other electronic sensors and equipment (corneal reflection technique television eye scanning system) was used. Nine young subjects with an average age of 22.3 years (standard deviation = 2.3) with an average driving experience of 6 years (6,000 mi/year) were paid to participate in the experiment. All the drivers were fairly familiar with the experimental car and the television system used for the eye scanning behavior measurements since they usually drove from Athens, Ohio, to the experimental site on Route I-70; usually before running the actual experiment, all the drivers were made to drive in and around Athens by wearing the helmet with the television system components.

Each driver serving as his or her own control made a number of runs through the curves at an average speed of 41.8 km/hr (26 mph). The prevailing traffic conditions on I-70 and the entrance and exit ramps caused some of the runs to be performed at very low speeds (because of slow-moving vehicles ahead). For this reason, eye fixation sequences for an unequal number of runs per subject (three to eight) were analyzed, yielding 51 analyzed runs. Lateral positions were also measured for all the experimental runs, but since the scope of this paper is limited primarily to the analysis of the driver eye scanning behavior, no lateral position data are presented.

The exact sequence and spatial coordinates of all eye fixations on the road ahead, or the adjacent flat road environment up to a radius of 88.4 m (290 ft), were determined. Only 0.7 percent of the eye fixations during curve driving were on a vehicle ahead. All forward and backward eye fixation sequences were determined for each run and also recorded as a function of each previous eye fixation sequence. Conditional matrices and histograms indicating the frequency of forward or backward EFSs (including forward and backward ending EFSs) consisting of a number of eye fixations were prepared to quantify the eye fixation sequences. The sequences were examined for each run, then for all the runs for a given driver, and finally for all runs for the entire group of drivers. These data were previously analyzed in terms of eye fixation distributions (spatial analysis) and in terms of eye fixation durations (temporal analysis) for night driving on both tangential and right curve (entrance/exit ramps) Interstate sections (*9*). The two-dimensional eye fixation distributions indicated a single mode located at $x = 0.5$ degrees and $y = -0.5$ degrees for tangent sections (focus of expansion at 0, 0; $N = 11{,}780$) and at $x = 14.5$ degrees and $y = -1.7$ degrees for the right curve (imaginary focus of expansion 0,0; $N = 8{,}884$). The average fixation durations were 0.43 sec (2.3 fixations per sec) for the tangent section and 0.29 sec (3.4 fixations per sec) for the right curve (standard deviations = 0.35 and 0.16 sec, respectively). These results indicate that more eye fixations are needed in curve driving, which is a visually more demanding task than straight road driving. Figure 2 shows the cumulative relative frequencies as a function of the fixation durations (in seconds), and it can be seen that the fixation durations for curves are considerably shorter than those for straight sections.

DEFINITIONS OF EYE FIXATION POINT, EYE FIXATION SEQUENCE, AND EYE FIXATION

An eye fixation point is defined as the point on a feature of an object or of the curve environment (except the sky) on which a driver has fixated his or her eyes for a short duration of time (about 0.1 to 0.5 sec) in such a way that visual information can be obtained with the greatest resolving power for visual detail (fovea). The coordinates of the eye fixation points for the features of the objects or of the curve environment can be determined mathematically, provided one knows the coordinates of the surfaces (usually assumed to be a horizontal and level plane), the horizontal and vertical angles of the eye fixation direction, and the coordinates of a driver's eye position. Figures 3, 4, and 5 illustrate the graphical definitions

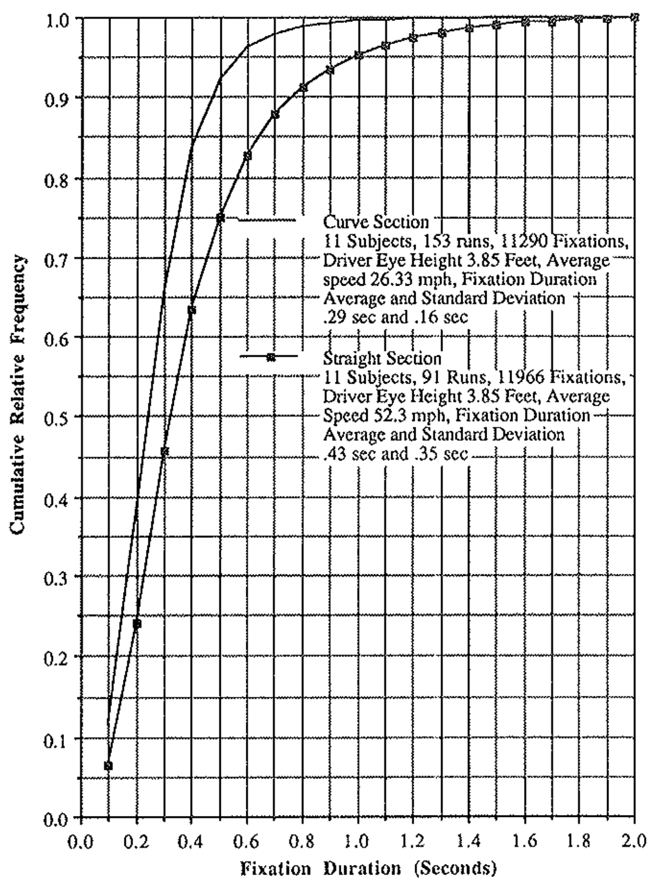

FIGURE 2 Cumulative relative frequencies as function of fixation durations.

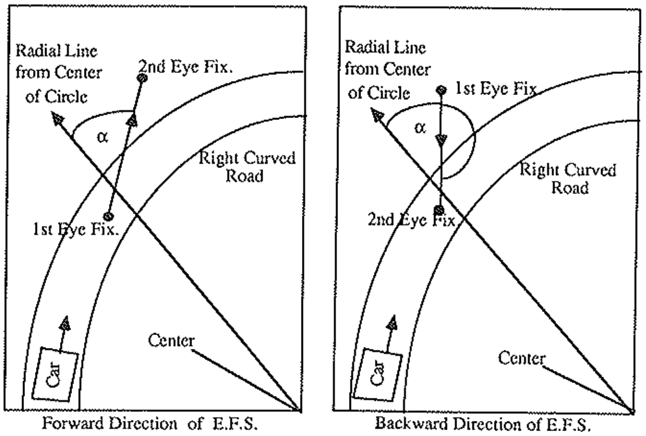

FIGURE 3 Graphical definition for direction of single EFS: *left*, 0 degrees ≤ α < 180 degrees; *right*, 180 degrees ≤ α < 360 degrees.

for the direction of single EFS, for forward and backward EFSs and for forward ending and backward ending EFSs, respectively. A forward or a backward ending EFS was obtained whenever there was no eye fixation point visible on the TV screen (eye blink or out of view) after the last eye fixation point, or when the next eye fixation point was either above the horizon or outside the 88.4-m (290-ft) curve radius region. Figure 6 illustrates and defines some typical eye fixation sequences observed when a driver drives through a curve.

In this study, the definition of an eye fixation when a driver's eye spot moved within the same object was made dependent on two factors: (a) the length of time of the shorter of two adjacent "would-be" fixations (separated by a saccade) and (b) the magnitude of the direct distance (saccade) between the two would-be fixations in the visual plane. Keeping in mind a reasonable trade-off between accuracy and analysis time, it was decided that in general, the longer the duration of the shorter of the two would-be fixations, the smaller the magnitude had to be of the direct distance between them in the visual plane in order to define both as separate eye fixations. On the other hand, the shorter the duration of the shorter of the two fixations, the longer the magnitude of the direct distance between them in the visual plane in order to define them as separate. If these criteria were not met in a specific case, the shorter of the two fixations was incorporated into the larger fixation, making up one eye fixation. If a driver's eye spot moved enough (a few degrees) to indicate that the foveal attention shifted to a different object, it was defined automatically as a new fixation regardless of the duration and magnitude of the saccade distance. However, if one would define an eye fixation such that many fixations are incorporated into one large fixation, the fixation durations increase significantly, thereby resulting in an error in the summary measures of the temporal distributions.

Two computer programs were written in FORTRAN. The first one plots a top view for each 90-degree section (total three sections, 270 degrees) of the right-hand curve, a point at which each eye fixation intersects with the horizontal plane, a point for each head position of the driver, and a line between each set of two corresponding points indicating a driver's eye fixation direction from the head to the fixation point (intersection with horizontal plane). These fixation direction lines were plotted only if the eye fixation intersection points with the horizontal plane were within a selected maximum radius

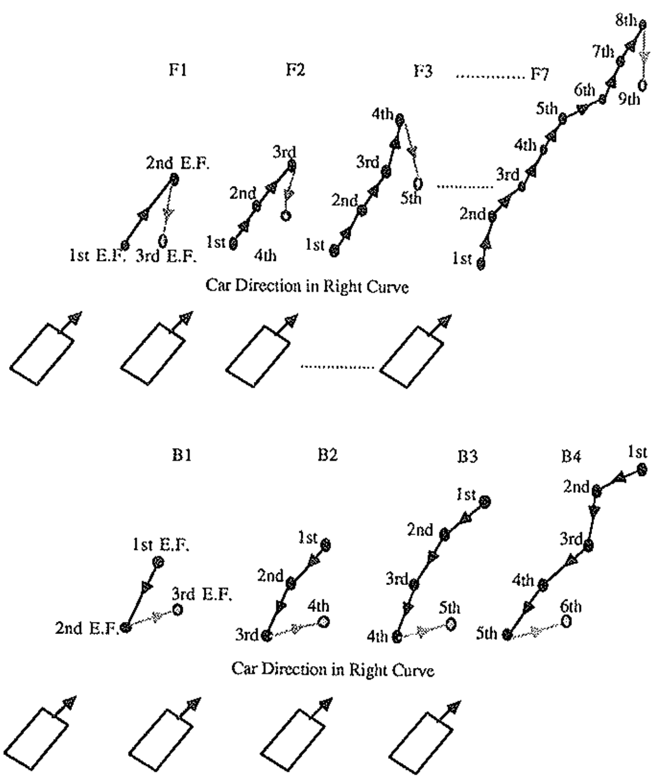

FIGURE 4 Graphical definitions for forward sequences (*top*) and backward sequences (*bottom*.)

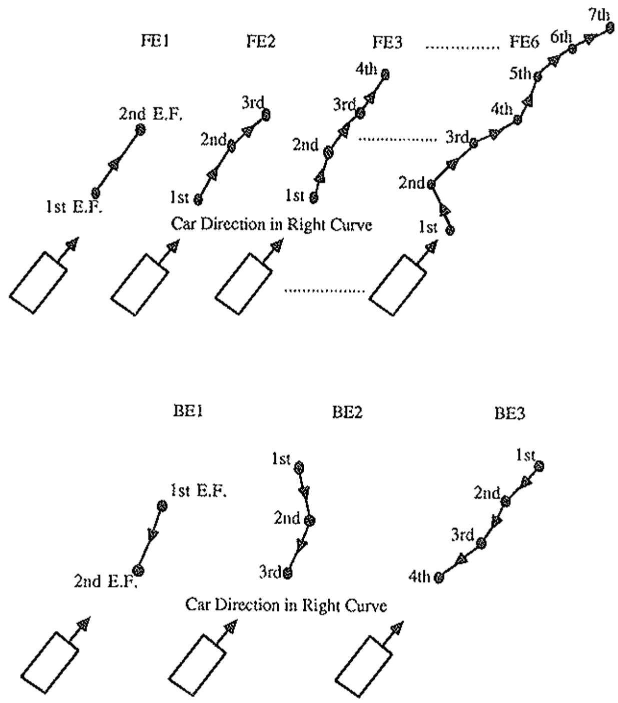

FIGURE 5 Graphical definitions for forward ending sequences (*top*) and backward ending sequences (*bottom*.)

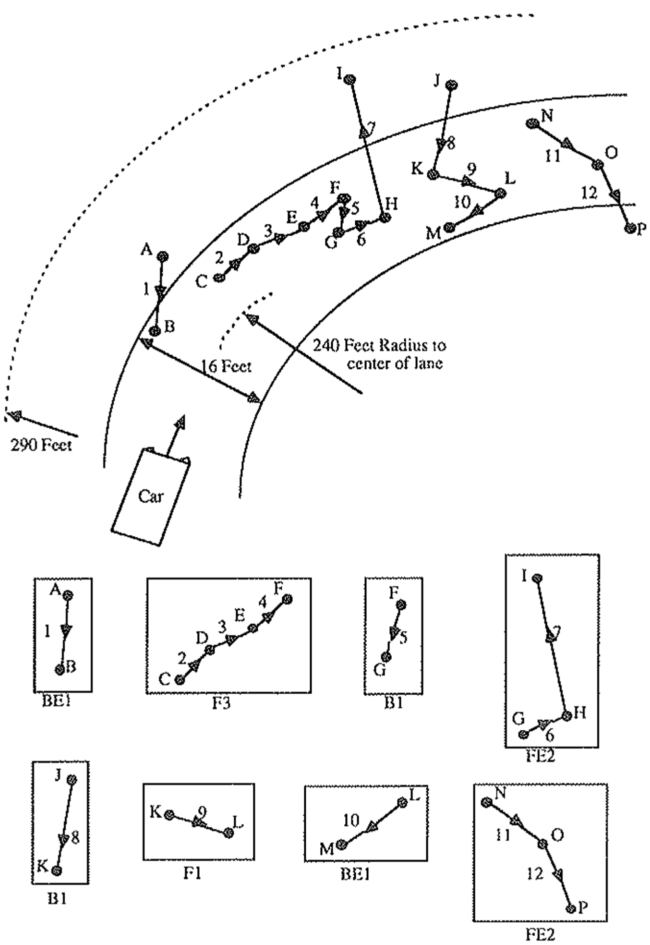

FIGURE 6 Example of eye fixation sequence analysis.

of 88.4 m (290 ft). The second program plots the top view for each 90-degree section, each eye fixation point below the horizon and within the 88.4-m (290-ft) radius only, and draws straight lines connecting the consecutive eye fixation points. These two top-view plots for eye fixation direction and consecutive eye fixation obtained for each run along with the definitions provided in this paper represented the basis upon which the conditional eye fixation sequences were determined.

RESULTS

The results indicate that there appears to be no discernible simple, systematic eye fixation sequence pattern within and between the runs of a single driver, as well as between the runs of different drivers. Therefore, the data obtained from all the runs for all the subjects were combined for further analysis. The results indicate that the drivers made a maximum of seven consecutive forward eye fixations and a maximum of four consecutive backward eye fixations. Table 1 presents the summary matrix of forward, backward, forward ending, and backward ending eye fixation sequences for all 51 runs as a function of the eye fixation sequence that the subjects exhibited before. It can be seen from Table 1 that 643 eye fixation sequences—which resulted in 1,013 (forward or forward ending = 613, backward and backward ending = 400) eye fixation directions (based on 2,175 eye fixation points)—were analyzed.

On the basis of the EFS results for fixations ahead of the car below the horizon and within a curve radius of 88.4 m (290 ft), the expected number of consecutive forward fixations (including forward ending fixations) is 1.89, and the expected number of consecutive backward fixations (including backward ending fixations) is 1.26. The ratio between forward and forward ending sequences is 3:1 and that of backward and backward ending sequences is 6:1, indicating that the forward sequences occur about three times as often as the forward ending sequences and that the backward sequences occur six times as often as the backward ending sequences. Figures 7 and 8 further illustrate the conditional probabilities as given in Table 1. It can be seen in Figure 7 that the relative frequencies of a forward or forward ending EFS appear to be independent of the previous number of eye fixation points of the backward or backward ending EFS. There is about 50 percent probability that an F1 sequence will follow a previous backward or backward ending EFS. Similarly, there are about 25, 15, 5, 2, and 2 percent probabilities that an F2, F3, F4, F5, and F6 sequence, respectively, will follow a previous back-

TABLE 1 Summary Matrix of Eye Fixation Sequences

		Forward Seq.							Backward Seq.				Forw. End. Seq.						Backw. End. Seq.			
Previous	Present	F1	F2	F3	F4	F5	F6	F7	B1	B2	B3	B4	FE1	FE2	FE3	FE4	FE5	FE6	BE1	BE2	BE3	Total
Forward Seq.	F1								107	28	3								18	5	1	162
	F2								53	14	3								10	1		81
	F3								30	4	3	1							5	1	1	45
	F4								13	2									2			17
	F5								4										1			5
	F6								5		1											6
	F7								2													2
Backw Seq.	B1	103	46	30	11	5	5						32	13	10		1	1				257
	B2	18	9	6	1			2					8	6		2						52
	B3	2	4	2	1								3	2								14
	B4	1												1								2
Total		124	59	38	13	5	5	2	214	48	10	1	43	22	10	2	1	1	36	7	2	643

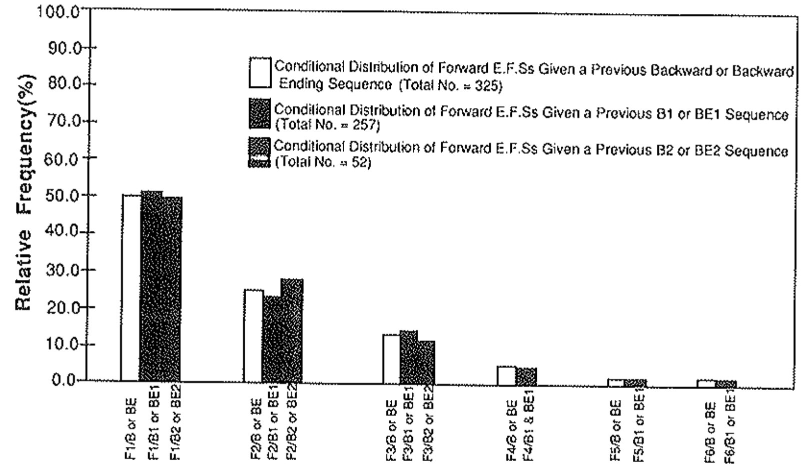

FIGURE 7 Relative frequencies of forward EFSs given a previous backward EFS or backward ending EFS (shown only if their sum is greater than 5).

ward or backward ending EFS. Similarly, in Figure 8 it can be seen that the relative frequencies of backward or backward ending EFSs also appear to be independent of the previous number of eye fixation points of the forward or forward ending EFS. There is about 80 percent probability that a B1 sequence and about 18 percent probability that a B2 sequence will follow a previous forward or forward ending EFS.

DISCUSSION OF RESULTS AND CONCLUSIONS

The results of this study indicate that drivers use both forward and backward eye fixation sequences. There appears to be no predictable, simple, systematic EFS patterns within a driver or between drivers, such as a repeating sequence of one or two fixations far ahead (possibly for perception of curvature, directional control, and obstacle detection) followed by one or two fixations closer toward the car (possibly for lateral control) when driving through a curve. Therefore, fairly experienced drivers appear to have much freedom in choosing what they want to look at in the driving scene and what combinations of EFSs they want to use to get the necessary visual driving information, without impairing their successful driving performance through a curve, or even on a straight section of a highway. Because no such pattern was discovered and because each of these fairly experienced drivers exhibited different combinations of EFSs on each run, it may be tentatively concluded that many different EFSs and strategies must provide adequate visual input for proper curve driving and that there is probably no need for very specific objects or sequence-oriented eye fixation recommendations for driving on a curve or a straight section of a highway.

Moreover, looking at the results of the spatial and temporal eye fixation analysis (*9*), it would appear that drivers make

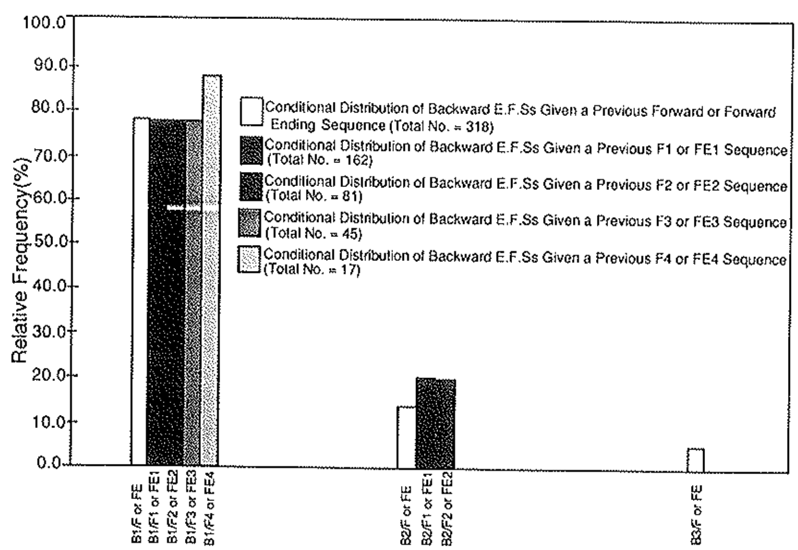

FIGURE 8 Relative frequencies of backward EFSs given a previous forward EFS or forward ending EFS (shown only if their sum is greater than 5).

considerably more eye fixations on curves than they do on straight roads. One may conclude that curve driving appears to be much more demanding in terms of acquiring and processing visual information than does driving on a straight section of highway; very little spare visual capacity is left for the driver. Traffic engineers might also note this fact and limit the placement of traffic signs in curves as much as possible, especially traffic signs placed along the inside of the curve.

The observed forward and backward eye fixation sequences, the cumulative eye fixation duration frequencies, and the spatial eye scanning data published by Zwahlen (*9*) appear to support, to some degree, some of the recommendations and rules given in the U.S. driver education and training literature. However, some of these rules cannot be supported by the results and might be inherently dangerous if one follows them consistently and accurately, especially when driving through a curve at night.

For example, "aim high at steering" (*1*) is a general recommendation since it does not make any distinction between driving on a straight road and on a curve, or during the day and during the night. Looking at the EFS results and the spatial eye fixation distributions for straight road and curve driving at night published by Zwahlen (*9*) and assuming that the eye scanning behavior of the test drivers who participated in the study is fairly well learned and close to an optimal information acquisition process, one can state that drivers cannot always "aim high at steering" since they make backward EFSs toward the front of the car, especially during curve driving at night. The spatial eye fixation distribution results also indicate that drivers do fixate once in a while relatively close in front of the car during straight road and curve driving at night. Overall, a recommendation of "aim high at steering" that is qualified by adding "wherever and whenever possible and feasible" appears to have some validity and merit when looking at the eye scanning behavior results and would give a driver a longer preview time, which is desirable from the point of view of control systems and tracking. According to the spatial eye fixation results and the EFS analysis, in curve driving at night, the test drivers appeared to not maximize their preview time or forward fixation distance across the curve (beyond the major illumination of the lowbeams) and instead followed a strategy of placing most of their eye fixations anywhere from fairly far ahead in the curve (but still mostly within the low-beam illumination pattern) to closer in front of the car on the curve surface or on the immediate curve environment ahead.

The recommendation to "have a wide picture" (*1*), although somewhat nonspecific, is fairly well supported by the spatial eye fixation data shown elsewhere (*9*), especially for curve driving at night, which shows a larger horizontal dispersion of eye fixations (horizontal eye fixation average = 12.79 degrees to the right of the imaginary focus of expansion with a standard deviation of 3.79 degrees) than does straight road driving at night (horizontal eye fixation average = 0.84 degrees to the right of the focus of expansion with a standard deviation of 1.92 degrees) if one assumes that the horizontal width of the "wide picture" is about 10 degrees. It is assumed and fairly well established that drivers acquire detailed visual information only when fixating their eyes on an object or a road feature and not when moving their eyes from one fixation point to another. Therefore, to "have a wide picture" a driver would probably have eye fixations over a certain area of the visual field in order to get visual details about the most important objects or road features in the driving scene. It should be noted that the most important road features and objects are below the horizon within a rectangle of about 30 degrees horizontal ahead and from the horizon to 6 degrees below for both straight roads and curves, which is not a large area considering the extent of a driver's whole visual field ahead.

"Keep your eyes moving," according to the authors, involves glancing near and far, to the right and left, in the mirrors and at the instrument panel, and looking ahead after each glance. This recommendation appears to be partially validated by the EFS analysis, the cumulative eye fixation duration frequencies, and the spatial results shown elsewhere (*9*). If one wants to move his or her eyes frequently, the eye fixation durations must be rather short, which is supported by the temporal eye scanning behavior results (saccade durations of usually much less than 0.1 sec) especially for curve driving situations, where the average fixation duration is only 0.29 sec. Furthermore, the spatial results indicate that drivers do move their eyes over a certain region of the driving scene for straight road driving (most of the time within ± 3 degrees horizontal and ± 3 degrees vertical around the focus of expansion) and a moderately larger area (most of time within a rectangle from 6 to 18 degrees horizontal and -4 to 0 degrees vertical from the imaginary focus of expansion, centered on the outer curve lane-marking stripe) for driving through a right curve with a 73.2-m (240-ft) radius at night. Overall, the results indicate that drivers do look ahead after making fixations close to the front of the car but not in a systematic and consistent pattern, as is suggested by Smith et al. (*1*). "Keep yourself an out" and "make sure you are seen" are general recommendations (*1*) and are suited more for strategic driving rules, which do not recommend specific eye fixation patterns or sequences to be followed by drivers.

The brief-glance technique is the one that has been claimed to avoid the dangerous condition known as captured attention (*2*). Again, this technique does not distinguish between the various driving situations (curves, straight roads, day, night, traffic, etc.). However, the recommendation is similar to "keep your eyes moving" (*1*) and thus appears to be partially validated as a rule by the EFS analysis results, the cumulative eye fixation distribution frequencies, and the spatial results shown elsewhere (*9*). The rule does stress fixation durations, which should be brief instead of long, and the cumulative fixation duration frequencies for curve driving indicate that there are practically no glances with durations of more than 1.1 sec.

Aaron et al.'s statement that drivers should develop a habit of scanning the entire traffic scene and that their eyes should move in a continuous effort to assess the potential hazards is again similar to "keep your eyes moving" (*3*), but according to the spatial eye fixation results given by Zwahlen (*9*) the horizontal extent of the recommended scanning activity (about 300 degrees) appears much too large for both straight road and curve driving at night. And no reference is made with regard to any vertical scanning activity (ahead of the car). Again, a driver acquires detailed visual information during a continuous string of discrete eye fixations rather than during a continuous movement of the eyes. The eyes move very quickly between two successive fixation points with no significant detailed visual information intake during these times.

It should also be remembered that a driver obtains detailed visual information around the center of the fixation point (circular area, visual cone). The size of this visual circular area is dependent on the fineness of the visual detail that needs to be obtained and the amount of detailed information in that circle. For very fine visual information and a large density of such information around the fixation point, the diameter of such a visual cone can be from less than 1 degree to a few degrees. Information about larger objects (if they are sufficiently conspicuous) will be picked up by the visual system outside this visual cone and, if it is of interest to a driver, the information will most likely trigger a movement of the eyes to this object (saccade) with a subsequent eye fixation or several subsequent eye fixations to acquire, process, and verify the visual information at a detailed level within a driver's expectation and memory framework.

The recommendation to "center on the travel path" (*4*) is fairly well supported by the spatial results published by Zwahlen (*9*) that indicate a single mode (largest number of fixations in a 1- × 1-degree cell) located at $x = 0.5$ degrees horizontal and $y = -0.5$ degrees vertical for tangent sections (from focus of expansion, mostly on the road surface ahead) and at $x = 14.5$ degrees horizontal and $y = -1.7$ degrees vertical for a right curve with a 73.2-m (240-ft) radius (from imaginary focus of expansion, mostly on the illuminated curve surface ahead). However, these modes contain only about 13.5 and 3.9 percent of the total number of fixations for straight road and curve driving, respectively, which indicates that even though the drivers have a relatively large number of fixations at one point, a larger percentage of the fixations are spread around the mode cell and many of them on the travel path. "Scan and search the traffic scene" (*4*) is again similar to "keep your eyes moving" and thus is partially validated by the results of the EFS analysis and the results of Zwahlen (*9*). "Check mirrors and instruments" (*4*) is a useful recommendation especially before slowing down, stopping, or changing direction. However, from the results of Zwahlen (*9*), mirrors and instruments were looked at very infrequently during straight road driving and practically never while driving through a curve at night since very few slowing, stopping, or direction-changing maneuvers were executed.

"Look at each event in the traffic scene briefly" (*4*) is also similar to "keep your eyes moving" and can be partially validated by the results of this study, the cumulative fixation duration frequencies, and the results published elsewhere (*9*). "Scan darkened areas when driving at night" (*4*) is very vague in terms of specific scan locations. This recommendation cannot be supported by the spatial results of Zwahlen (*9*), which indicate that drivers have a large portion of their eye fixations within or close to the illuminated pavement surface of the curve at night or on the road pavement surface ahead. "Look at the edge of the pavement ahead of your car until the oncoming vehicle has passed" is also a general recommendation that helps drivers lessen the likelihood of being temporarily blinded by the glare of an oncoming car's headlights. Whereas this rule appears reasonable and most likely useful, there was no opposing traffic present in the immediate next lane on the straight road sections (four-lane highway) or in the curve (one-directional exit ramp) to investigate its validity.

"Center on a target 12 seconds ahead" (*5*) is one of the few recommendations in which the authors make a clear distinction between driving on a straight section and on a curve, although nothing was mentioned about night driving. The results of the EFS analysis and the spatial results given by Zwahlen (*9*) indicate clearly that a driver cannot consistently center on a target 12 sec ahead. Again, the same comments as discussed before with regard to the recommendation "aim high at steering" would apply here. "Keep your eyes scanning and searching" (*5*) is similar to "keep your eyes moving," and the same comments apply. "Take quick glances across the curve to identify oncoming traffic" is somewhat supported by the spatial eye fixation results (*9*), especially for curve driving at night, which indicate that drivers once in a while make eye fixations across the curve. Again, it should be noted that the curve in the experiment was one-directional and precluded opposing traffic, which could represent a potential hazard.

"Orderly visual search pattern" (*5*) is a process in which drivers are recommended to search critical areas in a regular sequence. An example of this process is "glance ahead, check rear view mirror, glance ahead again, search the sides of the roadway intersections, glance ahead again, check speedometer and gauges, and glance ahead again." The results of the EFS analysis do not indicate any systematic eye fixation patterns when driving through a curve that would indicate that drivers acquire visual information through such an orderly sequential search pattern.

Selective seeing is the process of selecting and identifying only those events and clues that pertain to a driving task. Although one would hope that drivers follow a selective seeing procedure, there was no objective way to investigate whether the drivers who participated in the study used such a selective seeing procedure. Moreover, it should be reiterated that the results of the EFS analysis do not show any consistent pattern of eye fixation sequences from run to run within a driver or between drivers, which could suggest a consistent selective seeing process. One might question whether the spatial and temporal eye scanning behavior results between daytime and nighttime (under low-beam illumination) are much different from each other. A comparison with daytime eye scanning results for straight road driving given by Zwahlen indicates small differences between the eye scanning behavior of drivers during daytime and nighttime straight road driving, with the only exception that the daytime horizontal eye fixation dispersions are somewhat larger than the nighttime horizontal eye fixation dispersions (daytime horizontal standard deviation = 2.45 degrees, nighttime standard deviation = 1.92 degrees (*10*). Furthermore, Zwahlen provides temporal eye scanning behavior results (averages and standard deviations of fixation durations when looking at curve warning signs, and Stop Ahead and Stop signs) for day and night driving that indicate that there is no consistent trend in terms of average fixation durations between daytime and nighttime driving (*11,12*).

Overall, a few general recommendations or rules with regard to eye scanning behavior when driving through curves or when driving in general—such as "aim high at steering wherever and whenever possible or feasible"—might be helpful to a novice driver. However, it would be highly desirable that the need for such rules as well as the conditions for which they apply would be carefully researched and justified and that such rules would be carefully developed and validated on the basis of driver eye scanning behavior studies conducted in representative driving environments under representative conditions with a sufficiently large group of representative drivers.

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