Curve Radius Perception Accuracy as Function of Number of Delineation Devices (Chevrons)

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Monocular and binocular curve radius perception accuracy of ten young drivers under curve approach and nighttime conditions using a 1:50 scaled laboratory setup was investigated. The experiment consisted of a sequential comparison of a 90 degree segment of a right curve with a standard radius equipped with 12 equally spaced 1:50 scaled retroreflective yellow/black miniature chevron signs with a 90 degree segment of a test curve (right curve), which could have either two, three, four, or eight equally spaced 1:50 scaled retroreflective miniature chevron signs along a curve radius of either 95, 97.5, 100, 102.5, or 105 percent of the standard curve radius. For each experimental presentation the standard curve was presented first to the subjects (black road environment and chevrons illuminated by electrically controlled headlamps) for 2 sec, then the subjects rotated 90 degrees and were presented with the test curve (one of five curve radii, with either two, three, four, or eight equally spaced chevrons) for 2 sec. A forced-choice response (smaller, larger than standard curve radius) was required from the subjects. All experimental conditions five radii, four chevron levels, five replications for each subject) were randomized within a viewing condition for each subject. The curve approach viewing distance from the subject's eyes to the beginning of the 90 degree segment of the curve was 4.57 m (15 ft), which represents 228.6 m (750 ft) in the real world, whereas the curve radius of the standard curve was 0.914 m (3 ft), which represents a curve radius of 45.6 m (150 ft) (38 degrees of curvature) in the real world (moderately sharp curve). All chevrons were within a total visual field of view of about 11 degrees. The overall averages for the percentage of the number of correct responses were calculated for the two, three, four and eight-chevron conditions for each radius of the test curve for binocular viewing and monocular viewing, and these percentages were plotted against the number of chevrons. On the basis of the results of this study, it is safe to tentatively state that the average of correct responses for the 95, 97.5, 102.5, and 105 percent curve radii increases for the binocular viewing conditions from 56 percent for two chevrons, to 62.5 percent for three chevrons, to 82.5 percent for four chevrons, and remains about the same (81.0 percent) for eight chevrons. For monocular viewing, the average correct responses increase from 50 percent for two chevrons, to 64 percent for three chevrons, to 70.5 percent for four chevrons, and remains about the same (72.5 percent) for eight chevrons. Overall, for the five test curve radii and for the four chevron levels, the binocular viewing condition (especially for four and eight chevrons) produces on the average a somewhat higher overall average value for correct responses (70.6 percent versus 64.3 percent monocular). On the basis of analysis of variance, the curve radii, the number of chevrons, and the viewing conditions are all statistically highly significant factors (0.05 level, interactions not significant). Considering the monocular results as more applicable for the real-world curve approach, it is concluded that, for the conditions investigated in this study, four equally spaced chevrons within a total visual field of about 11 degrees provide adequate curve radius estimation cues for unfamiliar drivers approaching a curve at night.

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Many run-off-the-road (ROR) vehicular accidents occur on curves, especially at night. Limited advance information about the sharpness of a curve and excessive speed have been identified as primary reasons for these accidents. Initially, when the first roads were built, there was no warning system in place to provide an unfamiliar driver with information about the existence and the sharpness of a curve ahead. Along with the development and the increased paving of the road network, a curve warning sign system was designed and installed on selected curves, which provided a driver with advance information that either a curve or a turn (a very sharp curve) was ahead. At a later time, retroreflective pavement markings were added (center line, edge lines) and advisory speed plates were added to the upgraded retroreflective advance curve-and-turn warning signs. Among others, Zwahlen (*1*) investigated the effects of advisory speed plates and found no speed-reducing effects. Further, a retroreflective black arrow (on a yellow background) sign was placed in the beginning section of selected curves to indicate to an unfamiliar driver exactly where the curve started. All these devices were helpful, especially to an unfamiliar driver at night, but they did not provide any specific visual curve radius information or cues. Recently, more and more chevrons, or other discrete delineation devices, were placed in selected curves to provide a driver with curve radius information or cues. Also, spacings for curve delineation devices were established by Zwahlen and others (*2,3;* and in a paper in this Record). These spacings were mainly based on photometric calculations and assumed that four discrete delineation devices should be visible to a driver under low-beam night driving conditions. It is hypothesized that by providing drivers with actual curve radius information before they enter the curve, most unfamiliar drivers will be able to adjust their speeds more appropriately and therefore drive with a larger margin of safety through the curves, especially at night. Further, the Ohio Manual of Uniform Traffic Control Devices [OMUTCD (*4*)] specifies that the spacing of chevron alignment signs (on the outside of a curve or sharp turn) shall be such that the motorists always have two in view and that they should be visible for at least 152.4 m (500 ft). No research studies were found that could justify the "two-in-view" chevron rule, and there is no quantitative information available for the angular extent of the field of view. It was the objective of this study to find a suitable experimental paradigm and to investigate the binocular and monocular (more realistic for curve approach) curve radius perception accuracy of young drivers under curve approach and nighttime conditions as a function of the number of equally spaced chevrons in a 90 degree segment of a moderately sharp right curve. Since the observation conditions of the stimuli were such that they represented a right curve ahead in a real driving situation as seen from about 228 m (750 ft), it seemed to be reasonable to assume that the perceptual accuracy would not be influenced by vehicle motion. The initial angular rate of a change per unit time for the displayed chevrons in a driver's visual field, when approaching curves viewed from a relatively far distance ahead is generally small and negligible from a perception point of view.

METHOD

Subjects

Ten young subjects (drivers) were used for both the monocular (preferred, better-eye) viewing condition and the binocular viewing condition. All drivers had valid U.S. driver's licenses, normal vision, and contrast sensitivity.

Experimental Apparatus

A black observation booth was constructed in which the subject was seated on a rotating chair and could view the standard right curve (level surface, outlined with 12 equally spaced miniature chevrons, height 12.2 mm, width 9.1 mm) and after a 90 degree head and body turn to the test curve (level surface, right curve, one of five different radii, with either two, three, four, or eight equally spaced miniature chevrons). Figure 1 illustrates the experimental setup. Two electrically controlled headlamp sets were used to illuminate the miniature chevrons on the two black presentation tables with black backgrounds. Luminances of the miniature chevrons were measured and adjusted (by voltage and aiming of the lamps) so that the 1:50 scaled laboratory situation provided similar luminances as were found in the real world (see Figure 2). The change in the appearance of the color yellow of the miniature retroreflective chevrons (3M high intensity) caused by the lower operating voltage (lower than 12.8 volts) and subsequent lower-color temperature of the headlamps was not noticeable to the subjects and was not considered to be a significant factor in this study. The total field of view of the 90 degree curve segment containing the chevrons for the investigated curve approach situation was about 11 degrees. Subject eye height with respect to the presentation tables and the miniature chevrons was also adjusted to fit the 1:50 scale.

Experimental Design

The major independent variable was the number of equally spaced chevrons used to indicate the sharpness of a 90 degree curve segment displayed 4.57 m (15 ft) ahead of a subject's eye(s). The other two independent variables were the viewing condition and the radius of the test curve. The dependent variable was the forced-choice response, which indicated whether the test curve radius was perceived as greater or smaller (curve sharpness) than the standard curve radius in the sequential comparison with 2 sec of exposure time for each presentation.

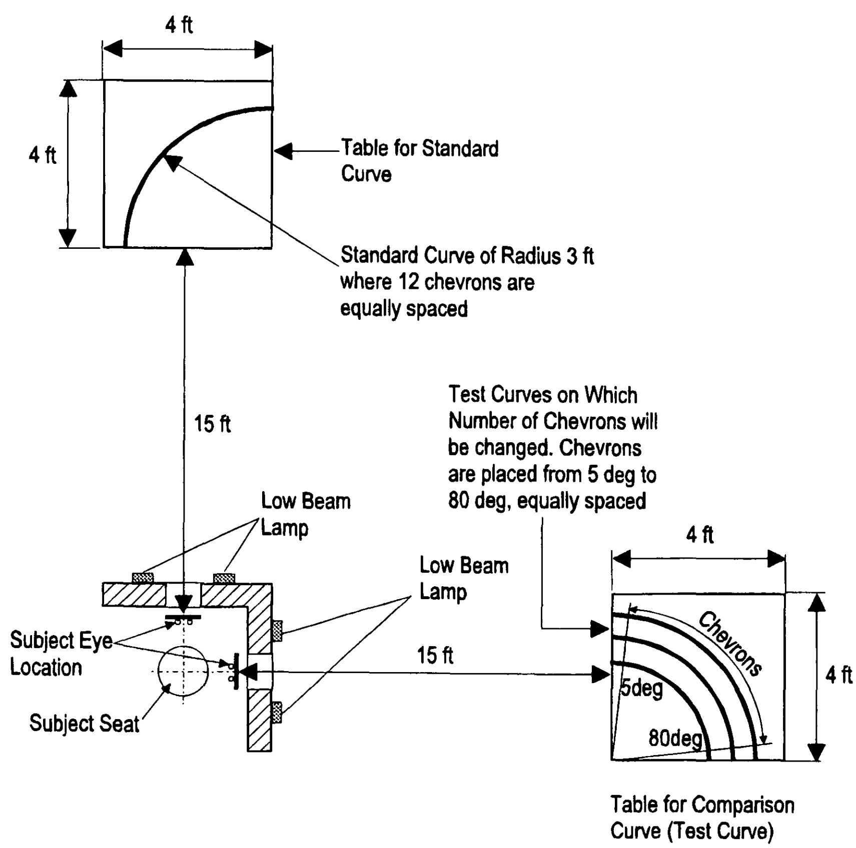


FIGURE 1 Plan view of experimental setup.

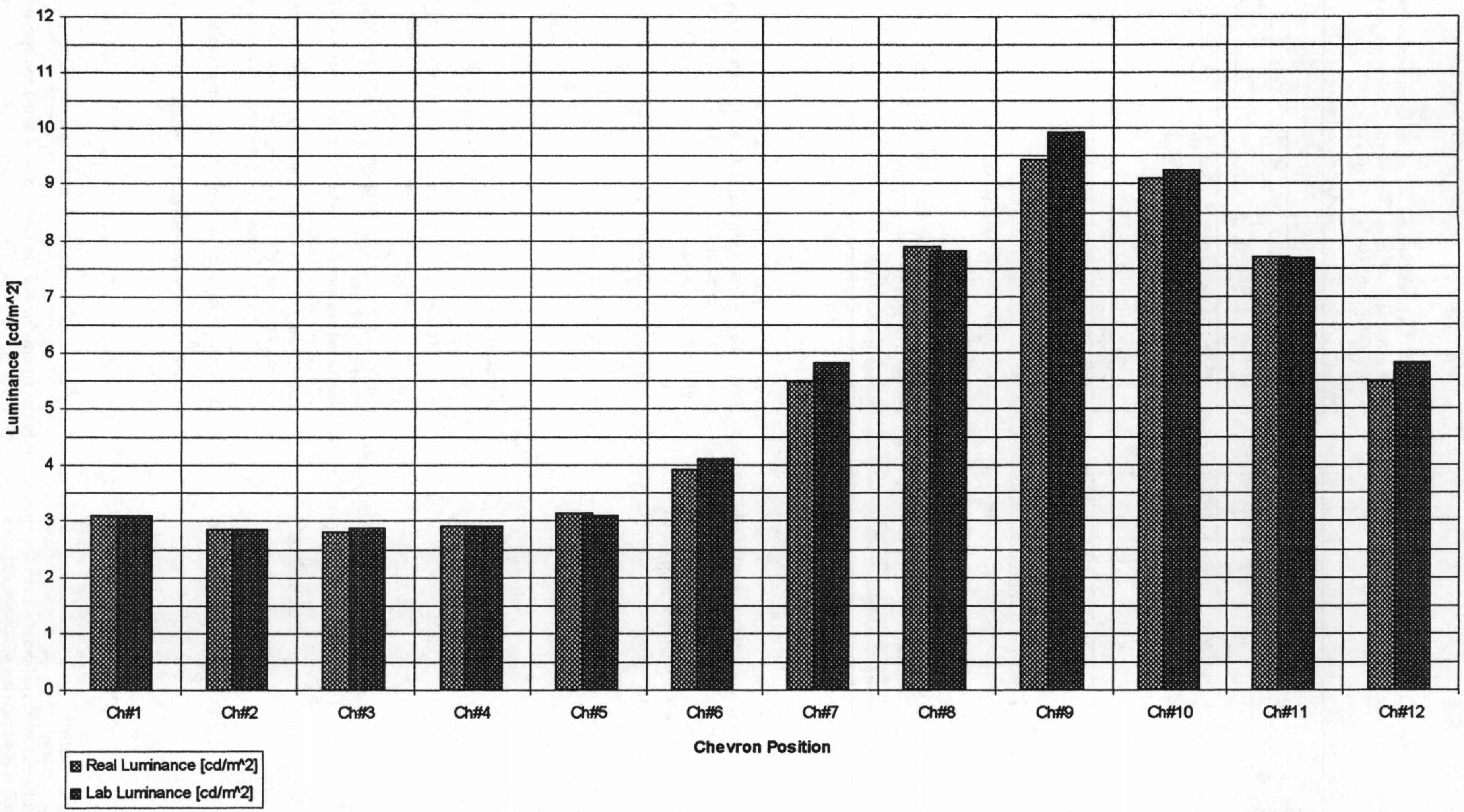


FIGURE 2 Comparison of real luminances (field) and laboratory luminances for 12 equally spaced chevrons (Ch) along standard curve (laboratory headlamps: current = 11A, voltage = 6 V).

TABLE 1 Average percent of Correct Responses as Function of Curve Size and Number of Chevrons for Binocular Conditions (10 Subjects, N = 50 per cell)

	Number of Chevrons Level					
Curve Size	Two	Three	Four	Eight	Total	Average % of C.R.
95%	64	70	88	84	306	76.5
97.50%	50	56	72	76	254	63.5
100%	54	54	46	58	212	53
102.50%	54	56	80	78	268	67
105%	58	68	90	86	302	75.5
Total	280	304	376	382	1342	
Avg. % of C.R., Excluding 100% Curve Size	56.5	62.5	82.5	81	282.5	70.625
C.R.= Correct Responses						

TABLE 2 Average Percent of Correct Responses as Function of Curve Size and Number of Chevrons for Monocular Viewing Conditions (10 Subjects, N = 50 per cell)

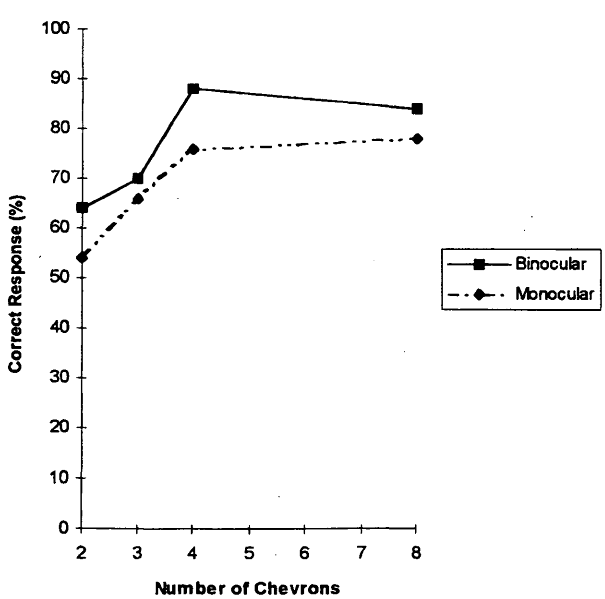
	Number of Chevrons Level					
Curve Size	Two	Three	Four	Eight	Total	Average % of C.R.
95%	54	66	76	78	274	68.5
97.50%	52	62	64	70	248	62
100%	62	62	44	48	216	54
102.50%	44	56	68	66	234	58.5
105%	50	72	74	76	272	68
Total	262	318	326	338	1244	
Avg. % of C.R., Excluding 100% Curve Size	50	64	70.5	72.5	257	64.25
C.R.= Correct Responses						

After an initial learning period, each subject was presented with 100 sequential comparison trials (five curve radii, four chevron Levels 2, 3, 4, and 8, and five replications) for the binocular viewing condition and the monocular viewing condition each. Although it would have been desirable to investigate the intermediate chevron Levels 5 through 7, it was decided that to keep the experimental duration reasonable for the subjects, chevrons Levels 5 through 7 were not of sufficient experimental interest. Further, from an economical point of view, having more than four chevrons within a visual field of about 11 degrees was not considered to be practical. The chevron level of 8 was added to see whether there would be, in fact, a considerable increase in the curve radius perception accuracy when going from four to eight chevrons.

The presentations within a viewing condition were completely randomized. One-half of the subjects started with the binocular viewing condition (total 100 trials per subject) first and then did the monocular viewing condition (total 100 trials per subject), whereas the other half of the subjects were tested in the reverse order. The percentage of correct responses for each test curve radius was then computed for each chevron number level and plotted and analyzed using analysis of variance (ANOVA) and other statistical techniques.

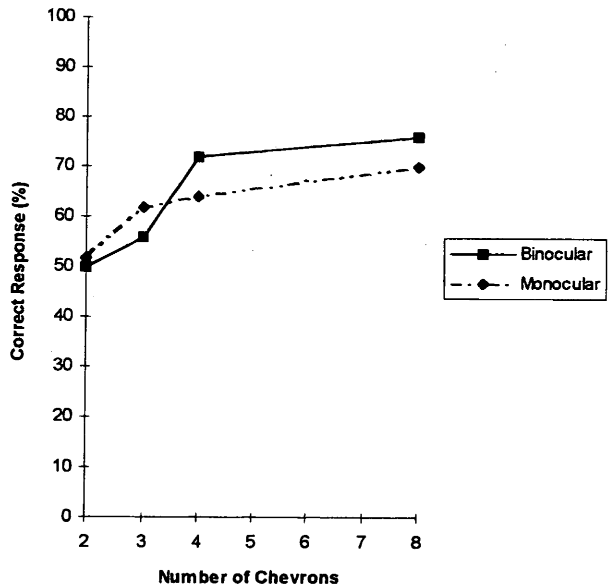
RESULTS

Table 1 shows the average percent of correct responses as a function of the test curve size and the number of equally spaced chevrons for the binocular viewing condition. The average percent of correct responses as a function of the test curve size and the number of equally spaced chevrons for the monocular viewing condition are shown in Table 2. Figures 3 to 7 show the average percent correct responses as a function of the number of equally spaced chevrons (placed along the test curve from 5 to 80 degrees) for a given test curve radius (expressed in percent of the standard curve radius) for the binocular and monocular viewing condition. With the exception of the 100 percent test curve radius data (Figure 5), the increase in perceptual judgment accuracy from two to three to four chevrons and the rather flat extension from four to eight chevrons holds fairly well for both the binocular and the monocular viewing conditions. Table 3 and Figure 8 show the overall average percent correct responses for all chevron levels as a function of the five different test curve radii for the binocular and monocular (more realistic for curve approach situation) viewing conditions. It can be seen that the average percentage of correct



- Binocular vision
  - 10 subjects each 5 observations, N=50
- Monocular vision
  - 10 subjects each 5 observations, N=50
- Size of equally spaced chevrons (yellow retroreflective material) Width=9.1mm, Height=12.2mm, vertical distance from approximately eye level or from simulated road surface (level) to bottom of chevron = 28.4mm
- Horizontal distance from eyes to begin of curve = 4572 mm
- 95% curve radius = 868.7 mm
- Dark viewing conditions with reflectorized miniature chevrons
- Viewing sequence: Standard curve, then test curve
- Viewing Duration: 2 seconds for standard curve and 2 seconds for test curves
- Chevrons always shown within range 5 degrees to 80 degrees in test curves
- Standard curve delineated with 12 equally spaced chevrons using 0 degrees to 90 degrees.

FIGURE 3 Average of percent correct responses as function of number of equally spaced chevrons (placed along test curve from 5 to 80 degrees) with curve radius of 95 percent of standard curve.



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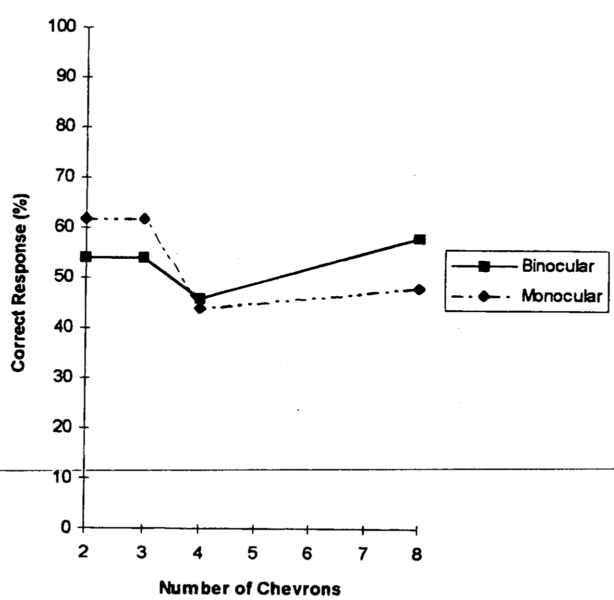
- Horizontal distance from eyes to begin of curve = 4572 mm
- 97.5% curve radius = 891.5 mm
- Dark viewing conditions with reflectorized miniature chevrons
- Viewing sequence: Standard curve, then test curve
- Viewing Duration: 2 seconds for standard curve and 2 seconds for test curves
- Chevrons always shown within range 5 degrees to 80 degrees in test curves
- Standard curve delineated with 12 equally spaced chevrons using 0 degrees to 90 degrees.

FIGURE 4 Average of percent correct responses as function of number of equally spaced chevrons (placed along test curve from 5 to 80 degrees) with curve radius of 97.5 percent of standard curve.

responses increases from 53 and 54 percent (slight bias, 50 percent expected) at the 100 percent test radius almost linearly and fairly symmetrically with increasing or decreasing test curve radius. The steeper slope for the binocular viewing condition indicates its expected superiority over the monocular viewing condition. An ANOVA was performed for the binocular viewing condition for the curve size and the number of chevron factors. Although curve size and number of chevrons of the two factors are statistically highly significant, the interaction at the $\alpha = 0.05$ level is not. An ANOVA was also performed for the monocular viewing condition for the curve size and the number of chevron factors. Again, the two factors—the curve size and number of chevrons—are statistically significant, although the interaction at the $\alpha = 0.05$ level is not. An ANOVA was performed to compare the binocular versus the monocular viewing condition and the number of chevron factors using 10 replications because each subject participated in both the binocular and the monocular viewing conditions. The viewing condition (binocular/monocular) and the number of chevrons are statistically highly significant, whereas the interaction at the $\alpha = 0.05$ level is not.



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- Horizontal distance from eyes to begin of curve = 4572 mm
- 100% curve radius = 914.4 mm (standard curve)
- Dark viewing conditions with reflectorized miniature chevrons
- Viewing sequence: Standard curve, then test curve
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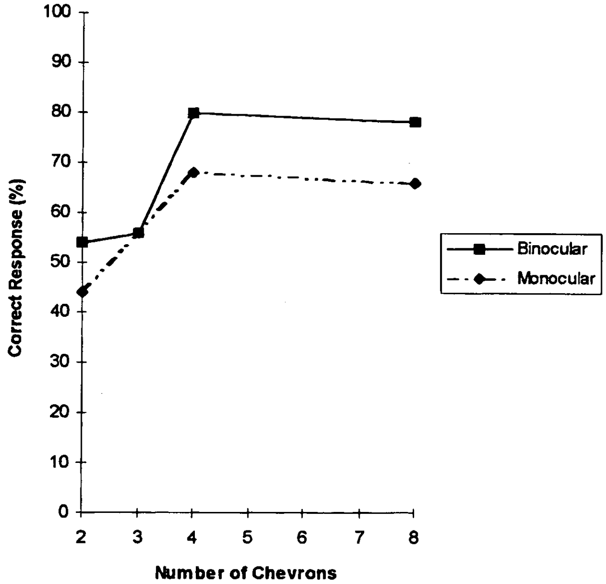
- Standard curve delineated with 12 equally spaced chevrons using 0 degrees to 90 degrees.

FIGURE 5 Average of percent correct responses as function of number of equally spaced chevrons (placed along test curve from 5 to 80 degrees) with curve radius of 100 percent of standard curve.



- Binocular vision
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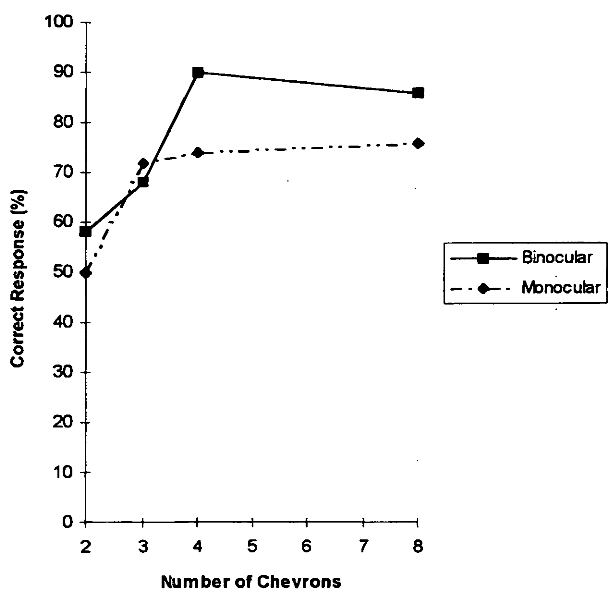
- Horizontal distance from eyes to begin of curve = 4572 mm
- 102.5% curve radius = 937.3 mm
- Dark viewing conditions with reflectorized miniature chevrons
- Viewing sequence: Standard curve, then test curve
- Viewing Duration: 2 seconds for standard curve and 2 seconds for test curves
- Chevrons always shown within range 5 degrees to 80 degrees in test curves
- Standard curve delineated with 12 equally spaced chevrons using 0 degrees to 90 degrees.

FIGURE 6 Average of percent correct responses as function of number of equally spaced chevrons (placed along test curve from 5 to 80 degrees) with curve radius of 102.5 percent of standard curve.

DISCUSSION AND CONCLUSIONS

An experimental paradigm had to be developed that would allow one to quantitatively assess the influence of the number of discrete delineation devices (within a defined field of view) on the accuracy of curve radius perception. Because a direct and absolute estimation of the curve radius (in meters or feet), or the curvature (in degrees) of a displayed curve (curvature in degrees = 1746.5 divided by radius in meters, or 5730 divided by radius in feet) is a hard task, for which regular subjects have little or no practical experience, an experimental paradigm had to be developed that would simplify a subject's perceptual response as much as possible while providing quantitative data relevant to the actual curve radius estimation task. A sequential comparison procedure (always standard curve presented first, then shortly after the presentation of the test curve) was therefore selected as the experimental paradigm because this method allows a subject to make a forced choice (smaller, larger-than-standard-curve) decision and because it can be argued that a higher perceptual accuracy (more correct responses) in this sequential comparison task would most likely also result in more accurate perceptual absolute judgments of the radii of curves in the real world. Further, if it is assumed that a portion of the ROR accidents



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- Horizontal distance from eyes to begin of curve = 4572 mm
- 105% curve radius = 960.1 mm
- Dark viewing conditions with reflectorized miniature chevrons
- Viewing sequence: Standard curve, then test curve
- Viewing Duration: 2 seconds for standard curve and 2 seconds for test curves
- Chevrons always shown within range 5 degrees to 80 degrees in test curves
- Standard curve delineated with 12 equally spaced chevrons using 0 degrees to 90 degrees.

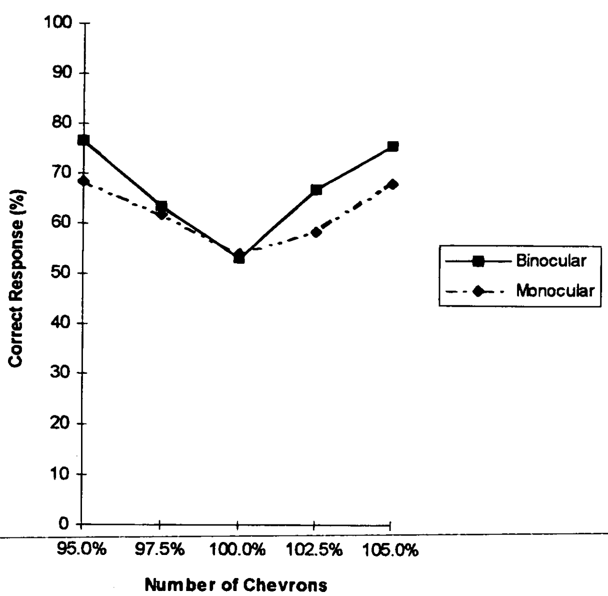
FIGURE 7 Average of percent correct responses as function of number of equally spaced chevrons (placed along test curve from 5 to 80 degrees) with curve radius of 105 percent of standard curve.

TABLE 3 Overall Average Percent of Correct Responses of Each Test Curve Size for all Chevron Levels for Binocular and Monocular Viewing Conditions

	Curve Size					
Vision Type	95%	97.50%	100%	102.50%	105%	Average % of C.R. Excluding 100% Curve Size
Binocular	76.5	63.5	53	67	75.5	70.625
Monocular	68.5	62	54	58.5	68	64.25
C.R.= Correct Responses						

in curves occur because drivers have perceptually underestimated the sharpness of a curve ahead (too high-speed for curve); then, providing drivers with an adequate number of discrete curve delineation devices such as chevrons may increase their perceptual judgment accuracy and may encourage them to adjust the speed more appropriately, resulting in a lower curve speed and a reduction in ROR accidents.

The developed experimental paradigm, although executed in the laboratory, is characterized by a high level of visual fidelity based on an accurate miniaturization (sizes, colors, luminances), a true three-dimensional presentation mode (superior over questionable two-dimensional slide, video, or driving simulator display presentations) and appears to provide useful quantitative answers with respect to the accuracy of curve radius perception as a function of the number of equally spaced delineation elements within a specified field of view. Further, the results obtained in this study match fairly well the results obtained in an earlier and similar exploratory study, in which four young subjects (drivers) were tested under monocular viewing conditions and seven young subjects (drivers) were tested under binocular viewing conditions (*5*). On the basis of these results, it is possible to tentatively conclude that for the conditions investigated four equally spaced discrete delineation devices, such as chevrons, within a total visual field of about 11 degrees provide adequate curve radius estimation cues for unfamiliar drivers approaching a curve at night. The use of four instead of three discrete delineation devices such as chevrons within the specified visual field not only improves the perceptual accuracy slightly, but more important where one of the discrete delineation devices is missing (because of a collision, vandalism, etc.), the remaining three curve delineation devices will be able to provide a driver with a level of perceptual curve radius estimation cues that most likely produce judgment accuracy levels considerably superior to those where only two discrete delineation devices would remain visible to a driver within a specified visual field. With the recent introduction of continuously illuminated curve guidance sections (3M lighted guidance tubes), it would be interesting to investigate how much the perception accuracy of a curve radius for a curve ahead can be improved when compared with discrete delineation elements. It would also be of interest to conduct further research to investigate the effect of the extent of the visual field within which the discrete or continuous delineation devices are contained, the type, shape, photometric properties of delineation devices, the exposure time duration, and to determine whether the apparent leveling-off of the curve radius perception accuracy from four to eight or more discrete delineation devices is mainly caused by human information processing limitations or by the visual information acquisition limitations (limited exposure time duration of 2 sec to make a sufficient number of eye fixations), or a combination of both.



- Binocular vision
  - 5 different radii for each subject (95%, 97.5%, 100%, 102.5%, 105% radius of standard curve), 5 observations, N=250
- Monocular vision
  - 5 different radii for each subject (95%, 97.5%, 100%, 102.5%, 105% radius of standard curve), 5 observations, N=250
- Size of equally spaced chevrons (yellow retroreflective material) Width=9.1mm, Height=12.2mm, vertical distance from approximately eye level or from simulated road surface (level) to bottom of chevron = 28.4mm
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- Dark viewing conditions with reflectorized miniature chevrons
- Viewing sequence: Standard curve, then test curve
- Viewing Duration: 2 seconds for standard curve and 2 seconds for test curves (95%, 97.5%, 100%, 102.5%, 105% radius of standard curve)
- Chevrons always shown within range 5 degrees to 80 degrees in test curves
- Standard curve delineated with 12 equally spaced chevrons using 0 degrees to 90 degrees.

FIGURE 8 Overall average of percent correct responses as function of five different test curve sizes for binocular and monocular viewing conditions.

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