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16. Abstract

One of the potential benefits of mirror-mounted turn signals is that, in certain important traffic situations, they are viewed at a smaller peripheral angle than are conventional turn signals. This smaller eccentricity in the visual field is likely to lead to better signal conspicuity. The present study examined this potential benefit of mirror-mounted turn signals. Specifically, this field study evaluated the effect of the eccentricity of a signal on its detectability under bright sunshine, while subjects performed a concurrent central visual task. Two levels of eccentricity were tested: 45° (representing a conventional turn signal when the observer is in the adjacent lane and just behind the signaling vehicle), and 30° (representing a mirror-mounted turn signal). Four levels of luminous intensity were used (1, 3, 9, and 30 cd) with older and younger subjects.

There are two main results of this study. First, luminous intensity of a signal had a strong effect on its detectability. The older subjects had difficulties with all levels of intensity tested, and only the two highest levels led to reasonably good performance by the younger subjects. Second, for the conditions in which the overall performance was reasonably good, the effect of eccentricity was statistically significant and moderately large in favor of the smaller eccentricity.

There are two implications of these results. First, under the demanding conditions represented by bright sunshine and a concurrent central visual task, low but legal levels of intensity led to poor detection performance, especially for older drivers. Second, under these conditions, the smaller eccentricity of mirror-mounted turn signals is likely to result in them being better detected than conventional turn signals.

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INTRODUCTION

Mirror-mounted turn signals

Recently, there has been growing use of turn signals on the exterior rearview mirrors. Because of their location on the vehicle, these signals may be effective supplements to the conventional turn signals. One advantage of the mirror-mounted signals is that they are visible to other drivers in situations in which there is no clear line of sight to any of the conventional signals. It is particularly significant that mirror-mounted signals are visible to drivers of other vehicles when those vehicles are in or near the blind zone of the signaling vehicle (Reed & Flannagan, 2003). In those situations, it is especially beneficial to insure that an intention to change lanes is signaled effectively. If the signaling driver fails to see a vehicle in the blind zone prior to a lane change, the driver of that vehicle may be better able to compensate by evasive action if the lane change has been clearly signaled.

A possible additional advantage of mirror-mounted signals is that, even when there are clear lines of sight to both mirror-mounted and conventional turn signals, the mirror-mounted signals will usually be closer to the center of a following driver's visual field, and therefore are likely to be more conspicuous. In this study, we first summarize the key literature relevant to the relative conspicuity of signals in the center and periphery of the visual field, and then report the results of a field experiment the we performed in order to provide an estimate of the likely conspicuity benefits of mirror-mounted turn signals in the most critical driving situation: when the observing driver's vehicle is in the blind zone of the signaling driver's vehicle.

Background: Field of view

Cohen (1984) studied the useful field of view during actual driving. He concluded that for various driving conditions, most eye fixations fall into an area of about ±10º horizontally from straight ahead. Peripheral vision—vision beyond 10º—also plays an important role in driving. Importantly, detection times for stimuli increase with increased eccentricities. In various driving experiments, Cohen (1984) found this to be a generally linear increase up to eccentricities of 35º horizontally.

While most visual functions degrade considerably in the periphery, sensitivity to movement and change is relatively well preserved in the periphery. This property of the visual system is important in driving because driving involves the cooperation of central and peripheral vision. The driver needs to observe traffic and vehicle displays in the central visual field for details, but simultaneously has to detect changes in the environment in the periphery of the visual field (Chan & Courtney, 1993).

With increased task load during driving, a perceptual narrowing has been reported, both restricting the useful field of view and reducing the sensitivity of peripheral vision (e.g., Bhise, 1971). There is also a body of literature from basic research demonstrating that cognitive or visual load in the central task has a negative effect on the effectiveness of peripheral vision (Leibowitz & Appelle, 1969), thus contracting the useful visual field. This decrease in peripheral performance is usually interpreted as the result of a narrowing of the focus of attention (Chan & Courtney, 1993).

Background: Visual attention

Visual attention can be conceived of as a limited supply of processing resources to be spread over the entire visual field. The distribution of processing resources has been described by various models, including an attentional zoom lens model (Eriksen & St. James, 1986; Eriksen & Yeh, 1985) as follows:

- At a low power (broad) setting, there is an even distribution of the attentional resources over the effective visual field, but little detailed information can be extracted;
- At a high power (narrow) setting, the attentional resources are concentrated on a very small part of the visual field to extract very detailed information.

The interference of central task load with peripheral vision has been addressed by two competing types of models. A "general interference" model predicts proportional decreases in performance throughout the visual field (Williams, 1982). On the other hand, the "tunnel vision" model postulates that with increasing central task load, there is progressively more impairment in performance with increased eccentricity (Chan & Courtney, 1993). Crundall, Underwood, and Chapman (1999) addressed these different models in the context of the functional field of view during driving. Their results favored the model of general interference over tunnel vision.

From a theoretical perspective, information processing can be separated into three distinctive stages: detection, identification, and response. While detection is the process by which an observer becomes aware of the mere presence of an object in the visual filed, identification is the process of classifying the detected object (Sivak & Flannagan, 1993). A turn signal, for instance, conveys the intention to turn and is designed to attract drivers' attention. After detecting and identifying the turn signal information, a response has to be selected. Recarte and Nunez (2003) analyzed driving behavior with respect to the above-described information processing stages and showed that, in most driving situations, response execution is carried out rather quickly and automatically due to the well-learned and practiced nature of driving behavior. On the other hand, in driving it is primarily the detection stage that is affected during high workload conditions. There is ample research evidence that late detection is a major cause for traffic accidents (Rumar, 1990).

Sanders (1970) defined the functional visual field as that part of the visual field to which a subject is attending while performing a visual task. This functional visual field is divided into three parts: (1) the stationary field that can be covered without eye movements; (2) the eye field that is covered by eye movements; and (3) the head field, which requires head movements for coverage (Houtmans & Sanders, 1984; Sanders, 1970). Experiments performed by Sanders (1970) revealed a decline of performance as a function of display angle. However, this decline was not linear. Sanders identified the stationary field as being effective up to about 30°, and the eye field up to about 85°.

Sanders' categorical division of the functional filed of view for visual attention illustrates the need for eye-movements during driving in order to extend the useful field of view into the periphery. While most visual attention during driving is concentrated in the useful field of view straight ahead, peripheral information outside the useful field of view also has to be attended to. There is evidence in the literature showing decreasing performance for a peripheral stimulus with a simultaneous central task (see Leibowitz & Apple, 1969). However, the magnitude of this effect varies widely, which may be attributed to a task-dependent allocation of different attention strategies in the visual field (Eriksen & Yeh, 1985). Table 1 summarizes several experiments in which performance effects in the visual periphery were tested.

Table 1
Visual performance in the visual periphery.

Type of task	Task load	Dependent measure	Baseline central reaction time	Peripheral reaction time (degree)	Increase in reaction time (%)
Driving (Cohen, 1984)	high (traffic with oncoming vehicles)	reaction time of eye movements to signals	≈ 1000 ms	≈ 1500 ms (35°)	50
Single-target detection task, laboratory (Chan & Courtney, 1993)	high (arithmetical problem)	reaction time to arrows	≈ 300 ms	≈ 600 ms (12°)	100
Target detection task, laboratory (Schumann et al., 1995)	intermediate (tracking task)	reaction time to flashing arrows	≈ 700 ms	≈ 800 ms (35°)	14
Visual search task, laboratory Sanders (1970)	low (differing numbers of dots)	reaction time to differing numbers of dots	≈ 650 ms	≈ 950 ms (34°)	46

Research questions

In several important situations, mirror-mounted turn signals appear at smaller visual angles than conventional turn signals. This difference is greatest when a leading car and a following car in the adjacent lane are close to each other. There were two main research questions addressed in the present study:

(1) Is there a conspicuity benefit for a mirror-mounted turn signal due to its smaller eccentricity compared to a conventional turn signal?

(2) Higher luminous intensities should enhance the conspicuity of a turn signal. How does signal intensity affect the peripheral conspicuity of turn signals?

METHOD

Tasks

The task of primary interest was to detect a briefly presented flash of a signal light in the visual periphery. The signal duration was set to 333 ms, corresponding to the "on" portion of a flash cycle with a duty cycle of 50% and a flash rate of 1.5 Hz (the midpoint of the 1 Hz to 2 Hz range recommended for turn signals).

A loading task required the subject to concentrate his or her attention straight ahead. The task consisted of identifying single letters presented on a computer monitor straight ahead of the subject at a distance of 6 m. The letters were large (19 cm high) and clearly visible.

Experimental setup

The experiment simulated a passing situation in which the subject's vehicle is passing a vehicle that is one lane to the right. The subject's vehicle is just behind the other vehicle, so as to be in the blind zone of the other driver. This blind zone was calculated from average field-of-view data of passenger car mirrors (Reed, Lehto, & Flannagan, 2000). With the car positioned in this blind zone, we calculated viewing angles to the driver-side mirror and the left conventional turn signal lamp of the leading car on the basis of data from average passenger car dimensions (Schoettle, Sivak, & Nakata, 2002). This calculation resulted in the following viewing angles:

- About 28º to the driver-side mirror; and
- About 47º to the driver-side conventional turn signal.

The setup with the corresponding viewing angles is shown in Figure 1.

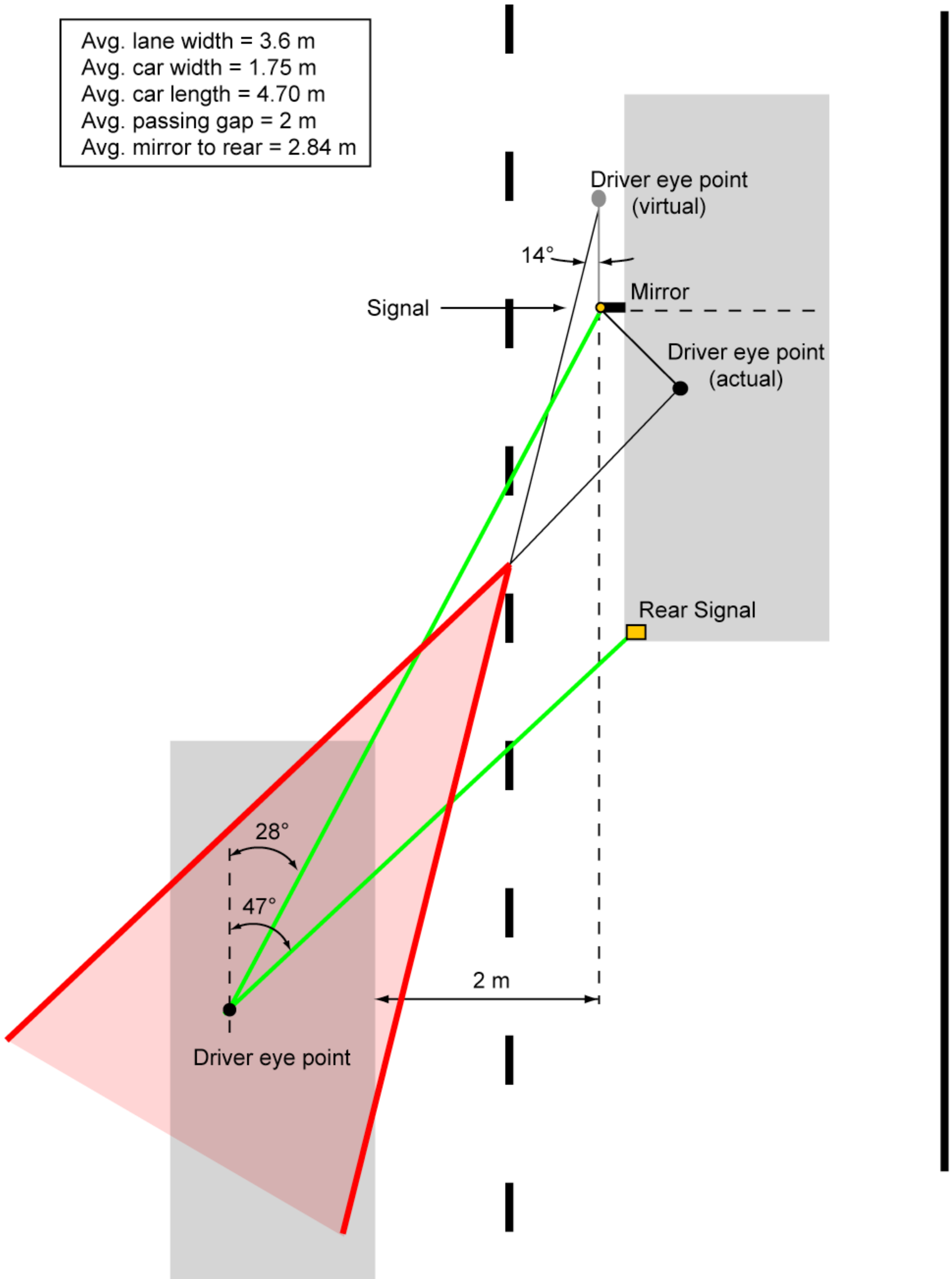

Figure 1. Experimental setup with calculated blind zone and corresponding subject's viewing angles to driver-side mirror and left conventional turn signal on the leading car.

Figure 2 shows the corresponding driver's view. Notice that neither the mirror nor the conventional turn signal on the driver's side is obstructed by body pillars.

Figure 2. Driver's view of overtaking a car while in the leading car's blind zone.

For the experimental setup, the above-described overtaking situation was simplified as follows. The subject was seated outdoors, and four round amber light sources (5 cm diameter) were placed in front of the subject. The lamps were at 30º left and right (simulating the mirror-mounted turn signal) and at 45º left and right (simulating the conventional turn signal). The subject's eye height was set to the average passenger car's eye height of 1.09 m (Reed et al., 2000). Table 2 and Figure 3 summarize the specific parameters selected for the experimental setup. The lateral distance of 3.30 m for the mirror-mounted turn signal corresponds to the average distance in a car-passing situation (Reed & Flannagan, 2003). The lateral distance of 3.54 m takes into account the average mirror size (0.24 m, Reed et al., 2000).

Table 2
Signal position data for the experimental setup.

Signal position	Eccentricity	Lateral distance from eye-point	Longitudinal distance from eye-point
mirror-mounted	30º	3.30 m	5.72 m
conventional	45º	3.54 m	3.54 m

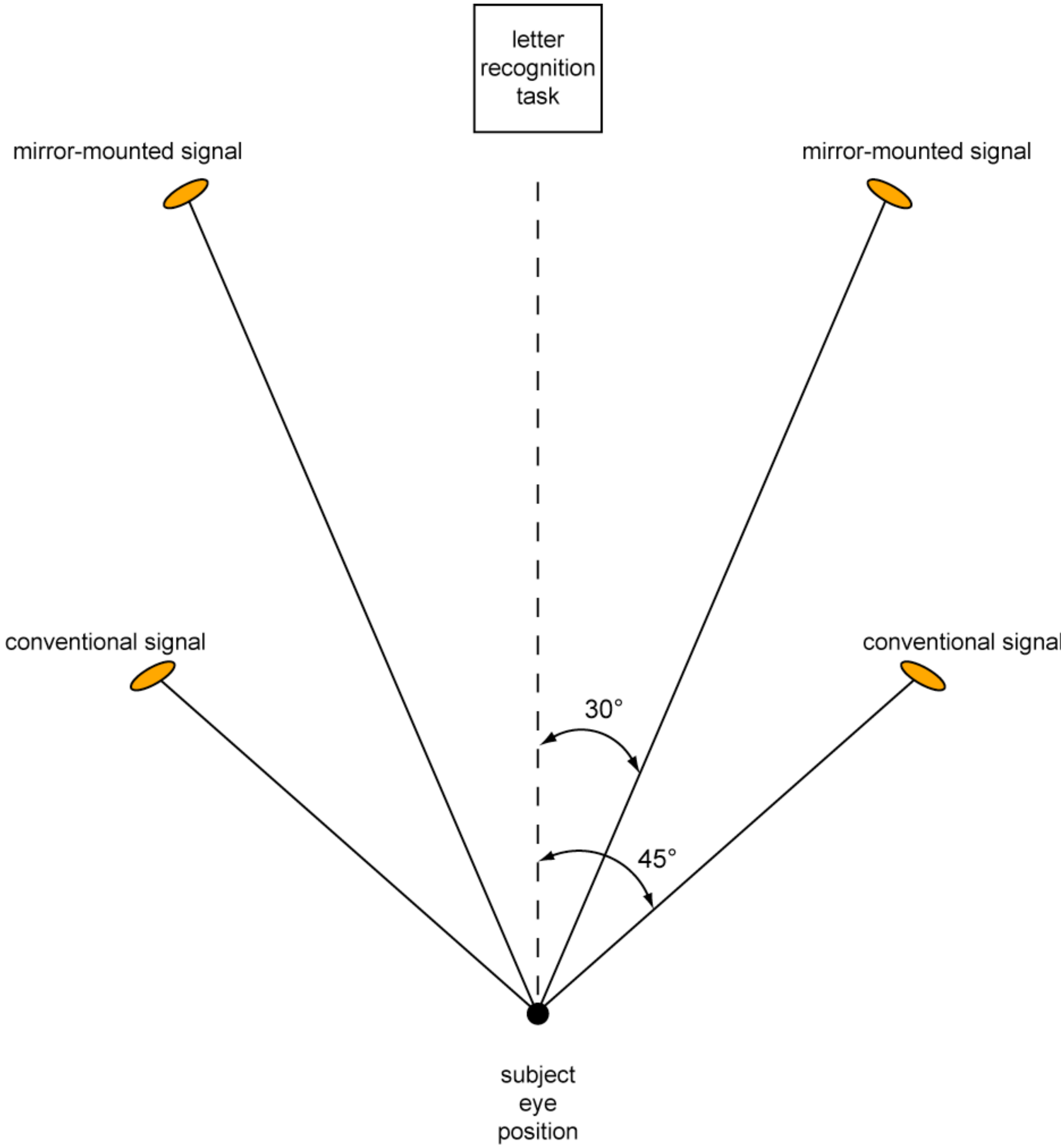

Figure 3. Experimental setup with signal position eccentricities of 30º and 45º.

To set realistic luminous intensities for the signals, photometric measurements were taken of a conventional amber turn signal on a mid-size sedan. The measurements were obtained using an illuminance meter (Minolta T-10), mounted at the same height as the turn signal. The converted luminous intensities are shown in Table 3.

Table 3
Luminous intensities for a conventional amber turn signal as a function of the viewing angle.

Horizontal viewing angle	Luminous intensity (cd)
0°	172
10°	108
20°	27
30°	21
40°	18
50°	16
60°	14
70°	12
80°	10

Measurements were also taken from two mirror-mounted turn signals, representing the two existing types. The luminous intensities are shown in Table 4.

Table 4
Luminous intensities for two different types of mirror-mounted red turn signals as a function of the viewing angle.

Horizontal viewing angle	Luminous intensity (cd)	
	Conventional flashing incandescent light source	LED lamps forming a red flashing chevron[1]
0°	1.6	6.1 – 0.1
10°	1.6	22.5 – 3.5
20°	3.9	22.8 – 17.3
30°	21.9	11.7 – 19.4
40°	9.7	2.5 – 12.5
50°	7.1	0.2 – 1.8
60°	4.8	0.1
70°	1.6	N.A.
80°	0.3	N.A.

[1] Two measurements were taken for two different adjustments of the mirror, resulting in two different mirror surface angles.

Based on these measurements, four intensity values were tested: 1, 3, 9, and 30 cd. (The current ECE regulation allows a minimum intensity of 0.6 cd for supplementary side direction indicators [ECE, 2001]).

Ambient conditions

The experiment was set up in a section of the UMTRI parking lot away from traffic, and took place on bright, sunny days, representing a difficult condition for detecting turn signals. The subjects faced north and the signal lamps faced south, into the sun. The experimental hours were between 1 p.m. and 5 p.m. The ambient illumination was measured before the start of each experimental session. Illuminance on a south-facing vertical surface just in front of the signals averaged 42,185 lux. Illuminance on a north-facing vertical surface at the eyes of the subject (who was seated under a large umbrella) averaged 17,260 lux.

Subjects

Sixteen paid subjects participated in the experiment. There were 8 younger subjects (ranging from 22 to 30 years old, with a mean of 26), and 8 older subjects (ranging from 60 to 73 years old, with a mean of 68). Each age group included 4 males and 4 females. All subjects had normal (or corrected to normal) visual acuity, and wore the same eyewear, if any, that they would normally wear when driving. All subjects were licensed drivers.

Design

Subjects were tested individually in sessions lasting about 45 minutes each. Each session consisted of four intensity blocks with 20 trials each (4 signal positions, and 5 replications of each position). The order of the 20 detection trials was randomized. The order of the 4 intensity blocks was counter-balanced following a digram-balanced Latin Square design, in which each intensity level is preceded and followed by each other intensity level just once (Wagenaar, 1969).

There were four independent variables:

- Age (young and old)
- Intensity (1, 3, 9, 30 cd)
- Eccentricity (30° and 45°)
- Side (left and right).

Procedure

One experimenter ran the experiment. The subject was seated in a chair under a large umbrella. The subject's seating height was adjusted so that the eye height was 1.09 m. Before the start of the experiment, the subject received written instructions about how to perform the two concurrent tasks (the letter identification task and the signal detection task).

The letter identification task was introduced as the main task to insure that the subject's gaze was on this task. The task consisted of a randomly presented Power Point slide show of capital letters at a distance of 6 m. The subject only had to respond when the letter “X” was presented. Each presentation consisted of two parts, a pre-cue slide presented for 5 s, followed by a letter slide presented for 3 s. The pre-cue slide with the word “focus” and a star in the middle of the display was designed to remind the subject to concentrate on the letter identification task. All letters were black, except for the letter “X” which was red to enhance its conspicuity. When the subject saw the letter “X,” he or she was asked to name it. There were 20 “X”s in a series of 80 letters.

The turn-signal task was controlled with PsyScope software (Cohen, MacWhinney, Flatt, & Provost, 1993). The task consisted of detecting a peripherally presented signal. The time between successive trials varied randomly between 4 to 17 s. There was a short break after each block of 20 trials, with the experimenter changing the intensities of the signals between blocks by using neutral density filters. The subject was instructed to respond as quickly as possible to a signal onset. The subject’s response times were recorded.

RESULTS

The subject's response was recorded as a miss if the subject did not respond to the onset of a lamp within 1500 ms. The hit rates by age and intensity are shown in Table 5. It is evident from Table 5 that the older subjects had difficulties at all levels of intensity (mean hit rates failed to reach 75% for any of the four intensity levels). The lowest two levels of intensity resulted in poor performance by younger subjects as well. (Because of the high miss rates in several conditions, the reaction time data are not very meaningful, and they will not be discussed further.)

Table 5
Mean signal hit rates by intensity and age.

Intensity (cd)	Hit rate (%)		
	Younger subjects	Older subjects	Overall
1	16.9	5.0	10.9
3	32.5	8.8	20.6
9	76.3	22.5	49.4
30	86.9	65.6	76.3

The effect of eccentricity was examined for the younger subjects at the two highest intensity levels—the two age-by-intensity conditions that had an overall hit rate (averaged across both eccentricities) of more than 75% (see Table 5). For these two conditions, the hit rate (averaged across both intensities) was 87.5% at 30° and 75.6% at 45°. A *t*-test showed this difference to be statistically significant ($t = 2.26$, $p = 0.029$, one-tailed). Figure 4 shows the hit rates by eccentricity and intensity for the younger subjects and the two highest levels of intensity.

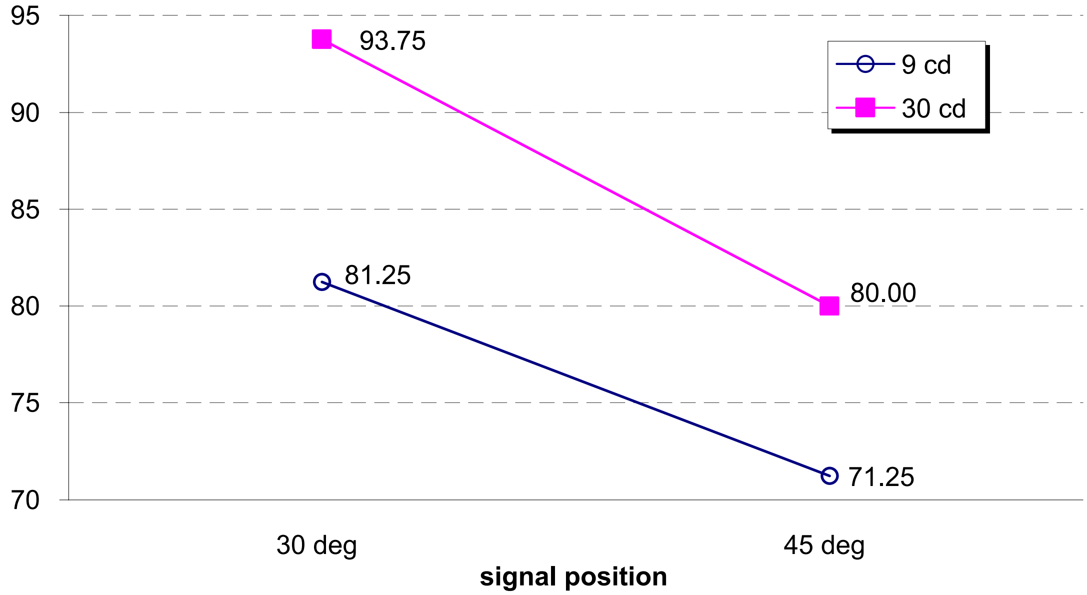

Figure 4. Mean hit rate (%) for the two highest intensity levels and younger subjects only, by eccentricity and intensity.

DISCUSSION

There are two main results of this study. First, under the demanding conditions tested (strong sunlight and a concurrent central visual task), the luminous intensity of a signal had a strong effect on its detectability. The older subjects had difficulties with all levels of intensity tested (1, 3, 9, and 30 cd), and only the two highest levels led to reasonably good performance by the younger subjects. Second, for the conditions in which overall performance was reasonably good (the younger subjects at the two highest levels of intensity), the effect of eccentricity was statistically significant and moderately large (hit rates of 87.5% for 30°, and 75.6% for 45°).

There are two implications of these results. First, under the demanding conditions represented by bright sunshine and a concurrent central visual task, low but legal levels of intensity lead to poor detection performance, especially for older drivers. Second, under these conditions, the smaller eccentricity of mirror-mounted turn signals is likely to result in them being better detected than conventional turn signals.

REFERENCES

Bhise, V. D. (1971). *The relationship of eye movements and perceptual capabilities to visual information acquisition in automobile driving*. Columbus: Ohio State University.

Chan, H.S. & Courtney, A.J. (1993). Effects of cognitive foveal load on a peripheral single-target detection task. *Perceptual and Motor Skills, 77*, 515-533.

Cohen, A.S. (1978). *Eye movement behavior while driving a car: A review*. Zürich: Swiss Federal Institute of Technology, Department of Behavioral Science.

Cohen, A.S. (1984). *Einflußgrößen auf das nutzbare Sehfeld.* Bergisch Gladbach: Bundesanstalt für Straßenwesen.

Cohen, J., MacWhinney, B., Flatt, M., & Provost, J. (1993). PsyScope: An interactive graphic system for designing and controlling experiments in the psychology laboratory using Macintosh computers. *Behavior Research Methods, Instruments, and Computers, 25*, 257-271.

ECE [Economic Commission for Europe] (2001). *Uniform provisions concerning the approval of direction indicators for motor vehicles and their trailers* (Regulation No. 6). Geneva: United Nations.

Eriksen, C.W. & St. James, J.D. (1986). Visual attention within and around the field of focal attention: a zoom lens model. *Perception & Psychophysics, 40*, 225-240.

Eriksen, C.W. & Yeh, Y. (1986). Allocation of attention in the visual field. *Human Perception & Performance, 11*, 583-597.

Henderson, R.L., Sivak, M., Olson, P.L. & Elliot, W.M. (1983). *Motor Vehicle Rear Lighting and Signaling* (SAE Technical Paper Series 830565). Warrendale, PA: SAE Publications.

Houtmans, M.J.M. & Sanders, A.F. (1984). Perception of signals presented in the periphery of the visual field. *Acta Psychologica, 55*, 143-155.

Leibowitz, H.W. & Appelle, S. (1969). The effect of a central task on luminance thresholds for peripherally presented stimuli. *Human Factors*, *11*, 398-392.

NHTSA [National Highway Traffic Safety Administration] (1998). *Lamps, reflective devices, and associated equipment* (Federal Motor Vehicle Standard No. 108). Washington, D.C.: Office of the Federal Register.

Recarte, M.A., & Nunes, L.M. (2003). Mental workload while driving: effects on visual search, discrimination, and decision making. *Journal of Experimental Psychology: Applied, 9*, 119-137.

Reed, M.P., Lehto, M.M., & Flannagan, M.J. (2000). *Field of view in passenger car mirrors* (Technical Report No. UMTRI-2000-32). Ann Arbor: The University of Michigan Transportation Research Institute.

Reed, M.P. & Flannagan, M.J. (2003). *Geometric visibility of mirror-mounted turn signals* (Technical Report No. UMTRI-2003-18). Ann Arbor: The University of Michigan Transportation Research Institute.

Rumar, K. (1990). The basic driver error: Late detection. *Ergonomics, 33*, 1281-1290.

SAE [Society of Automotive Engineers] (2000). *Turn signal lamps for use on motor vehicles less than 2032 mm in overall width* (SAE Standard J588). Warrendale, PA: SAE Publications.

Sanders, A.F. (1970). Some aspects of the selective process in the functional visual field. *Ergonomics, 13*, 101-117.

Schoettle, B., Sivak, M., & Nakata, Y. (2002). *The locations of signaling & lighting equipment on passenger vehicles sold in the U.S.* (Technical Report No. UMTRI-2002-8). Ann Arbor: The University of Michigan Transportation Research Institute.

Schumann, J., Sivak, M., Flannagan, M.J., Aoki, M., & Traube, E.C. (1995). *Visual displays and selective attention: do the elderly benefit if the information is flashing?* (Technical Report No. UMTRI-1995-32). Ann Arbor: The University of Michigan Transportation Research Institute.

Senders, J.W. (1976). Speculations and notions. In, R.A. Motty & J.W. Senders (Eds.), *Eye movements and psychological processes* (pp. 355-365). Hillsdale, NJ: LEA.

Sivak, M. & Flannagan, M. (1993). Human factors considerations in the design of vehicle headlamps and signal lamps. In, B. Peacock & W. Karwowski (Eds.), *Automotive Ergonomics* (pp. 185–204). London: Taylor & Francis.

Wagenaar, W.A. (1969). Note on the construction of digram-balanced Latin squares. *Psychological Bulletin, 72*, 384-386.