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Forward Looking Blindspots: A Report of A A-Pillar Induced Field of Obstruction and Driver Performance in a Simulated Rural Environment

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16. Abstract (Limit: 200 words)

This study analyzed the relationship between the size of the forward looking blindspot (FLB) produced by vehicles A-post (windshield frame), the speeds of two vehicles approaching an intersection at right angles, and driver behavior relative to a likely accident event.

Researchers observed 28 volunteer participants directly and by four channels of on-board video cameras while they drove in a simulator at the Human Factors Research Laboratory. They noted the way that participants scanned the virtual environment and scored at four levels of scanning activity. They also tracked visual acquisition of the target vehicle and incidence of collision.

Only 6.3 percent of the total fell into type one scanning (eyes fixed). Type II (eyes only) accounted for the highest incident rate at almost 44 percent. The study considered both as "inactive" forms of scanning.

Target vehicle acquisition rate increased with the activity level of the scanning type. The target acquisition rate increased significantly from scanning level one to level two and from scanning level two to level three. There was not a significant increase in the acquisition rate from scanning level three to level four.

Not surprisingly, collision rates decreased with increases in scanning level. Collision rates significantly dropped between scanning levels two and three and scanning levels three and four. Yield signs at intersections produced no significant correlation with acquisition rate, collision rate, or scanning level.

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Forward Looking Blindspots:

A report of A-Pillar induced field-of-view obstruction and driver performance in a simulated rural environment.

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Table of Contents

Figures and Tables

Executive Summary:

Blindspots occur when the driver's field of view is compromised as a result of the obscured line of sight produced by the support pillar on either side of the windshield. This differs from the "traditional" concept of the rear-view blindspot. With a support pillar (A-pillar) width of approximately 10cm, the line of sight extended out 150m can produce a blindspot of sufficient size to "hide" a vehicle or several vehicles approaching an intersection from either the left or right of the direction of the approaching vehicle. This obscured region enables an approaching vehicle to remain hidden for an extended time due to coincident acceleration or deceleration. This interaction holds serious implications for real world events as well as research results in traffic interactions.
This study analyzed the relationship between the size of the forward looking blindspot (FLB), the approach speeds of two vehicles approaching an intersection at right angles, and driver behavior relative to an accident likely event.
The wrap around simulator (WAS) at the University of Minnesota Human Factors Research Lab (HFRL) is a large dome like structure with wrap around screens and multiple projectors that produce a forward field of view image of approximately 130 degrees. The simulator uses three Proxima 9250+ projectors to provide a 180-degree forward view. The projectors have a 1024x768 resolution. The vehicle is a Honda Acura modified for data acquisition and simulator interface. All vehicle hardware is connected to a PC running Linux. This PC communicates using TCP/IP with an SGI Onyx.
Volunteer participants (N=28) in the study were observed directly and by four channels of on-board video cameras while driving the HFRL simulator. The manner in which the participants scanned the virtual environment was noted and scored in four categories:

I. Eyes fixed- peripheral vision only
II. Eyes only scan
III. Eye/head scan – head turns but no change in head position
IV. Active scan – head moves around left/right, forward/back (looking around A-pillar)

Participants were also scored as to whether they visually acquired the target vehicle. These scores were acquired by either voluntary reporting by the participants, obvious adjustment to the course and speed or by observation of reactions by the participants. Participants were also scored relative to their incidence of collision.
Results produced a low incidence of type I scanning (eyes fixed) with only 6.3% of the total falling into this category. The highest incidence rate was type II (eyes only) at almost 44%. Both are considered to be "inactive" forms of scanning.

Target vehicle acquisition rate increased with the activity level of the scanning type. A similar inverse relationship was observed in collision rates relative to scan type. The target acquisition rate increased significantly from scanning level I to II ($p<.05$) and from scanning level II to III ($p<.05$). There was not a significant increase in the acquisition rate from scanning level III to IV ($p>.05$).

Not surprisingly, collision rates decreased with increases in scanning. With an increase in the scanning level there was no significant decrease in the collision rate from scanning level I to II ($p > .05$). Collision rates dropped significantly between scanning levels II and III ($p < .05$) and scanning levels III and IV ($p < .05$). It was not until scanning behaviors became "active", with movement of the head, that the collision rates dropped significantly.

Signage (yield) at intersections produced no significant correlation with the acquisition rate, collision rate or scanning level ($p < .05$). The high incidence of low level scanning types (eyes fixed, eyes only, types I&II) may be an artifact of the VE design. The sparse landscape, which is reminiscent of some rural roads, may have contributed to a state of complacency in the participants. Since we had no real world (RW) data on the individual participants driving habits under these specific conditions we might assume the results to be valid. One may think of this situation as, "If there is nothing to look at, why look?" Therein lays one of the concerns of rural road intersection design. With no required deviation in heading (such as left turn lane affords) or a reason to more actively scan (such as a series of buildings might produce) and with nothing present to obscure vision for miles (with the exception of seasonal crops) the wide-open rural road intersection may induce a false sense of safety and a state of complacency.

Forward Looking Blindspots:

A report of A-Pillar induced field-of-view obstruction and driver performance in a simulated rural environment.

1. Introduction

1.1 Background

Research that directly focuses on the problem of forward looking blindspots (FLBs) generated by interruptions in the field of view by the A-pillar (front support pillars) of a car as it approaches an intersection is sparse. As can be mathematically demonstrated, these blindspots can comfortably "hide" the presence of very large vehicles. The size of these obstructed fields of view allows vehicles to remain hidden from one another's view for extended periods if the acceleration or deceleration of the two vehicles occurs while approaching an intersection at right (or near right) angles. This issue is further exacerbated if the behavior of one vehicle signals to another that they are aware of their presence by slowing, for example at a yield sign, when in fact the slowing vehicle is unaware of the other's presence.

These FLBs can obscure the presence of the other vehicle all the way to intersection. In such specific conditions, a collision is a high probability. One study that addresses this issue is by Rumar (1990) in Ergonomics. Rumar notes that ergonomics and human factors contributions to the design and use of energy absorbing techniques have reduced the injuries of car occupants dramatically, but we have been less successful in reducing the risk of collisions occurring. Rumar goes on to note that when drivers are asked why the accident occurred, they often claim they either saw the car too late to avoid collision or did not see the other car at all. This issue has received little empirical attention in the research literature or even general discussion.

1.2 General methodology and approach

Two stages of software were initially developed for this experiment. The first was a simple demonstration program described in the following section and the second was the actual simulated environment used in the wrap around simulator (WAS) in the University of Minnesota's Human Factors Research Lab. Before proceeding with software development the existence and scope of the FLBs were determined under real world conditions by simply going to a large open lot having one individual walk in an arc at 30 and 60 meters and noting the areas which were obscured from our "driver's" point of view. The sizes of the obscured regions were in agreement with the trigonometric calculations even though the real world experiment involved binocular vision which we suspected might decrease the size of the blindspot area.

1.3 Participants

The participant population consisted of 28 volunteer participants (16 male, 12 female). The population mean age was 29 years with a range of 21 years to 60 years of age. The mean number of years the participants had driving was 9.18.

1.4 Review of Literature

The review of literature is a representation of published work on issues that relate primarily to visual aspects of driving and the implications that these issues may have relative to the role of blindspots generated from the driver's perspective looking forwards as a function of angular displacement of the field of view through the front support pillars of the car. In reading this literature we believe that it is beneficial to categorize the articles and technical reports that we have extracted from the literature and thus we have created the following categories:

- **I.** Driving and the role of vision
  - **A.**
  - **B.**
- **II.** Older drivers with visual problems
- **III.** Visual aspects of driving (general)
- **IV.** Car design and older drivers
- **V.** Error detection in driving

By dividing the literature into these categories it aids in assimilating the literature as well as providing a natural way of thinking about elements that can contribute to traffic accidents that are caused by the level of active viewing on the part of the operator as well as the design aspects of the particular road intersection, as well as the support pillars in their part of the actual automobile construction period.

The Bibliography that follows is annotated. These annotations represent summaries or abstracts provided by the authors of the different papers, or they are summaries done by us. We have in some instances added further comments to author summaries.

I. Driving and the role of vision

A. Gale, A.G. (ED), Summala, H. (Helsinki Univ, Finland) (1998). *Forced Peripheral Vision Driving Paradigm: Evidence For The Hypothesis That Car Drivers Learn to Keep In Lane With Peripheral Vision.* Vision in Vehicles – VI, pp51-60 (14 Refs.).

An early well-known hypothesis of Mourant & Rockwell (1970, 1972), which is based on their eye-movement measurements, states that drivers learn to use peripheral vision in lane-keeping while beginners need foveal vision for it. This hypothesis has not been confirmed in real-life experimental settings, however. We recently showed that when forced to do a foveal in-car task, more experienced drivers are better able to keep the car in the lane than novices when the task eccentricity increases from 7 degrees to 23 degrees, thus supporting the hypothesis. This paper reviews two further experiments using the same forced peripheral vision driving paradigm. The first, using a similar representative sample of young male conscripts in similar conditions (lane width of 3m and speed of 30km/h), confirmed the result. The other, using psychology students in conditions closer to normal highway driving (lane width of 3.75m, speed of 60km/h), also included blind-fold driving in order to check the use of kinesthetic and tactual information in each experience group. The results were in the expected direction but far from significant, presumably due to somewhat different conditions and to the fact that subjects were from highly selected population who were able to develop ad hoc strategies in the task. No experience effect was found in blind-fold performance. The results also showed that the foveal task load does not influence peripheral lane keeping performance, by contrast with the concept that attention within the visual field is a function of foveal load.

Szlyk, J.P., Severing, K., Fishman, G.A. (1991). *Peripheral Visual Field Loss and Driving Performance.* Illinois University, Chicago, P.O. Box 4348, Chicago, IL, 60680, USA. AAA Foundation for Traffic Safety, 1730 M Street, NW, Suite 401, Washington, DC, 20036, USA. pp39 (2 Photos, 16 Fig., 3 Tab., Refs.).

The objective of the present study was to determine the predictors of accident risk associated with peripheral visual field impairment. The authors evaluated the driving performance of an experimental group of subjects having varying degrees of peripheral visual field losses on an interactive driving simulator. Their performance was compared to a group of normally-sighted control subjects. The authors also obtained information about real-world accidents through a self-report questionnaire and state accident records in order to relate simulator performance to the incidence of on-road accidents. The results of multiple regression analyses showed that in the experimental group visual function factors predicted real-world accidents and simulator accidents, but accounted for only 26% and 6% of the variance, respectively. However, visual function factors combined with simulator indices accounted for 71% of the variance in real-world accidents, and 80% of the variance in simulator accidents. Subjects with peripheral visual field loss reported significantly more real-world accidents than the control subjects. In addition, it was found that accident risk increases with greater severity of visual field loss. On the driving simulator, the experimental group traveled further distances before responding to the presentation of a peripheral stimulus. This index of reaction distance increased with extent of visual field loss, and was marginally related to state-recorded accidents. The experimental group was also found to stray out of lane significantly more often than the control subjects. This index of out-of-lane events was found to be significantly related to state-recorded accidents combined with convictions for traffic violations. Also, subjects with peripheral field loss showed a tendency for compensating for those losses through increased lateral eye movement. Some psychosocial factors expected to be related to driving performance, including risk-taking and anxiety were also measured.

B. Troutbeck, R.; Wood, J.M., (1994) *Effect of Restriction of Vision on Driving Performance.* Journal of Transportation Engineering. 120(5) pp737-752 (10 Fig., 2 Tab., 33 Ref., 1 App.).

Experts estimate that vision provides 90 percent of the sensory input used by drivers to guide and control their vehicles. In a field study, investigators restricted vision to determine the effect on driving performance. Commonly occurring binocular visual-field defects were simulated for a group of young normal subjects and then their driving performance was assessed on a private closed rural road, free of other vehicles. The monocular condition did not significantly affect performance for any of the driving tasks assessed; however, restricting binocular vision had several effects. When binocular vision was 40 percent or less, the time to complete the course significantly increased, the ability to detect and correctly identify road signs decreased, and the ability to avoid obstacles and maneuver through limited space decreased. Accuracy of road positioning and reversing was also impaired. Some other driving tasks, such as driver's ability to estimate speed and stopping distance, were not affected by restriction of binocular visual fields. More definitive research on the interrelationship between visual performance and performance on the road is necessary.

II. Older drivers with visual problems

Maag, U. (Montreal University, Canada); Joly, P. (Institut de Readapation de Montreal, Canada); Gagnon, R. (Montreal University, Canada); Desjardins, D. (Montreal University, Canada); Messier, S. (Montreal University, Canada); Laberge, Nadeau, C. (Montreal University, Canada) (1996). *Older Drivers with Vision Problems.* Proceedings of the 40th Annual Conference of the Association for the Advancement of Automotive Medicine, Vancouver, British Columbia, Canada, October 7-9, 1996. Pp317-34 (27 Refs.).

Driving records (1987 to 1990) for 7500 class 5 (automobile) permit holders aged between 70 and 85 years were collected from different files (permit holders, medical, infractions, demerit points, crashes) of the public insurer for injuries (SAAQ). The aim is to answer the following question: Do older drivers (aged 70 to 85) with certain vision problems have a worse driving record than healthy ones of the same age? The health status was cross-validated with additional information from the Quebec (Canada) provincial health insurance (RAMQ). Up to six groups with specific vision problems, mainly low acuity (for instance 20/40 or 20/50 for the best eye) and visual field reduction were retained for comparisons with a corresponding healthy group with good vision, separately for women and for men. The study has shown that among the elderly drivers who have visual problems a few cohorts registered more crashes than their controls of the same age group with normal vision. For this latter, their accident rate per driver was low, particularly for women. Older drivers tend to adjust their driving behavior in accordance with their limitations. The results do not support relaxing further the regulation for the elderly driver.

Owsley, C; Ball, (1993). *Assessing Visual Function in the Older Driver.* K Clinics in Geriatric Medicine. 9(2) pp389-401.

Because visual functional problems and eye disease are more prevalent in the older population, a natural hypothesis is that visual disorders are the major cause of driving difficulty in elderly individuals. Despite the intuitive appeal of a link between vision and driving ability, studies have found only weak correlations between visual deficits (e.g., visual acuity, visual field loss) and vehicle crashes. These correlations were often statistically significant due to very large sample sizes but accounted for less than 5 percent of the crash variance in these studies. Thus, these data are insignificant in reaching the practical goal of successfully identifying which older drivers are seriously at risk for crash involvement.

Decina L.E. (The Bionetics Corporation, USA), Staplin L. (The Bionetics Corporation, USA) (1993). *Retrospective Evaluation of Alternative Vision Screening Criteria for Older and Younger Drivers.* Accident Analysis and Prevention. 25(3) pp267-75 (19 Refs.).

Visual examinations of 12,400 drivers in Pennsylvania were conducted at the time of their license renewal. Static binocular tests of visual acuity, horizontal visual field, and contrast sensitivity at varying spatial frequencies were given to license renewal operators who were unaware that their vision would be tested when they arrived at a facility where license photographs are processed. Examination results were correlated with involvement in selected crash categories over a 3.67-year period, taking (self-reported) mileage into account. Neither visual acuity nor horizontal visual field measures in isolation were significantly related to crash involvement. The combination of visual acuity, horizontal visual fields, and broad contrast sensitivity criteria was significantly related to increasing crash involvement for drivers aged 66-75 and also 76 and over. The implications of including contrast sensitivity measures in driver vision screening protocols are considered. (Author / publisher).

Klein, R., (1991). *Age Related Eye Disease, Visual Impairment, and Driving in the Elderly.* Human Factors. 33(5) pp 521-525 (Tab., Refs.).

As people age, a number of visual functions such as acuity, visual field, and night vision deteriorate. This decline in vision is associated in part with an increase in vehicular accidents per mile driven by the elderly. Four age-related ocular conditions - cataract, macular degeneration, open-angle glaucoma, and diabetic retinopathy are primarily responsible for the decline in visual acuity and visual field in the elderly. Few epidemiological data are available about these diseases, and at present they cannot be prevented. There is need for more information about visual decline and how it affects driving performance and for development of pragmatic approaches for detecting and assessing the elderly driver with functional visual deficits.

Loevsund, P. (Chalmers University of Technology, Goeteborg, Sweden), Hedin, A. (Karolinska Hospital, Stockholm, Sweden), Toernros, J. (Swedish Road and Transport Research Institute (VTI), Linkoeping, Sweden), (1991). *Effects on Driving Performance of Visual Field Defects: A Driving Simulator Study.* Accident Analysis and Prevention. 23(4) pp 331-42 (15 Refs.).

To elucidate the possible traffic safety risks induced by visual field defects, a method was developed based on a driving simulator. The capacity to detect stimuli of different sizes appearing in 24 different positions on the screen in front of the driver was measured. Two groups of normal subjects and a number of subjects with different visual field defects were studied. In the groups of normals, the median reaction times were fairly homogenous. There was a slight difference between central and peripheral stimuli, which was somewhat larger for the older subjects. Among the subjects with field defects, the individual variations were very dominant. Very few of these showed a capacity to compensate for their deficiency. In order to gain insight into possible compensatory mechanisms of these persons, eye movement recordings were made. The results indicate that the visual search pattern may be of importance in this respect. Some comparisons with respect to detection capacity were also made with one-eyed subjects and with optically generated field restrictions (spectacles and spectacle frames). (Author / publisher).

III. Visual aspects of driving (general)

Gale, A.G.(ED) (Derby University, UK); Bichao, I.C. (New York State University, USA); Yager, D. (New York State University, USA) Lewis, A. (Ferris State University, Big Rapids, USA), (1996) *Computer Simulation of Some Visual Aspects of the Driving Situation: A Preliminary Report.* Vision in Vehicles, Fifth International Conference, Glasgow. pp 27-32 (17 Refs.).

In this paper the effect of luminance in reduced visibility conditions at night, visual field position, and blur (up to two diopters), on the ability to discriminate between a simulated common potential hazard (a pedestrian who is about to cross the street) were studied, and a situation that is visually very similar, but that a priori does not involve danger (a pedestrian on the side of the street, facing away from it). Target real-life video images of a pedestrian surrounded by a background of trees and a wooden fence, on the side of a road, were used. Throughout the experiment the subjects viewed this same scene under different conditions; with foveal or 10 deg fixation, with non-blurred or blurred images, and at several mean luminance levels in the mesopic and scotopic range. (A) For the covering abstract, see IRRD 892069.

Bartmann, A. (University of Technology, Aachen); Spijkers, W. (University of Technology, Aachen Hess, M. (University of Technology, Aachen), (1991) *Street Environment, Driving Speed and Field of Vision.* Vision in Vehicles III. pp381-9 (15 Refs.).

The aim of the study was to examine the effects of driving speed and route characteristics on the visual field. Subjects had to driver along different road types under slow and fast driving speed instructions. While driving, eye movements were recorded. The results suggest that the effect of the factor "driving speed" depended on road type. An additional variable that affected perceptual behavior was traffic load. It was observed that as speed increased the driver fixated driving task relevant objects more often. On the basis of the results it is argued that the often-postulated "tunnel vision" effect of driving speed should be regarded as a consequence of focal attention to driving task relevant objects. (A) For the covering abstract of the conference see IRRD 839978.

Loevsund, P. (Chalmers University of Technology, Goeteborg, Sweden); Hedin, A. (Karolinska Hospital, Stockholm, Sweden); Toernros, J. (Swedish Road and Transport Research Institute (VTI), Linkoeping, Sweden) (1991). *Effects on Driving Performance of Visual Field Defects: A Driving Simulator Study.* Accident Analysis and Prevention. Vol.23 (n.4) pp 331-341 (References, Diagrams, Tables).

To test the effect of visual defects on driving performance, subjects with normal vision and subjects with defective vision were tested using a driving simulator. Median reaction times varied little among the group with normal vision, but varied considerably among members of the group with defective vision. Subjects with field deficits often did not have the ability to compensate for this difficulty.

Zwhalen, H.T. (1989). *Conspicuity of Supra-threshold Reflective Targets in a Driver's Peripheral Visual Field at Night.* Transportation Research Record. (1213) pp35-46 (9 Fig., 1 Tab., 7 Ref.).

Past investigations and experimental studies dealing with the visual detection of either nonreflectorized or reflectorized objects or targets in the driving environment at night have been limited primarily to foveal or line-of-sight visual detection. A geometric model is developed to analyze reflectorized targets located ahead of a car at different locations along a tangent-curve and curve-tangent section of a highway. Typical night driving eye scanning data are also presented. The model demonstrates that in many cases unknown or unexpected reflectorized targets, such as a reflectorized license plate or an advance warning sign, will appear initially at moderately large peripheral angles up to 15 deg or more away from a driver's foveal eye fixation point, or line of sight. A field study involving the foveal and peripheral detection of a reflectorized target is presented to show that peripheral visual detection distances decrease considerably as the peripheral visual angle away from the fovea, or line of sight, increases. A 10 deg peripheral visual detection angle results in an average visual detection distance approximately one-half of the average foveal detection distance. It is concluded that in a situation where drivers approach or negotiate a curve at night, where reflectorized objects or targets will become visible for the first time probably in the periphery of a driver's visual field, and where there is a need for early detection, the reflectivity of the target should be increased to ensure timely recognition, information processing, and decision making, and appropriate control actions.

IV. Car design and older drivers

Peacock, B. (ED) (General Motors Corporation), Karwowski, W. (ED) (Louisville University, USA); Smith, D.B.D. (Southern California University, USA); Meshkati, N. (Southern California University, USA); Robertson, M.M. (Southern California University, USA), (1993). *Automotive Ergonomics, Chapter 21: The Older Driver and Passenger.* Automotive Ergonomics, pp 453-71.

This chapter defines and describes the older car user population and reviews the current database available for use in car design with this section of the population in mind. Factors to be considered in connection with older drivers and passengers are considered including the wide variation in the population, particular problems related to age and disabilities. Functional data to be considered are discussed including physical and motor changes, body size and shape, range of motion and joint flexibility, strength, sensory changes, sensitivity to glare, acuity, visual field and cognitive changes. Older people are increasingly dependent on private transport to lead an independent life. Designs however are mostly aimed at a younger population. Research is summarized and references given for more detailed information. For the covering abstract see IRRD.

V. Error detection in driving

Anderson, G. (University of California, Riverside), Cisneros, J. (University of California, Riverside), Atchley, P. (University of California, Riverside), Saidpour, A. (University of California, Riverside) (1999). *Speed, Size, and Edge-Rate Information for the Detection of Collision Events.* Journal of Experimental Psychology: Human Perception and Performance. pp 256-69.

In the present study an alternative analysis was considered that was based on perceived speed and size and that assumed constant deceleration for the detection of collision events. Observers were presented with displays simulating a 3-D environment with obstacles in the path of observer motion. During the trial, observer motion decelerated at a constant rate and was followed by a blackout prior to the end of the display. Observers had to detect which trials resulted in a collision. The results indicate that collision detection varied as a function of the size of the obstacles, observer speed, and edge rate- findings not predicted by analysis. The results suggest that observers use an analysis based on speed and size information. A model that assumes constant deceleration is proposed for braking control.

Rumar, K. (Swedish Road and Transport Research Institute (VTI), Linkoeping, Sweden), (1990). *The Basic Driver Error: Late Detection.* Errors in the Operation of Transport Systems. Proceedings of a CEC Workshop Held at the Medical Research Council's Applied Psychology Unit, Cambridge, UK, May 26-28, 1989. Ergonomics, 33 (10/11). Pp1281-90 (11 Refs.).

Over the past two or three decades we have been quite successful in reducing injuries of car occupants by the use of energy-absorbing techniques; but we have not been as successful in reducing the risks of having collisions. When drivers are asked why an accident occurred very often they claim that they saw the other road user too late to avoid collision. This paper discusses the basic road user error of failing to see another road user in time, why such errors happen, and how they can be reduced. A detection error is basic, because without detection no processing of information, no decision process including that road user, takes place. Among the many causes of detection error two of the more important are: a lapse of cognitive expectation, illustrated by the failure to scan for a particular class of road user, or to look in the appropriate direction; a difficulty with perceptual thresholds, illustrated by the failure to discern the relevant stimuli in lower levels of ambient illumination or in situations where vehicles approach in the peripheral visual field of road users. (A) For the covering abstract of this conference see IRRD.

Summary Remarks:

To date our extensive literature research has revealed little that directly focuses on the problem of forward blindspots generated by the interruptions in the field of view by the front support pillars of the car as the driver approaches an intersection. As we can demonstrate mathematically, these blindspots can comfortably hide the presence of a large vehicle up to the size of a semi trailer, and as we proposed in the original research, if two drivers in a coincident fashion adopt similar deceleration rates approaching an intersection, these blindspots can be made almost of the point of intersection and that coupled with an unexpected need to generate a reaction time can easily produce collisions because of late detection. The only study to date that we have found is one by a Swedish group headed by K. Rumar in Ergonomics 1990 in Category V. of this report. Rumar notes directly that ergonomic and human factors contributions to our design and the use of energy absorbing techniques have reduced the injuries of car occupants quite dramatically, but we have been less successful in reducing the risk of having collisions. Rumar goes on to note that when drivers are asked why an accident occurred, they often claim that they either saw the other car too late to avoid collision, or as is the case in many instances the driver "did not see" the other driver. It is this later situation that is the focus of this research, and to date has not received much empirical attention in the research literature or even general discussion of this important category of collision producing events in driving behavior.

2. Development of Software

2.1 Demonstration software

An initial demonstration pilot software program was developed which preceded the actual Virtual Environment (VE) software development (see CD-ROM accompanying this document.). The software program is a Windows compatible executable with accompanying .dll libraries. The program is a simplistic demonstration of the interactive nature of the forward looking blindspots (FLBs) of two vehicles approaching an intersection at right angles and at variable speeds. The variables that may be controlled are; the scale or aerial distance from the intersection and the individual vehicle relative speeds. These parameters are adequate to demonstrate the effect of the FLB in contributing to an intersection collision.

3. Task and Experimental Protocol

3.1 VE calibration.

The virtual environment (VE) consisted of two scenarios, calibration and trial. Figure 3.1 illustrates the view from the driver's seat during the calibration phase. Figure 3.2 illustrates two sample views from the trial phase.

Figure 3.1 - Calibration screens, Left (driver side) and Right (passenger side).

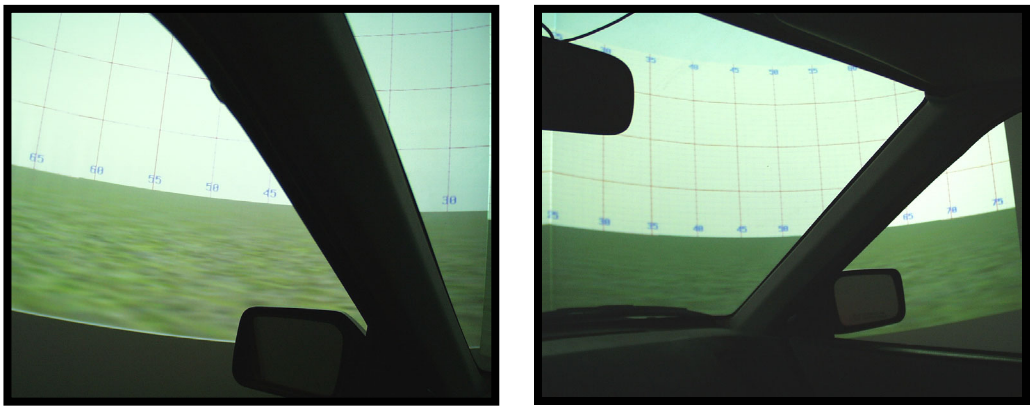


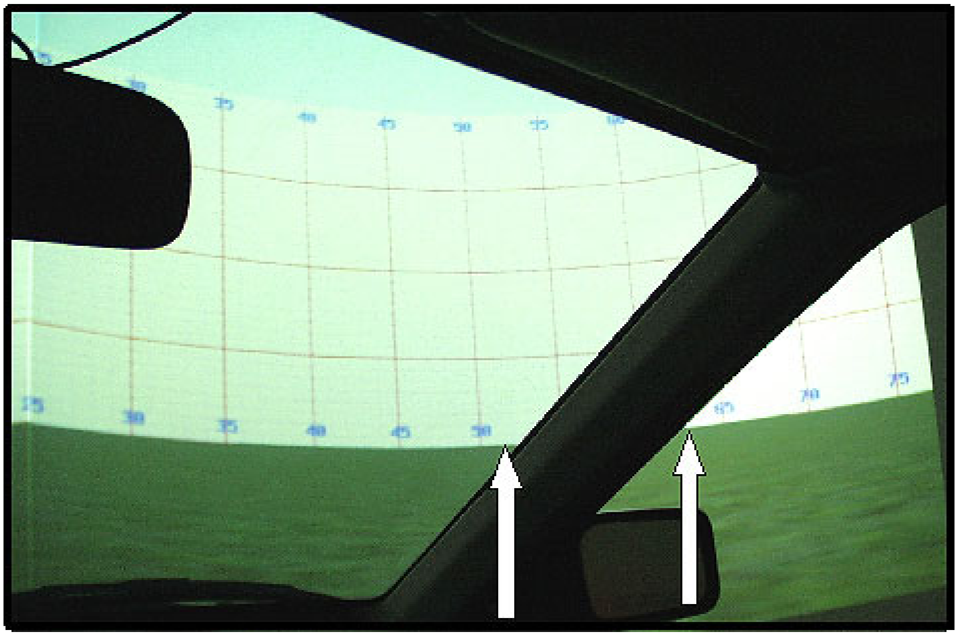
Figure 3.2 - Trial scenes, driver view forward and right.

Figure 3.2 is the actual driver view of the first intersection in the trial sequence. This particular intersection involved no interaction with another "vehicle".

3.2 Calibration scenario

The calibration phase consisted of a large virtual "wall" upon which was displayed a numbered grid (Fig. 3.3). It was set up as if the test car was situated inside of a large virtual environment (VE) cylinder.

Figure 3.3 - Forward looking blind spot (FLB) calibration, right view.



The numbers are at the bottom of the grid were situated at approximately eye level. The participants were shown a diagram explaining which set of numbers we were requesting (indicated by arrows in Fig. 3.3). These numbers are entered into the trial scenario parameters and are used to produce the FLBs for each participant's set of trials. This procedure was repeated for both the driver and passenger side A-pillars. The size and position of the FLB differed for each subject relative to their morphology (particularly height and leg length).

3.3 Trials

The trial phase consists of a straight road with 9 intersections, the first being a non-trial stop sign marking the beginning of the test road (Fig. 3.2). The trial phase is composed of two conditions at two levels producing four basic conditions: yield / no yield and "stimulus" VE vehicle slaved or un-slaved to test car.

I. Yield with slaved vehicle
II. Yield with un-slaved vehicle
III. no Yield with slaved vehicle
IV. no Yield with un-slaved vehicle

Each trial condition was repeated producing a total of eight trial intersections. Order effect was controlled for using a Latin square design.

Slaved vehicles begin their approach to the intersection when the RW car, traveling at approximately 55 mph, was at a predetermined distance (~300m) from the intersection. The slaved vehicle then proceeded at a VE road speed that kept it in the FLB of the RW car until the RW car was within 30 meters of the intersection where it was then "un-slaved" and proceeded through the intersection independent of the speed of the RW car.

The un-slaved vehicles begin their approach to the intersection when the RW car is at a given distance from the intersection. The un-slaved vehicle will proceed at a VE road speed that is predetermined (~88kph.) independent of the RW car. The direction of approach (from left or right) of the VE vehicle is distributed between the repeated conditions.

3.4 Data acquisition
Data pertaining to heading, road speeds, gas pressure, brake pressure, and "global" position coordinates were recorded directly by the computer and exported as a text file. Observational data was collected by direct observation by the investigator/passenger and by video cameras located inside of the test car.

Each participant was videotaped from the front aspect, from the right rear and directly ahead at the VE screen (Fig. 3.4).

Figure 3.4 - Camera views inside of test vehicle

Camera data was then used to cross check and confirm observed scanning behaviors and road incidents.

3.5 Data analysis
Data analysis consisted of ANOVA, Pearson Correlations and descriptive analyses of the following dependant variables:

I. Scanning level, coded;
 - 0- fixed gaze, predominantly forward, no head motion
 - 1- eyes scanning, no head motion
 - 2- eyes scanning coupled with left/right head motion
 - 3- eyes scanning coupled with full left/right, forward/backward head motion

II. Acquisition - Was the virtual vehicle detected by the driver?
III. Collision - Did the driver collide with the virtual vehicle?

Whether or not the intersection was “Yielded” was an independent variable which was also analyzed. Because this was a simulated environment it was possible to have a collision and not be aware of it. The other dependant variables consisted of any comments from the participants or aberrant driving behaviors we observed.

4. Results

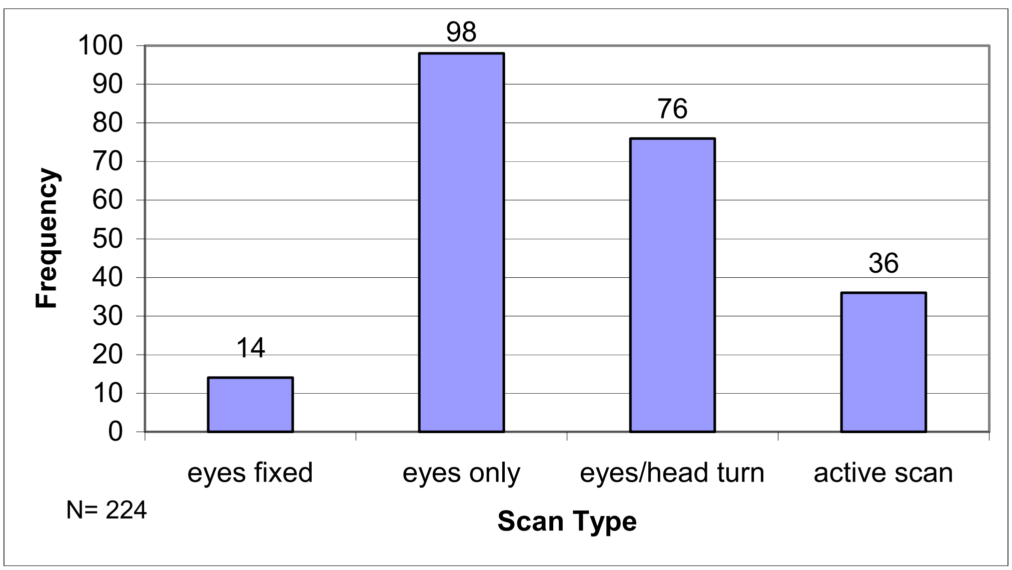
4.1 The FLB

It is very easy to hide a vehicle in the FLB on either side if the head is in a fixed position. If undetected by the driver a vehicle approaching from the left was obscured until the point of impact and even then the simulator driver often remained unaware of the collision. If undetected by the driver there was a brief moment of awareness of imminent collision when the vehicle was approaching from the right but there was usually too little time to react.

4.2 Complacency

Our simulated environment was fairly barren aside from road signs, roads, and the occasional shrub. While participants were aware that other vehicles were present, they exhibited a very high level of complacency. This complacency is represented by the frequency of "eyes only" scanning illustrated in figure 4.1. This usually altered after the first collision. The participant's style of driving and scanning usually changed at this point, if only briefly, to a more active form of scanning behavior. Even with this change in behavior collisions still occurred.

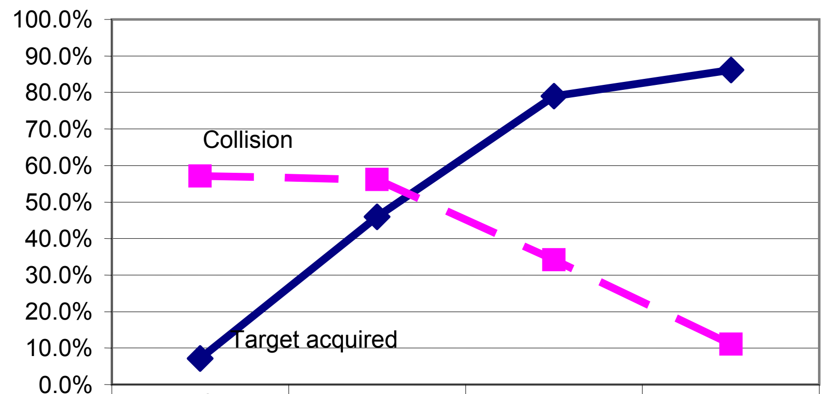
Figure 4.1 - Scan type count across all trials, all subjects (N =224)



4.3 Scanning behaviors, acquisition and collisions

Participants in this study drove very much as they would in the real world. This was determined by the information on their questionnaires and by comments made to the researchers. A few of the drivers were by their own description "active scanners", though this is not the term they used. These participants in particular had very few, if any, collisions. Other participants sometimes expressed mild anger at being tricked or fooled into a collision, which was not the case. It is simply that the A-pillars are very effective at obscuring the view of drivers to the point that even repeated scanning without an actual displacement of the head is insufficient to reveal the approaching test vehicle.

Figure 4.2 - The percentage of target acquisition and collision rate by scan type category



	eyes fixed	eyes only	eyes/head turn	active scan
Acquired target	7.1%	45.9%	78.9%	86.1%
Collided	57.1%	56.1%	34.2%	11.1%

The comment was often made that the car just "appeared" at the intersection. The "appearing" cars were easily visible for perhaps 10 seconds prior to the collision by anyone not seated in the driver's seat. Several participants never altered their scanning behaviors sufficiently even after repeated collisions. Figure 4.2 illustrates the increase in target acquisition rates and the decrease in collision rates relative to scanning level.

One-way ANOVA indicated significant differences ($p<.05$) in both the scanning acquisition and collision rates (Table 4.1).

Table 4.1 - One-way ANOVA of acquisition and collision rates.

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Acquire	Between Groups	11.007	3	3.669	19.127	.000
	Within Groups	42.202	220	.192		
	Total	53.210	223			
Collide	Between Groups	6.166	3	2.055	9.377	.000
	Within Groups	48.222	220	.219		
	Total	54.388	223			

As illustrated in figure 4.2 and table 4.2, there was a significant increase in acquisition rate between each scan level except between levels II and III ($p>.05$). However, the incidence of collision did not approach significance until scanning became "active" at scan type II (eyes/head).

Table 4.2 - Fishers LSD comparisons of acquisition and collision rates across scanning levels

Multiple Comparisons
LSD

Dependant Variables	(I) Scantype	(J) Scantype	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Level	
						Lower Bound	Upper Bound
Acquire	.00	1.00	-.3878*	.12514	.002	-.6344	-.1411
		2.00	-.7180*	.12738	.000	-.9691	-.4670
		3.00	-.7897*	.13795	.000	-1.0616	-.5178
	1.00	.00	.3878*	.12514	.002	.1411	.6344
		2.00	-.3303*	.06694	.000	-.4622	-.1984
		3.00	-.4019*	.08536	.000	-.5702	-.2337
	2.00	.00	.7180*	.12738	.000	.4670	.9691
		1.00	.3303*	.06694	.000	.1984	.4622
		3.00	-.0716*	.08862	.420	-.2463	.1030
	3.00	.00	.7897*	.13795	.000	.5178	1.0616
		1.00	.4019*	.08536	.000	.2337	.5702
		2.00	.0716	.08862	.420	-.1030	.2463
Collide	.00	1.00	.0102	.13377	.939	-.2534	.2738
		2.00	.2293	.13616	.094	-.0390	.4977
		3.00	.4603*	.14746	.002	.1697	.7509
	1.00	.00	-.0102	.13377	.939	-.2738	.2534
		2.00	.2191*	.07156	.002	.0781	.3601
		3.00	.4501*	.09124	.000	.2703	.6299
	2.00	.00	-.2293	.13616	.094	-.4977	.0390
		1.00	-.2191*	.07156	.002	-.3601	-.0781
		3.00	.2310*	.09472	.016	.0443	.4177
	3.00	.00	-.4603*	.14746	.002	-.7509	-.1697
		1.00	-.4501*	.09124	.000	-.6299	-.2703
		2.00	-.2310*	.09472	.016	-.4177	-.0433

* The mean difference is significant at the .05 level.

4.4 Correlations

Scan type produced a significant positive correlation with acquisition ($R=.432$, $p<.01$) and a significant negative correlation with collision ($R=-.324$, $p<.01$). No significant correlation was found for the yielded intersections ($R=.032$, $p=.630$). In fact, it should be noted that “yield” produced no significant results under any of the variables; scan type, acquisition or collision (Table 4.3).

Table 4.3 – Correlations

		SCANTYPE	ACQUIRE	COLLIDE	YIELD
SCANTYPE	Pearson Correlation	1	.432	-.324**	.032
	Sig. (2-tailed)	.	.000	.000	.630
	N	224	224	224	224
ACQUIRE	Pearson Correlation	.432**	1	-.165*	.046
	Sig. (2-tailed)	.000	.	.013	.495
	N	224	224	224	221
COLLIDE	Pearson Correlation	-.324**	-.165*	1	-.009
	Sig. (2-tailed)	.000	.013	.	.893
	N	224	224	224	224
YIELD	Pearson Correlation	.032	.046	-.009	1
	Sig. (2-tailed)	.630	.495	.893	.
	N	224	221	224	224

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

5. Discussion

It is apparent that the A-pillars produce a potentially hazardous situation. We are aware that the conditions were manipulated to produce these hazardous conditions. One should also be aware that we did not incorporate every possible interaction condition and that these interactions occur each and every day millions of times. This should demonstrate that despite the contrived nature of the experiment the potential for death and injury remains high. Many of the newer vehicles are now incorporating wider fields of view by moving the A-pillars back. This is usually expressed as a design issue addressing easier ingress and egress from the vehicle or as a frame stiffness issue.

5.1 Implications

There are two basic approaches before us. First, with respect to driver training, it is not sufficient that drivers be taught, "look left, look right, look left again" before proceeding into an intersection. An awareness of the weaknesses of human perception should be nurtured. Once we are made aware of the ability of our brains to fill in for missing information (visual) it is possible that a lessened sense of complacency while driving may result.

The second is an engineering approach. Either the vehicle itself must be re-engineered to provide for better vision or the road/intersection must be redesigned in order to re-orient the vehicle as it approaches the intersection. This could be accomplished by something as simple as small deviation in the lane position. Active warning flashers may produce the desired effect but this would be immensely expensive. Also, a warning without evident (visible) threat has limited meaning.

One should keep in mind that the vehicle used in this experiment had small mirrors and drove in a straight line. Large vehicles (buses, trucks, etc.) often have an even larger FLB. An equally critical issue not addressed here is that of the turning vehicle at pedestrian intersections. Pedestrians are predominantly vertical, as are A-pillars. A final observation of note is the significance, or lack thereof, of the effect of yield signs.
The intent of the yield is to communicate the right-of-way to traffic. The effect may go beyond this intent. Communication between vehicles occurs over long distances. Beyond flashers and brake lights, our primary means of communication is the vehicle itself. If one observes a "yielded vehicle slowing at an intersection one may think to oneself something along the lines of "hmm…they're slowing… they must see me." This may tragically not be the case. Many drivers have inexplicably pulled out in front of an oncoming car. This has possibly been due to the reasons presented in this paper. This communication of slowing by the "yielded" car may induce complacency of the "un-yielded" car. One may ask if no yield at all in this situation might be safer than none at all in rural low volume traffic settings. It is particularly in rural settings that the effect of complacent scanning behaviors may occur. It is, however, not limited to these regions. Any traffic location where a sense of false security exists is potentially hazardous. We assume people will stop at a four-way stop, primarily because we assume we are visible to the other driver. We assume that with a clear field of view that we are aware of any potential oncoming vehicle threats. This is not necessarily the case.