

EVALUATION OF DRIVER USEFUL FIELD OF VIEW (UFOV):
EFFECTS OF AGE AND ECCENTRICITY

By

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Abstract

Eighteen older subjects (62-82 years) and 19 younger subjects (18-35 years) took part in a 1 ½ hour driving experiment on eastbound highway 50 from Yankton, South Dakota to Vermillion, South Dakota. Subjects were asked to discriminate a central stimulus mounted on the rear of a lead-vehicle while simultaneously detecting a peripheral target on the windshield of the subject's vehicle.

Results of this experiment demonstrate that ***eccentricity related drops in peripheral target detection are NOT AGE DEPENDENT***. A “DC shift” was seen in which the older adult saw fewer overall targets but had detection slopes similar to that seen in the younger adults, only an octave lower. Results of this experiment support the *general interference* model of age related loss.

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Introduction

Crash Risk among Older Drivers

Motor vehicles are used by nearly everyone in the world and affect all aspects of modern living. The need for crash prevention has always been an issue of scientific importance because of our reliance upon the automobile. This becomes especially evident when you consider driving with respect to advancing adult age. Older drivers are one of the fastest growing segments of the driving population in terms of the number and proportion licensed and overall number of miles driven (Waller, 1991). Even though the aged as a group are underrepresented in the overall number of crashes, they do suffer from a higher crash rate per mile driven compared to their younger counterparts (Fig. 1).

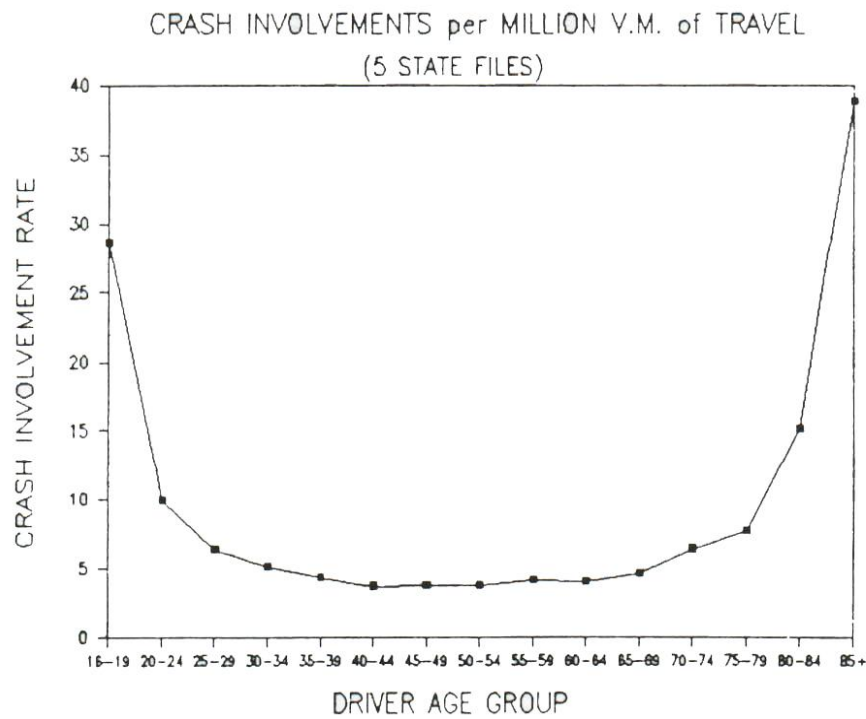


Figure 1. Crash involvement per million miles driven broken down by age. (Cerrelli, 1989).

In addition to their elevated crash rate, older drivers also demonstrate the highest number of fatalities per 100 million miles traveled (Evans, 1988; Waller, 1991; Cerrelli, 1989) (see Figure 2).

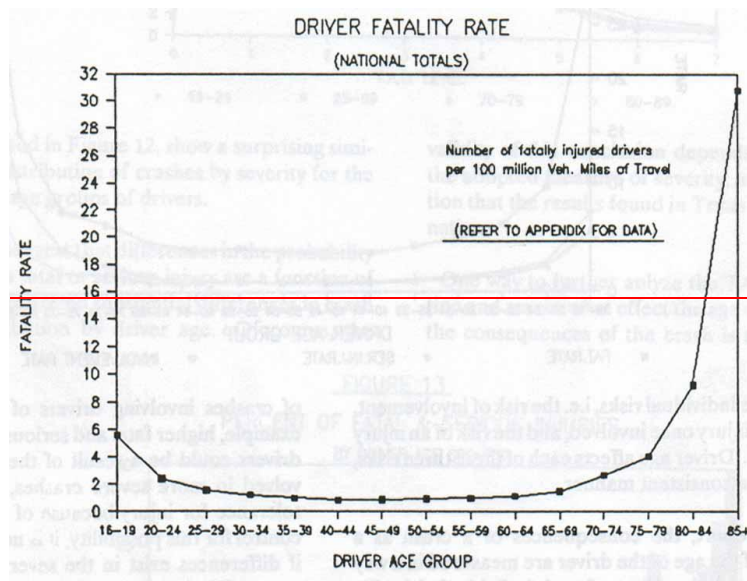
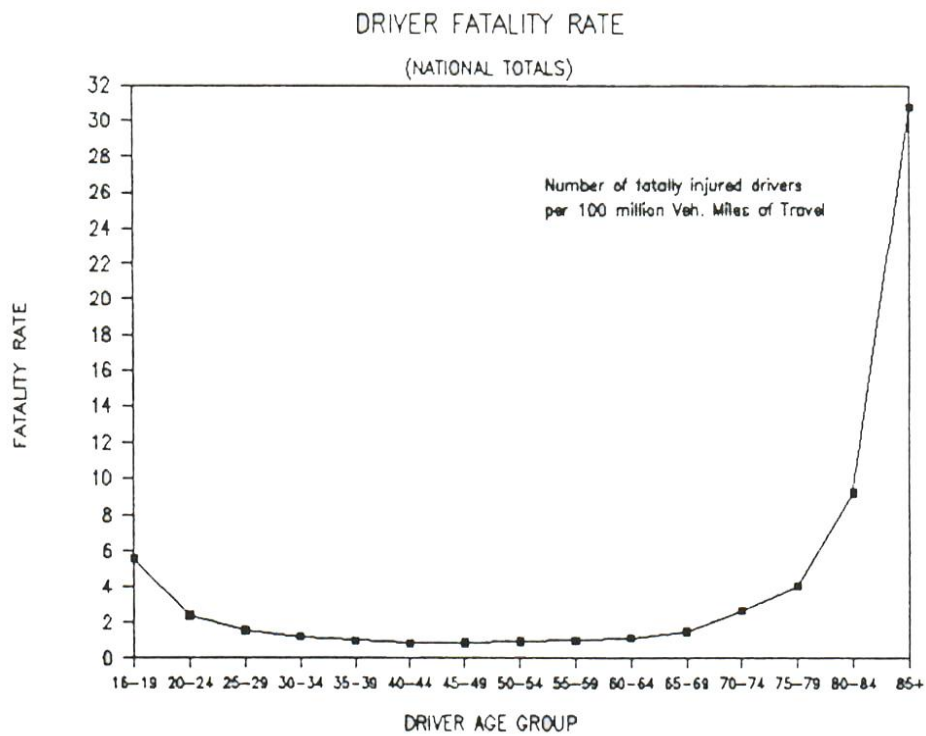
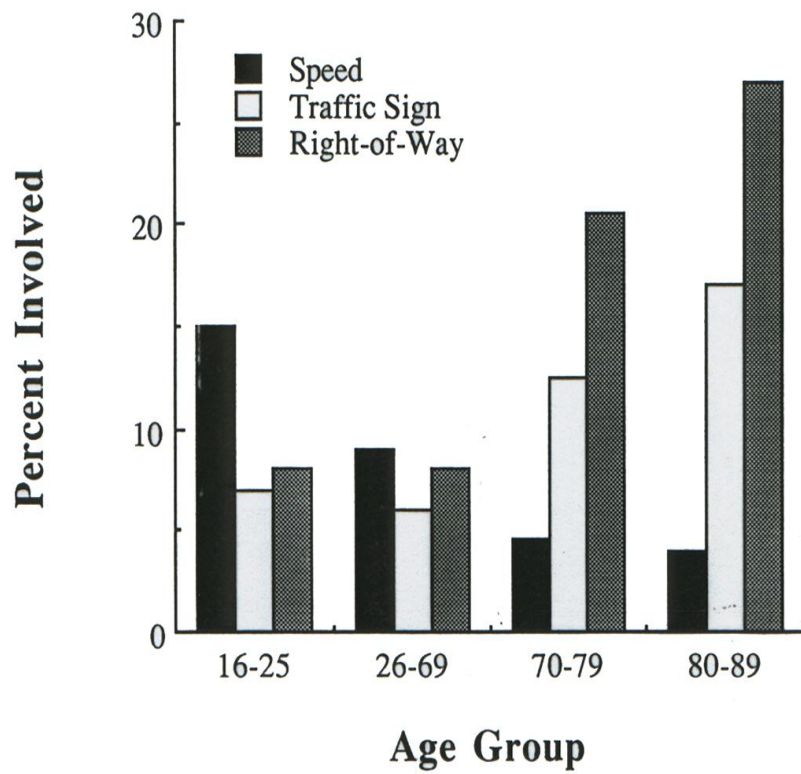


Figure 2. Once in a crash the driver has a much higher fatality rate as age increases (Cerrelli, 1989).

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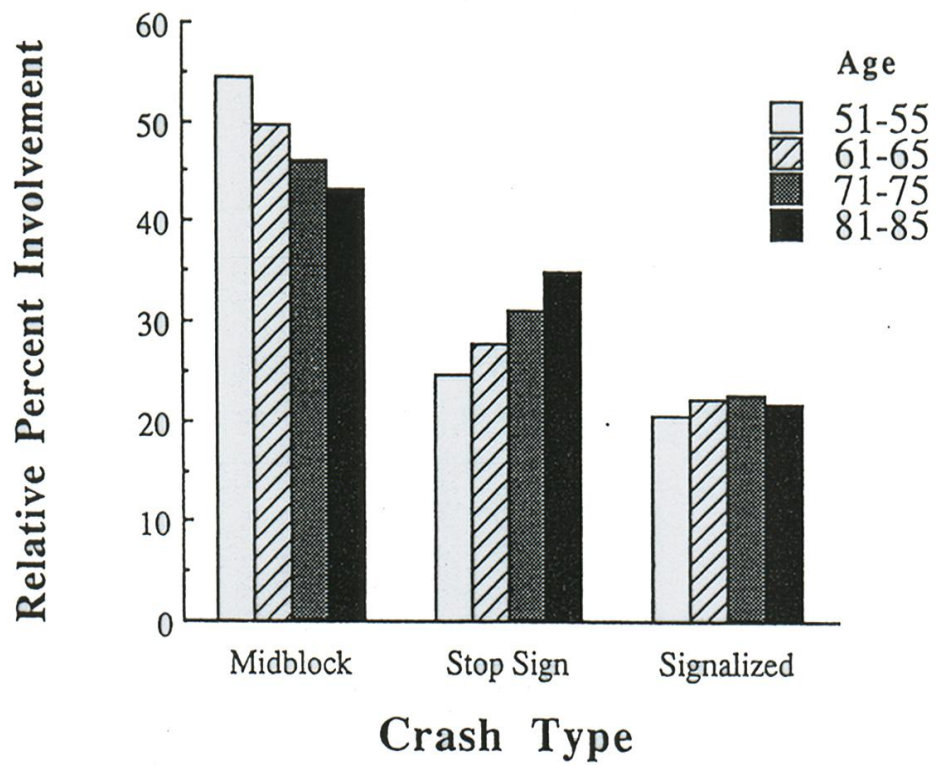
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A more detailed analysis of state and federal crash records appears to suggest that older drivers suffer from diminished functional vision and/or visual information processing. Cerrelli (1989) found that drivers over the age of 70 were more likely to be cited with traffic law violations coincident with a crash than younger drivers. This trend was exacerbated among drivers over 80 years of age. Although violations associated with excessive speed declined as a function of increasing adult age, traffic citations associated with visual information processing such as failure to yield the right of way and ignoring posted highway signs increased markedly among those over 70 years of age (see Figure 3). The percentage of crashes occurring at intersections also increases significantly with advancing age. Schieber (2000) analyzed crash data from the state of Pennsylvania and found that older driver over-involvement was particularly pronounced at intersections controlled by stop signs but not at intersections controlled by a traffic light (see Figure 4).



~~Insert~~ Figure 3. Crash involvement compared by type and age. (Cerelli, 1989.)

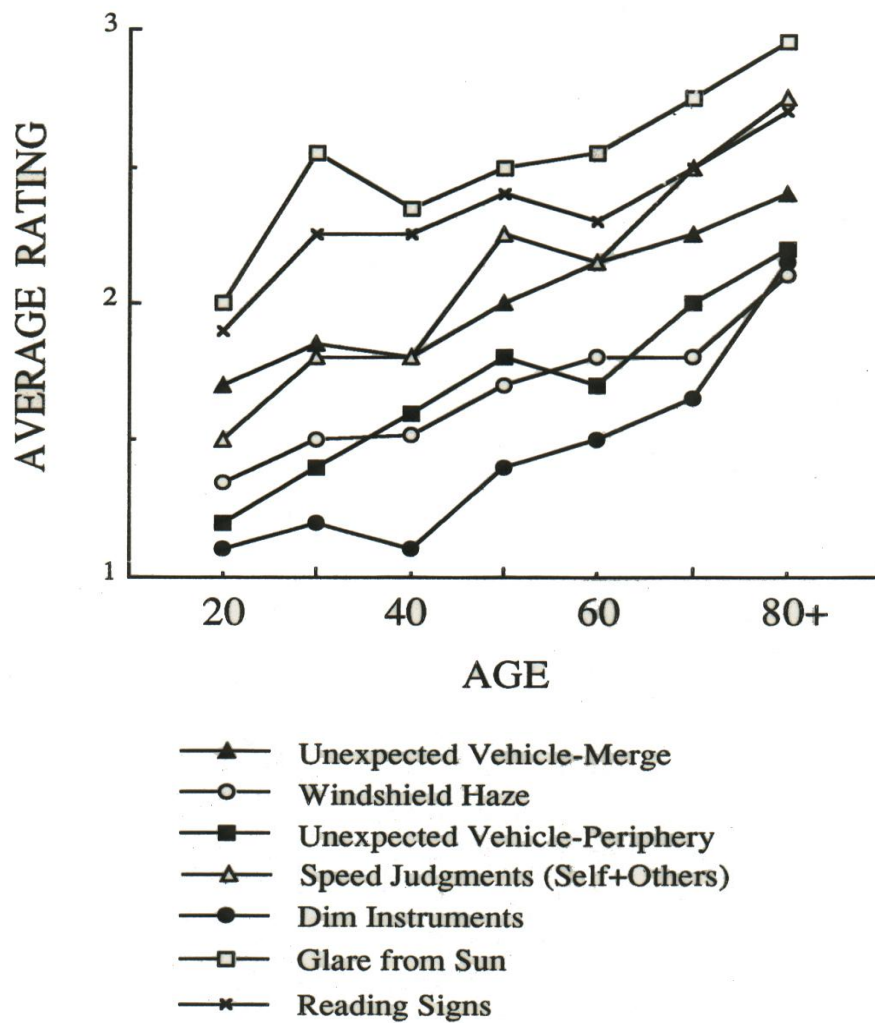
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~~Insert~~ Figure 4. Relative percent involvement three crash types as compared by age (Schieber, 2000.)

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Age-related changes in the number and type of traffic citations accompanying crashes as well as an increase in the relative involvement of crashes occurring at intersections strongly suggest that reduced visual function may contribute significantly to driving problems among the older population. It should not be surprising, therefore, that Kline, et al. (1992) found that self-reported visual problems associated with driving increased significantly among a large sample of older drivers. Visual functions that were found to represent significant problems for older drivers included: difficulty reading signs, instrument panels that were too dim, judging speed of self and others, glare and problems with situation awareness in the peripheral visual field (see Figure 5). A follow-up analysis of this data revealed that elevated self-reports of driving-related visual problems were significantly associated with age-related decreases in contrast sensitivity (Schieber, et al., 1992).



~~Insert~~ Figure 5. [Visual problems of the older adult \(Schieber et al. 1992.\)](#)

Basic Vision Function, Aging and Driving

The preceding analysis of crash records and self-report data strongly suggests that visual deficits contribute significantly to the problems experienced by older drivers. Indeed, several measures of basic visual function have been found to correlate significantly with automobile crashes in the aged population. These measures include: static visual acuity, dynamic visual acuity, contrast sensitivity and peripheral visual fields.

Static Acuity

In a driving situation you rely on your vision and its cooperation with a vast array of other perceptual processes (Owsley, et al., 1991). It has been well documented that visual acuity deteriorates with age (Shinar & Schieber, 1991; Schieber, 1992; Ball & Owsley, 1991; Pitts, 1982; Kline, et al., 1992; Danner, et al., 2001; Sekuler, et al., 2000; Schieber, 1994). It is also known that as luminance levels of the visual scene decrease, visual acuity is decreased. This is especially pronounced in the older populations (Sturr et al. 1990). However, numerous studies have found that age-related declines in visual acuity do not correlate significantly with crash rates (Owsley, et al., 1991) nor real-world driving performance (Carr, et al., 1992; Schlag, 1993; Schreuder, 1988). The few studies that have found a relationship between age-related declines in static acuity and increased crash risk have used enormously large sample sizes where even the smallest effects yield statistically significant outcomes (Burg, 1967; Henderson and Burg, 1974). However, even these studies have found that age-related changes in acuity can account for only 1-2 percent of the total variance in the crash records.

Dynamic Visual Acuity

Dynamic visual acuity (DVA) assesses the limits of spatial resolution for targets moving at relatively high angular velocities. Since this experiment deals with non-static vision and its relation to driving, it is important to discuss dynamic visual acuity in at least some detail because all experimental stimuli will be overlaid on a windshield through which a constantly moving environment will be viewed. It is known that complex driving environments require a large portion of available attention to be used for lateral motion sensing, depth scaling and DVA (Shinar & Schieber, 1991). Among older drivers, DVA has been shown to be more strongly correlated with crash history than static visual acuity (Burg, 1967; Henderson and Burg, 1974). Again, however, the strength of this relationship remains quite weak. Reanalysis of this data by Hills and Burg (1977) revealed that DVA scores could account for no more than 3-5 percent of the crash record variance.

Contrast Sensitivity

Contrast sensitivity is essentially a measure of the minimum amount of luminance contrast needed to discriminate visual form as a function of target size (specified in cycles per degree of visual angle). It is far more informative than static and dynamic visual acuity measures insofar as it assesses the visual system's sensitivity for targets of all sizes – not just the smallest possible size that one can discern. Some main points about contrast sensitivity that need to be realized for this study are that it tends to decrease for higher spatial frequencies (cycles per degree) as one ages (Owsley et al., 1983) and that it is also known to decline in low light conditions (Sloane et al., 1988). In addition, Crassini et al (1988) found that contrast sensitivity decreases as a target moves

further into the periphery, an effect that is especially pronounced in older individuals. Even though contrast sensitivity does play a roll in driving; one must consult a study by Owsley et al. (1995) that found that visual sensitivity to high contrast stimuli could only account for 36% of total stimulus localization performance. This explanatory value dropped to 13% when stimuli were presented against a distracting background. The findings from that study are basically saying that even though image discrimination does play a roll, there must be some other element involved because it did not account for all that much variability. Even with normal contrast sensitivity, approximately half of all older individuals will exhibit some difficulty in object location among a cluttered environment (Owsley et al. 1995). Furthermore, attempts to relate contrast sensitivity to driving history among older persons indicate that this measure of visual capacity accounts for only 1-3 percent of the crash variance (Brown, et al., 1993; Owsley, et al., 1991).

Peripheral Visual Field

Static visual field measurements document one's ability to detect briefly presented targets as a function of stimulus contrast and retinal eccentricity (i.e., angular distance from the fovea). Several studies have revealed that binocular field loss is associated with increased risk of an automobile crash (e.g., Johnson & Keltner, 1986). However, this relationship is not observed until massive loss of peripheral vision is encountered. Even under these extreme circumstances the strength of the statistical relationship between peripheral vision and automobile crashes remains relatively. That is, severe binocular peripheral field loss accounts for less than 5 percent of the crash variance (Owsley, et al., 1991).

Information Processing

The statistical relationship between aging, driving performance/crash risk and basic visual function (i.e., acuity, DVA, contrast sensitivity and peripheral fields) has been shown to be quite weak. None of these basic measures of visual status can account for more than 5 percent of the variation in the crash records of older drivers (Owsley, et al., 1991). Recently, however, a number of investigations have revealed that higher-order measures of visual information processing capacity can account for much greater proportions of the crash histories of older drivers. These important new developments are reviewed in the sections which follow.

Avolio et al. (1985) found that measures of visual selective attention were particularly strong predictors of “accident proneness” in drivers. This work replicated and extended previous studies of auditory selective attention (e.g., Kahneman et al. (1973)). Visual selective attention refers to one’s ability to focus upon task-relevant targets in the presence of numerous distracting stimuli. Avolio, et al. demonstrated that reductions in visual selective attention were associated with increased risk of automobile crashes. This finding is important in the context of the older driver since numerous investigators have demonstrated age-related decrements in visual attentional processes (e.g., Korteling, 1991).

It appears that as the visual environment becomes more complex; the human mind needs more attentional resources to cope with prevailing conditions. Unfortunately as a result of these resource demands, less attention is available to service other information processing requirements such as the detection of peripheral targets, etc. These deficiencies in the required amount of awareness are typically the result of a decreased

ability to integrate multiple aspects of attention. This inhibition of integration ability is related to increased accident rates (Parasuraman & Nestor, 1991). Attentional resources also seem to be dependent on age insofar as younger subjects are able to recruit more attention (Harms, 1998; Korteling, 1991; Parasuraman, et al.1989). This is most likely due to physiological changes such as the decreased firing rates of neurons in the brain due to the gradual loss of brain cells associated with aging (Korteling, 1990). Under ideal conditions where infinite time is allowed, individuals of all ages are able to perform reasonably well. Yet, in real world applications, individuals are given the same amount of time to process stimuli and this time is usually quite brief. Schieber and Benedetto (1999) showed in a simulator that a reduction in stimulus presentation times highly influenced peripheral target detection rates when compared by age. In addition, processing time requirements have been shown to increase in response to increased mental workload with the additional expenses of a decrease in a functional field of view (Miura, 1990). The elderly are the most affected by this because reaction times and information processing slow down with increasing age (Korteling, 1991). These findings suggest that information processing of targets in the peripheral field of vision may play an important role in mediating age-related changes in driving performance.

Several investigators have studied age-related changes in the “functional field of view” within the context of driving simulation scenarios. Szlyk et al. (1993) studied Atari driving simulator performance of stroke victims to show deficits or performance because of a loss of functional field of view. This correlation was chosen because a stroke victim’s functional field of view is very similar to an older subject’s natural aging. They found pronounced age effects in many of the variables measured including an increase in

virtual accidents, lane variances, etc. Others such as Walker et al (1992) have used simulator studies to deduce that the old subjects develop a decrease in functional field of view of the periphery under high attention conditions (central tracking task). Of all the studies relating visual information processing to driving behavior, the most promising measure to date is the *Useful Field of View* construct developed by Karlene Ball and colleagues (e.g., Sekuler & Ball, 1986; Owsley, C., Ball, K., Sloane, M., Roenker, D., Overlay, E., Graves, M., White, M. 1994; Owsley, Ball, & Keeton, D. 1995; Owsley, Ball, Sloane, Roenker, & Bruni, J. 1991; Ball & Owsley 1991, 1992).

Useful Field of View (UFOV)

UFOV is essentially the area in your visual field of view from which one can extract a useful amount of information during a single brief fixation (Sekuler & Ball, 1986; Sanders, 1970). The relative size of the UFOV is defined as the area of visual field in which a subject can localize 75% of peripheral targets consistently (Ball, et al. 1993). It can be large when driving demands are low, and small when workload demands are high as is proposed by Miura et al's (1998; 1999) *rubber band model* of attention. The significance of having a decreased UFOV is that one may not detect stimuli that are on the boundary of his or her periphery. One may "see" the stimulus but not be able to switch attention quickly enough to recognize its importance (Avolio, et al. 1985). The larger the UFOV is in size, the better the chance of a critical stimulus falling within that usable visual range. It has been demonstrated that as workload from driving complexity increases, the UFOV decreases and the amount of total information that can be obtained from any one look in that field of view also decreases (Miura, 1990). UFOV seems to decrease in direct proportion to scene complexity (Sanders, 1970). In addition Miura et al.

(1999) states that not only does the UFOV decrease with increased scene complexity, but reaction time also suffers especially when the stimuli are presented at increasing eccentricity in the periphery.

When angular distance to the target is taken into effect, visual attention must be shifted in order for the UFOV to acquire the area around the new target (Miura, et al., 1999). Attention reallocation is also faster when looking from long range to short range rather than the reverse as one might expect if attentional requirements were the same throughout the visual field (Miura, et al., 1999). To acquire the visual target in the distance after first looking at your dashboard requires much more effort. In order to cope with this increased attentional demand, information is processed from a narrower spatial area, the number of fixations increases, and the duration of fixations shorten. The result of this is deeper processing of information at the center of fixation due to an increased fixation rate.

It is proposed that as situations get more demanding, a subject attempts to process increasing amounts of information by scanning more rapidly and processing more deeply at each point (Miura, 1990). This seems to switch the attention of the driver from a more broad motion sensitive display to a deeper detail oriented display. As a result, reaction times are longer for the deeper fixations associated with greater distances because they ultimately raise the workload of the individual. This is good in that you attempt to become more aware of the surroundings when you really need it, but bad in that some people cannot operate on peripheral cues alone when the information is presented too rapidly or is very complex (such as while driving). This can be due to many reasons such as impairments in mental capacity, various eye conditions or especially decreased

processing speed and reaction times due to advanced age. One might try to focus on details that bring attention away from the periphery and miss cars approaching; or focus on periphery and miss details in the center such as taillights lighting up. In an emergency situation, a decreased UFOV may amplify the decreased awareness of the already taxed attention systems of the brain. This could in turn lead to an increase the likelihood of a pressured response which might result in an accident. The problem with UFOV in the older adult is not that they cannot "see" the information that is presented to them, but rather that the amount of information that can be processed within a UFOV becomes smaller (Sekuler, et al., 2000).

UFOV was first "coined" by Sanders (1970) and proposed to be broken down into three main categories: *stationary field*, *eye field*, and the *head field*. In the *stationary field* the subject uses only near peripheral vision (20° to 40° of visual angle) to sense the target stimulus. *Eye field* is when the stimulus is beyond the useful view of only near peripheral vision and eye movements need to be incorporated for its subsequent detection (40° to 90° of visual angle.) The final field entitled the *head field* is when the stimulus is beyond the useful range of eye movements and the head also needs to be repositioned to detect the stimulus presence (>90°.) Each field is defined as the maximum angle at which the visual task can still be performed efficiently using only the defined characteristics. As a result of more complex processes needed to be involved to compensate for increasingly disperse stimuli; there is an increase in reaction times for these stimuli. Sanders (1970) showed that the increase was only temporary at the beginning of each search and then got better as the stimuli were presented towards the center of the target viewing range. He

described this as a result of a changing of visual strategy with the best performance at the center of its intended range.

Retrospective UFOV and Driver Crash Risk

UFOV measurement started gaining validity as a crash predictor when Owsley et al. (1991) showed that a decreased UFOV could account for 13% of at fault crash variance among older drivers. To arrive at this impressive conclusion, they used driver self reports and public records and correlated past driving histories with visual problems and other impairments (cognitive status, eye health). Different visual impairments by themselves offered no significant relationship to crash rates. However, a significant relationship between impairments of UFOV and crash histories was observed. When intersection crashes were compared to the new UFOV concept, 29% of that variance could now be explained (Owsley, et al. 1991). It was then reasoned that the intensive visual information processing demands at intersections caused larger decreases in UFOV than normal straight line driving.

After this association had been made, Ball and colleagues devised a computer controlled UFOV measurement apparatus that assessed a subject's information processing speed, attention dividing capacity, and ability to selectively attend to a stimulus. Each of these subtasks is given a value and an overall *loss* in UFOV is calculated in the range between 0 and 90%. A zero meaning no deficit in UFOV and a 90 meaning a 90% decrease in UFOV. For the information processing part of the test, the stimuli ranged in durations from 40 to 240 ms with a mask presented after each stimulus trial. The *divided attention task* involved a central target (such a car silhouette) and

peripheral targets arranged in a grid work pattern. The subject has to identify the central target while at the same time localizing a peripheral target. A good visual demonstration of what this setup looks like would be the stimuli used by Seiple et al (1996) when they observed that UFOV is noticeably decreased as a function of age. Their stimuli array is shown here in figure 6 and explained in the next paragraph.

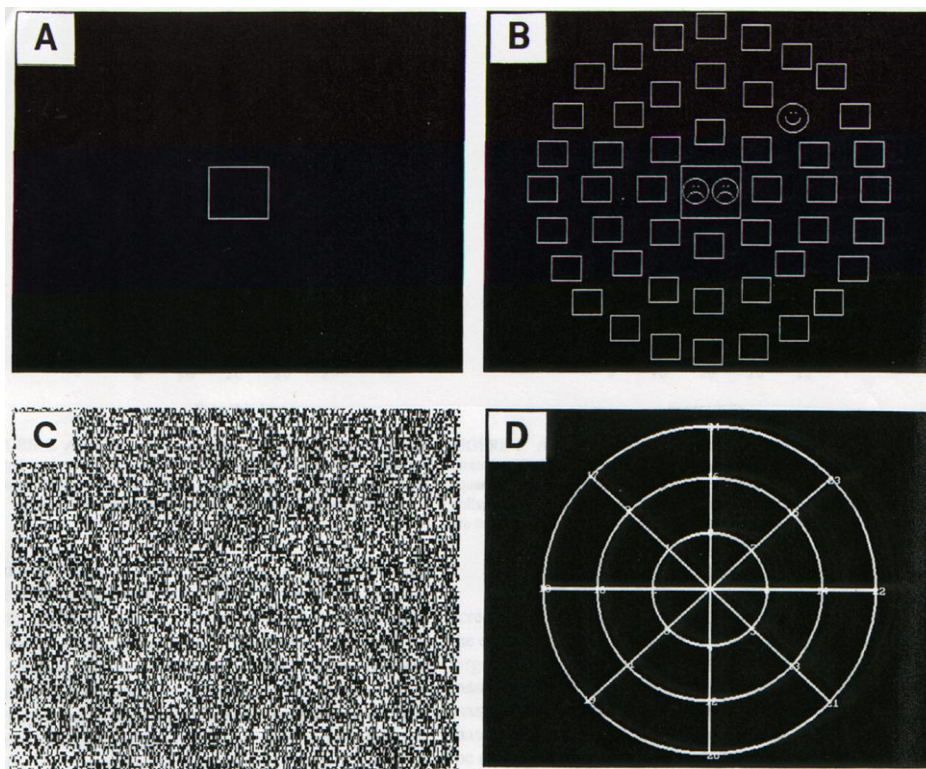


Figure 6. A-The area of central fixation. B- The stimulus display with peripheral target locations. C- Mask. D- Response display for localization of peripheral target. (Seiple et al. 1996).

In the Seiple et al. (1996) study they used a central stimulus of “happy” or “sad” faces within a central box perimeter (picture A). The subject was instructed to focus on that central stimulus and determine the disposition of the faces. Simultaneously with the

central target presentation was the presentation of a peripheral target (e.g., a happy face) somewhere within the range of possible peripheral target locations (picture B.) After the trial stimuli were flashed on the screen for the prescribed period of time, a masking screen would be presented which was designed to limit the processing of visual stimuli (picture C). The final screen in this protocol involved the localization of the peripheral stimulus by pointing to the corresponding area that they believed to have seen the stimuli (picture D.) To ensure that the peripheral target was indeed seen by peripheral vision and not foveated upon, they did not use trials in which the subject could not state the central stimulus correctly.

Ball et al. (1993) added strength to the previous findings by repeating the original 1991 correlations with a larger group of subjects. The crash data in this study spanned a five year period in time. They defined a cutoff point (pass/fail) of a 40% reduction in UFOV. With respect to predicting “at risk” drivers, they found that this point yielded a sensitivity of 89% and a specificity of 81% (Ball et al. 1993 as cited in Schieber, 1994). This means that if a subject had previous crash experience, then they had an 89% chance of failing the 40% UFOV cutoff, and the subjects without crash experience had an 81% chance to pass the test given this cutoff point (Schieber, 1994).

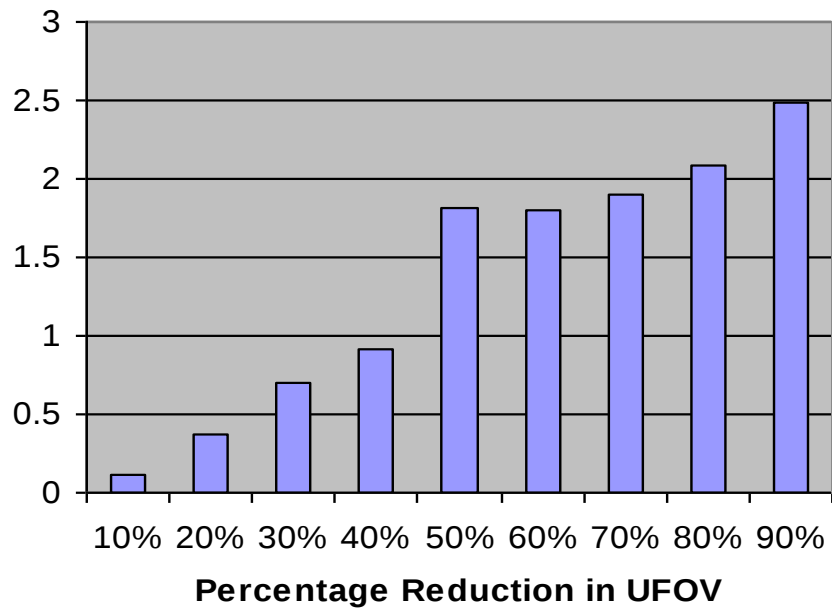
In summary, it can be concluded that UFOV is *strongly* related to crash risk in older adults particularly at intersections. One important note is that UFOV decreases can be seen in ALL individuals given very demanding conditions, but for younger adults it does not drop that much. In older adults it drops steadily with age and acutely with increasing stimulus demands. This is especially evident when one looks at high attention specific areas like intersections such as was discussed earlier. To this point in the review

of the literature, it has been seen that UFOV is related to driving and that the influence varied by age. But it has not been shown to have any *prospective* predictive power.

UFOV as a Predictor of Future Crash Involvement

There are many prospective experiments that have attempted the task of pinpointing the cause of a crash so that a general rule can be developed to prevent that specific type of incident in the future. One such experiment was a continuation of previous work by Owsley, et al. (1994) that shows elderly adults can have as much as a 5 times greater risk for a crash in the next three years, given that they have a 40% or greater reduction in their UFOV (Fig. 7). UFOV was also narrowed down to be very dependent on peripheral vision and visual search. This is an important idea when you consider that there is evidence that any novice can be taught to increase the span of peripheral vision used when driving (Summala, et al., 1996) which would indirectly increase the efficiency of visual search. This means that not only is UFOV a possible predictor of future crashes, but it may also be possible to train an individual to increase his or her UFOV which could decrease a person's likelihood of a crash.

**Mean Crash Frequency as a
Function of UFOV Reduction**



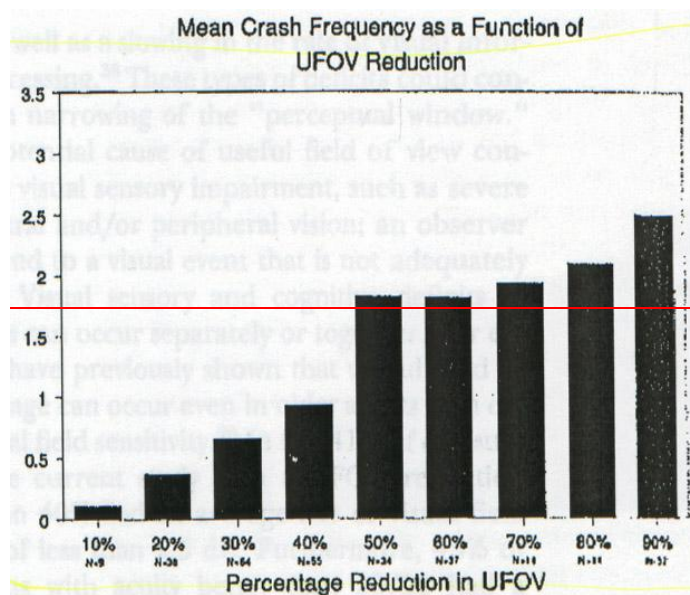


Figure 7. Mean crash frequency as a function of UFOV reduction for all drivers in the authors' sample. Note that the larger reductions in UFOV correspond with the larger frequency of crashes as compared to an individual with no reduced UFOV (Ball et al., 1993).

Why UFOV Works

UFOV has been shown to be a reliable predictor of crashes, but one must address why it can be so accurate. To date there are two main theories about why UFOV changes: the first is tunnel vision due to attention shifts and the second is a decrease due to age related slowing of visual processing.

The first theory of UFOV decrease is said to be because of tunnel vision caused by the onset of a more complex scene. This is to say that as the complexity of visual scenes increase, more information is presented to be processed. As a result, a person starts to process *smaller areas* of information (containing the same amount of visual stimuli of a previously larger area) and pays more attention to what the scene is directly in front of them. As the scene complexity rises, the area that the driver looks at to derive

information gets smaller and smaller as more attention is needed to process the greater amounts of visual information presented. In this theory, UFOV decrease is hypothesized to be caused by the shift of their attention from the periphery to the central viewing range as a coping strategy. While decreases in UFOV due to scene complexity have been shown to be true (Miura, 1990; Ball & Owsley, 1992) for a driving situation, it is still unclear why.

Most studies to date seem to rely on a lot of speculation and *post hoc* analysis because it is difficult to directly measure “amounts of attention needed”. The problem may not even be due to attention however. There are a few empirical studies such as Seiple et al. (1996) that show stimulus eccentricity is not a factor between ages if ample time is allowed to process information. Schieber & Benedetto (1998) found significant age differences could be obtained by changing *only* the presentation rate without any variation the stimulus complexity. These studies illustrate the second theoretical mechanism that may mediate the decrease of UFOV for a complex stimulus: namely, age related slowing of mental processing. The decrease of UFOV in this respect is caused by the decrease in the ability to process stimuli efficiently.

The Future of UFOV Measurement

Although the research to date has been pretty extensive, there really has not been any attempt to bring UFOV measurement to the real world. One would think this would be the next logical step since UFOV is geared toward predicting driving behavior. It would be very valuable to modify the UFOV paradigm so that it can be measured at the same time as a person is driving. In fact, this is the purpose of the proposed experiment. Simulator studies are important, but they will never be a complete replacement for the

real thing. Data accrued while actually driving has the potential to better diagnose problems much more accurately than the current computer based tests and protocols. A means to measure UFOV in a real time driving situation has the potential to bridge the gap between the world and the simulator with unlimited possibilities. This is the future of UFOV research.

Measurement of UFOV in a car would yield very ecologically valid results as one would no longer have to mimic the different distracters that one comes into contact with on an everyday basis. Studies can be performed on a much wider range of stimulus situations due to the decreased need for specialized equipment and computer programs in simulators. To date, there really is no method available to measure UFOV outside of a simulator, which severely hinders its validity. A general method that can be developed to work in a vehicle would potentially be more available for experiments because it could be more broadly adopted by those with limited lab space. In addition to the increased availability, increased stimulus combinations and decreased need for specialized equipment, there is also the fact that a UFOV measured in an actual application scenario should have a much higher validity than a simulator study that is just “guessed” to also be applicable to the real world.

Rogé et al. (2003) did an excellent study using a simulator that found age effects with UFOV are present in driving situations. Even more important was the finding that aging drivers seem to see a decrease in their UFOV during long or monotonous tasks, which lends validity to the *tunnel vision phenomenon*. In this study they used 19 subjects ranging in age from 18 to 51 years that each had normal or corrected to normal

sight. The stimulus display in their laboratory driving simulator had a screen that covered 45° of horizontal and 25° of visual field (see Fig 8).

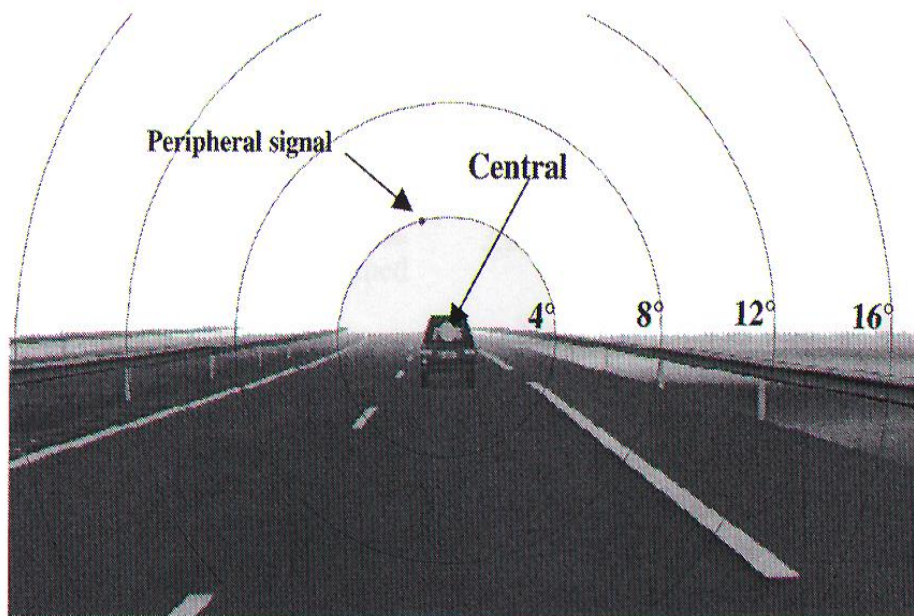


Figure 8. The simulator presentation viewing screen. (Rogé et al., 2003)

The subject was instructed to “follow” a virtual test car and maintain a following distance of approximately 36 meters while keeping focus on a colored circle that appeared in the rear window of the lead car about every 3 seconds (for a duration of 133 ms). The central task was to detect a darkening color change in the lead car stimulus. When a darkening was seen, the subject had to quickly press a joystick button on the right of the steering wheel. During the central target darkening, a second dot (0.2 deg) was presented for 100 ms at a random location in the peripheral field of view. If the subject detected the secondary visual stimulus on the windshield, another button on the

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left side of the steering wheel was pressed. A total of 120 stimulus pairings were shown in a one hour experiment.

Current UFOV Study

The Rogé et al. protocol described above was adapted to a real-world experiment by using the same principles, but an actual car instead of a simulator. There was a lead-car/following-car scenario in which the test participant in the following-car had to detect and identify a central stimulus presented in the rear window of the lead-car. This stimulus could have been either a “minus” or “plus” (see appendix A-1). In addition to the central stimulus presentation, there may or may not have been a peripheral stimuli synchronously flashed on the inside windshield of the subject’s vehicle. This flash was generated via a carefully crafted computer controlled light array mounted on the dashboard (see appendix B-1). The central task was the first to be distinguished verbally to assure main fixation is on central stimuli. After the central stimulus was identified the subject was instructed to localize the peripheral target via a simple left/right vocal announcement if one was present. Any trials in which the subject could not correctly identify the central target were excluded from final analysis because of the possibility of direct fixation of peripheral targets. We originally modified the Rogé, et al. task to include multiple peripheral stimulus durations in an attempt to even further isolate the role of information processing speed with age differences but this did not produce reliable detection rates at the shorter stimuli durations. Because of this we eventually chose to use a single duration for peripheral stimulus presentation as it provided the best spread in detection rates in pilot studies. The “simulated” part of the Rogé et al. experiment was an actual driving task in this study. This occurred on a nearly straight

section of highway between Vermillion, South Dakota and Yankton, South Dakota (SD Hwy 50).

Pre-Experimental Hypotheses

Main Hypothesis: Eccentricity X Age interaction. Older drivers should have decreased detection accuracy and hit rates when compared to the younger subjects as the peripheral stimuli move away from the fovea (8, 16 and 24 degrees, respectively.) This slope difference of peripheral detections between young and old should become increasingly separated as one attends towards the outer peripheral targets. This prediction is related to Miura's tunnel vision phenomenon where older subjects need to recruit more attention to focus on the central task and as a result "pull" attention from the periphery inward as more is needed. This theory is also supported by the Rogé et al. experiment which demonstrated this trend for long or monotonous driving tasks (following a lead vehicle).

Methods

Participants

The participants of this study were recruited from the Vermillion, South Dakota area. The younger subjects were recruited from various undergraduate classes through use of the University of South Dakota's Experimentrix Online subject recruitment system. There were a total of 19 young subjects (14 male, 5 female) recruited who ranged in age from 18 to 35 (average was 23 years of age). Data from all 19 of the younger subjects were used in this experiment. There were 19 older subjects (14 male, 5 female) who were recruited from area community service organizations (e.g., Lions Club, Rotary International, etc). They ranged in age from 65 to 82 (average was 73 years of age). The data from one of the older male participants was excluded from final analysis because he failed to detect *any* of the peripheral targets. All subjects held a current drivers license and had previous driving experience. All data was acquired between July 1st and Sept 23rd 2004.

Apparatus

There were two vehicles used in this study. The first was an instrumented research vehicle (Toyota Avalon, see appendix A-3) owned by the University of South Dakota. This vehicle had been outfitted with a panel of 24 laser diodes which were focused to project small red dots on carefully cut paper disks that were glued onto the windshield (see Appendix B-1). This approach was chosen because the paper “diffuser” gives the signal a much greater intensity than the mere “reflection” off the windshield and also prevents potentially harmful specular reflections.

All laser lights were configured to shine on the windshield in a grid pattern of 6 columns by 4 rows (see Figure 9, or Appendix B-1). Using this arrangement we could also analyze right verses left visual field detections by breaking down the 6 columns into 3 on each side. A layer of black felt was placed overtop the laser assembly to minimize possible reflections on the interior windshield. In addition to this preventative step, the exposed casing tops of each laser diode were darkened with a permanent black ink marker.

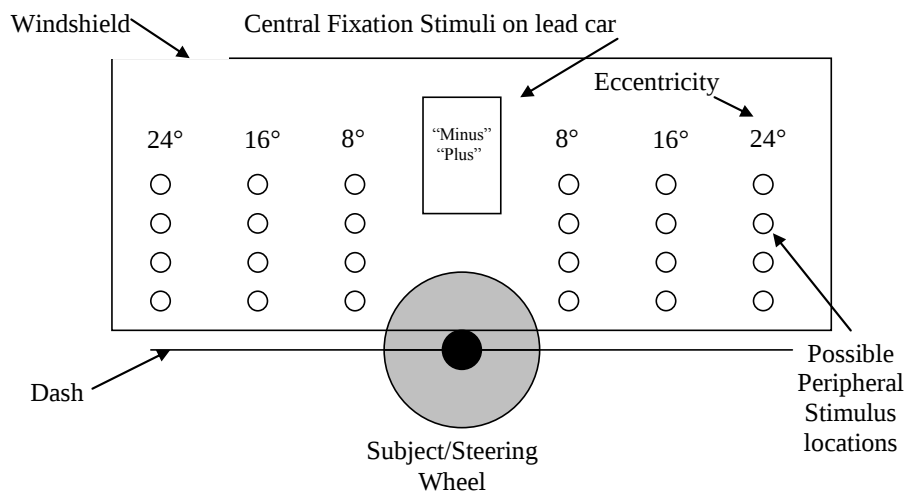


Figure 9. The stimuli arrangement in the test car. (Consult Appendix B-1 for picture of actual setup used)

Originally it was desired to have separation of 10 degrees of visual angle between rows of projected dots. Smaller separations were ultimately used as original specs were not feasible in the limited space above the car's dash. A balancing act was done to assure the paper disks acted as diffusers yet were still small enough to be barely noticeable and not hinder/distract the user. [Harms et al. \(2003\) found promising results using LEDs presented on a non-modified windshield which means the effect should be even more](#)

pronounced in this study given the increased salience of our stimuli. All Laser Diodes and control software (for lead vehicle) in this experiment were run directly off a computer at the rear of the Toyota Avalon. Power was supplied directly from the main car battery routed through a DC-to-AC converter. Laser reflections were a nominal 20,000 cd/m².

The second experimental vehicle (1990 Chevy Suburban) acted as the lead car and had a central stimulus presentation module mounted on a removable bar attached to the vehicle's slide hitch (see appendix A-2). The use of the slide hitch allowed the central stimuli to be physically removed and stored indoors between test trials which helped to assure all subjects saw the same stimuli and not a one that was weather degraded throughout the experiment. This central stimulus consisted of a series of 18 LEDs arranged into a "plus" but had the vertical and horizontal components wired as separate circuits. This allowed presentation of a "minus" or "plus" symbol using the same LEDs by turning on only one set or both sets of lights (see appendix A-1). These symbols were controlled via a laptop computer in the lead vehicle that was regulated by a radio modem held in constant communication with the Avalon test car's control computer. In order for a trial to occur, the modems in each vehicle had to send confirmation signals to each other assuring synchronization. The computer controlling both the central and peripheral stimuli was run under MS-DOS in order to achieve real-time process administration with millisecond precision. Accuracy of timing measurements used for stimulus display rates and synchronization was assessed by running hundreds of virtual trials and observing the latency averages. Data collection was accomplished by having an experimenter ride in the rear of the Avalon and manually key in verbal responses made by the subject.

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Procedure

Attaining Human Subjects Approval from the University of South Dakota was the first precursor to this project. All subjects were provided with a description of the study and told of the requirements that would be placed upon them. They were informed that they may quit the study at anytime if they felt uncomfortable. All were then required to read and sign an informed consent form outlining all aspects of the experiment before they would be allowed to participate. After permission was granted we started with some general information gathering including subject's age and dominant eye assessment. Next a series of 6 vision screening tests were given to evaluate the eyes independently and binocularly at both near and far distances. All eye measurements were done using a Bausch and Lomb Orthorater. For this study, a minimum far visual acuity of 20/40 was chosen because this value is the cutoff for driver licensing in many states including South Dakota. Lastly, a WAIS Information subtest was completed before heading into the field to begin the study.

Upon leaving the lab, the subject was driven to Yankton to where he or she would begin the experiment. Each experiment was slated to start approximately 1 ½ hours before sundown. This exact time was determined daily using a online sunset calculator provided by a government internet site listed in the references for this paper (NOAA). This evening time slot was chosen because of problems encountered in pilot studies to get interpretable results earlier in the day. It was originally planned to assess UFOV during "high noon" sunlight conditions, but the threshold contrast between the sky and the stimuli was simply too low. Following some exploratory efforts, it was eventually found that the two hour time slot prior to sunset resulted in a reasonably high contrast ratio

between stimuli and sky while at the same time still not allowing stimuli to be seen too easily. When changing from noon to evening we then had a new problem with sun glare. To alleviate this problem, we decided to run all subjects while driving in an easterly direction (*away* from the setting sun).

Upon arrival in Yankton, the subject was allowed to get into the driver's seat of the test car and adjust the seat, mirrors, etc. until they were comfortable. While the subject was making adjustments the computer in the lead car was turned on and the power to the main computer in the Avalon was turned on. We then had to determine which three rows of stimuli to use in order to accommodate the seated eye height of each observer. The goal was to vertically align the peripheral targets as close to center of vision as possible because not everyone will look through the window at the same height. Due to this problem, an extra row of lights was added to the apparatus to allow a 2 inch adjustment tradeoff for different heights of participants.

Finally after the computers were online, static test trials were demonstrated to the subject. Approximately 30 practice trials were administered until the subject felt confident with the task (or detection rate = 100% at 10°, whichever came first). At this point we would leave Yankton for the return trip to Vermillion. Subjects were instructed to follow approximately 7-10 car lengths behind the lead vehicle. Experimental trials were always begun at the same location near the city limits of Yankton. Speed was regulated via by lead vehicle and set the same for all participants with cruise control ($\approx$ 62 mph). Trials would proceed until about a mile past the overpass on Hwy 50 through Vermillion going east.

All participants~~still~~ received 36 possible targets at 18 different stimulus placements (2 targets at each location with either top or bottom row not used depending on viewing height) (See figure 9 in previous section). *It is important to note that actual placement of the peripheral stimuli were not at the preferred locations due to window curvature problems, mirror placement, and the driver's side frame pillar.* Actual placements of the two innermost columns were each 9.246° from center. The second set of columns were each 18.635° from center. The outside columns were different between sides due to windshield limitations but ranged from 28.657° for the entire RIGHT outside column to 27.096° (bottom) and 26.565° (top) for the LEFT outside column. Appendix A-3 contains a picture of what the actual setup looked like from the subject's perspective. All angular measurements are derived given an average viewing distance (from subjects head to center of peripheral targets) of approximately 21 ½ inches.

Stimulus presentations were timed and synchronized using the control computer from the Toyota Avalon. An important thing to note is that a Central Stimulus was presented on EVERY trial, whereas a peripheral target was only presented 50% of the time. This was done to guard against subject guessing. When a peripheral target was actually present, it was presented simultaneously with the Central target but with a lesser duration. Central Stimuli were presented for 500 msec while peripheral targets were presented for only 250msec. The reasoning for a decreased duration of the peripheral stimulus is that it was desired to have peripheral detections that were solely due to peripheral vision. The onset of the central stimuli would draw the immediate attention but the peripheral target was displayed at a rate too fast to allow the subject to foveate twice during the same trial, so only ambient peripheral vision could account for detection.

The 250 msec stimuli duration is well under the 300 msec average fixation duration typically needed to gather information from a single glance (Irwin, 1996). That alone should be adequate without taking into account an additional 30 msec (Irwin, 1996) needed for the saccade between fixations. This should further rule out the possibility of a dual fixation detection of a peripheral target and lend validity to our methods. Hypothetically there is one possible problem with this scenario which would be the subject scanning the windshield first and then looked at the central stimulus since it could be possible to foviate twice in that scenario. This should however produce a very high error rate in the identification of the central target if it is even identified at all. The rationale for this is because if one were to use 300 ms to acquire the peripheral target, then another 30ms for a saccade, it would leave only 170 ms to see find the central and interpret it. One might see that there was “something” there but most likely not have enough time to process what it was. Also, this alternative means of detection would only work assuming the subject was looking directly at the correct peripheral target when the trial started, as any search time used would dramatically decrease the amount of time that could be used in the processing of the second fixation.

Actual data accrued from this experiment was manually keyed into a data file by an observing experimenter in the rear seat of the Avalon. Subjects were instructed to verbally state the type of central stimulus (“plus” or “minus”, see appendix A-1) and whether a peripheral target was present. If a peripheral target was present they had to further differentiate to which side: left or right. “Left” side in this case would be defined as any peripheral location to the left of center and the “right” as anything to the right of center. There were 72 trials occurring at an average rate of four per minute but randomly

distributed within a time frame (max 19 second delay to min 10 second delay). Thirty-six of the trials presented no peripheral stimulus on the windshield. The other 36 trials presented a peripheral stimulus used to assess the UFOV. Seventy-two trials were chosen because it allowed us to present a peripheral stimulus twice at each of the 18 possible light positions while also presenting an equal amount of non trials to test for false positives or “guesses.” The subject viewed these trials on a carefully mapped section of highway between Vermillion and Yankton (Hwy 50). A tablet was used to record trials where a possible keying error might have occurred so that correction could be made after the experiment was over.

Upon arrival in Vermillion the experiment was complete and results recorded. Subject data (number, sex, visual acuity, etc) was then put in spread sheet form and results (hits, misses, errors) from each subject were tallied and recorded. Analyses were done using a combination of SPSS and Microsoft Excel.

Results

The experimental data were analyzed using a mixed model design with between groups of 2(age) by 2(gender) and within subjects of 3(eccentricities) by 2 (sides). We also analyzed some pre-experimental measurements to assess the possible covariate effects of visual acuity, cognitive status, and dominant eye. It was determined that none of the se covariates held any significance in this experiment. In all analyses, all false responses (incorrect identification of central stimulus, or a complete trial miss) were excluded from the “detections”. “Detections” are being defined as **only** when the subject identified **BOTH** central **AND** peripheral targets correctly. The detection rates were used as the dependent measure.

Out of the total (n=38) people who participated (19 old and 19 young), only 37 ultimately provided usable data (Old N=18: mean age =72.9, Young N=19: mean age =23.1). One older male subject was excluded because he did not detect any peripheral stimulus which leads to many questions in interpretation. Our decision to drop this subject as an outlier should yield more conservative results in the final analysis as a subject with no detections would have greatly strengthened our hypothesis of fewer detections with age. In the final analyses, there ended up being 5 females in each age group but one more young male than old male (14 versus 13).

Initial analyses found that there were significant differences in overall total detection rates collapsed across all groups ($F[1,33]=145.90, P<.05$). Significance was also found when the data was compared by age ($F[1,33]=14.807, P<.001$) and gender ($F[1,33]=6.959, P<.013$). Overall detection rates dropped from 71% correct detections per subject in the younger age group (mean =23 detections) to 36% correct detections in the older group (mean =11.6 detections). It should be noted that there was no observed age by gender interaction in overall detection rates ($F[1,33]=1.016, P>.05$).

The eccentricity effect was significant overall as a group ($F[2,66]=89.4, P<.000$) and when decomposed into each of the different levels. It was found that 8° was significantly different from 16° ($F[1,33]=55.354, P<.000$) and also from 24° ($F[1,33]=73.222, P<.000$). It was also found that 16° was significantly different from 24° ($F[1,33]=21.865, P<.000$). It should be noted that there was *no significance of an eccentricity interaction with **age or gender***. The overall drop by eccentricity is depicted by Figure 10.

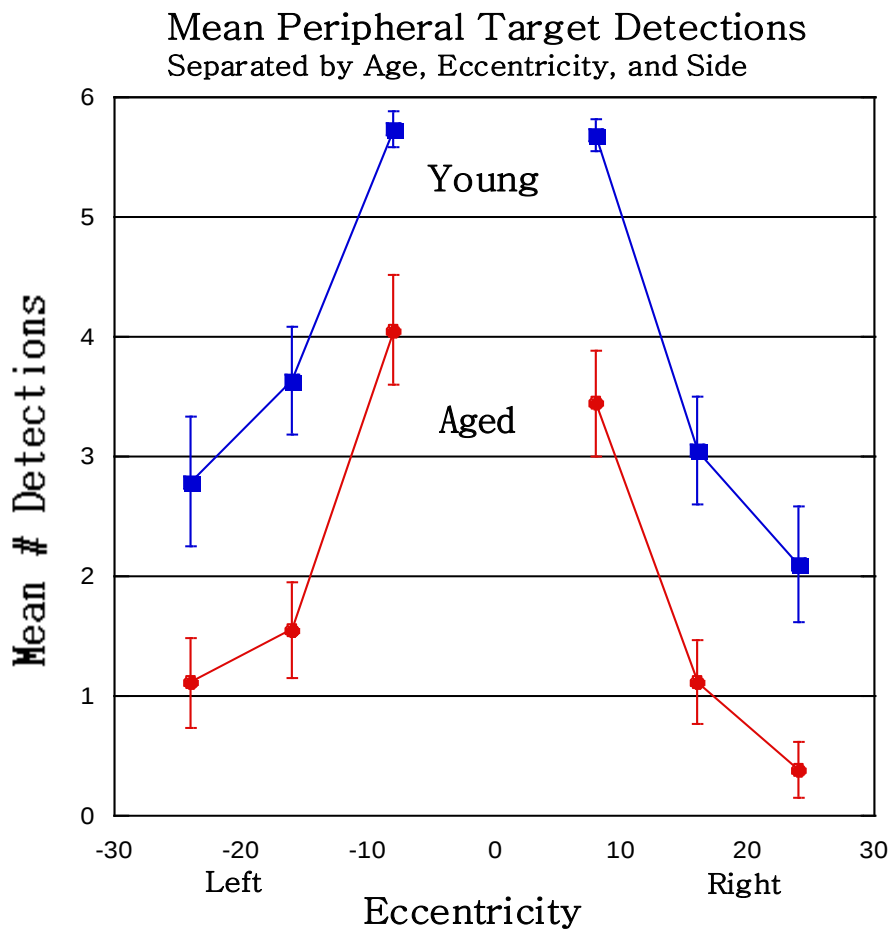


Figure 10. Peripheral detection rates broken down by age, eccentricity and side. (Error bars depicted are derived from the square root of the standard deviation at each level divided by the square root of N for the group at that level)

A significant difference was also found between the total number of peripheral targets detected on the right (mean = 7.97) versus left (mean = 9.51) ($F[1,33]=5.355$, $P<.027$). It was observed that direction held significance in its interaction with gender

($F[1,33]=4.4142$, $P<.043$). It should be noted that the *age X direction* interaction *did not* elicit any significance ($F[1,36]=.477$, $P>.05$).

Mean hit rate differences between gender and side are shown in figure 11. Males as a whole tended to do much better on the left side (59.7% correct; mean =10.74) than the right side (48.1% correct; mean = 8.66), whereas females tended to retain a constant detection rate across sides (34.4% left (mean = 6.2) versus 33.9 % right (mean = 6.1)).

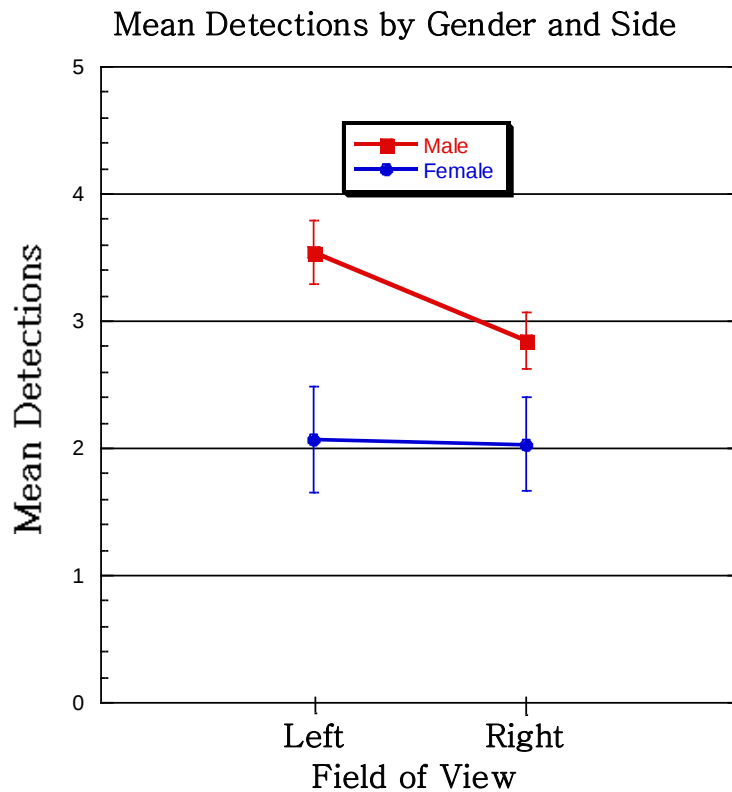


Figure 11. Overall detection rate drops by gender and side.

Discussion

Eccentricity was not significant when compared by gender or age. This means that even though the data sets possess different values showing obvious age differences from a group level, the rates follow the same quadratic equation for each age group. This is saying that there are simply fewer overall detections with age but these missed detections are spread just as equally across eccentricities in the young group as the old (see figure 10). ***Age related declines in detection rates were NOT eccentricity dependent.*** Age can be concluded to be definitive factor, but only with detection rates as statistically significant *Age X Eccentricity* interaction drops were not observed.

We did not explicitly predict differences by side although they were observed. One possible reason for these findings might be that we observed a “road side eye” phenomenon and people just simply placed more attention to where normal traffic and hazards were expected. One could test the “roadside eye” hypothesis by repeating this study where the norm is driving on the other side of the road. If it truly is a factor, then the results should be reversed from what was observed in this study. Another possible explanation might be that the left side was just easier to see because we had to place the 24-degree stimuli closer to center on the left side than the right. This was done due to the curvature of the window and side pillar placement which decreased suitable positions for optimal stimuli placement (can be seen in Appendix B-1).

As far as the gender interaction with side is concerned, it could be an artifact resulting from only having 10 females total in the experiment. This was significant although it had a very small critical *F ($F=4.4$). The fact that it was observed at similar levels at both age groups suggests that it probably is just an accurate representation of the

natural population that we didn't expect. All subjects *exhibited the same statistical drop* from left to right even taking into effect that older males and females scored much lower overall than the younger males (19% higher) and females (8% higher). This suggests that whatever caused this phenomenon to occur, it was equally sensitive to all ages and genders and should not bias our analyses any.

The results of our study lead to the conclusion that peripheral vision or one's UFOV undergoes a "DC shift" with age rather than a true perceptual narrowing as proposed by Miura's tunnel vision theory. Instead of a gradual slope for the young with a dramatic tapering for the old, we observed similar slopes for both age groups except the overall performance of the old was an octave lower. This finding is not a complete surprise as it is consistent with other studies (Seiple et al., 1996; Scialfa et al., 1987; Sekuler et al., 2000) which also concluded that age related detections were not eccentricity dependent. It is a surprise however as Miura (1998, 1999) strongly supports tunnel vision with age and Rogé et al. (2003) supports tunnel vision with monotonous driving tasks. Our task and the Rogé task were very similar which should have elicited the same results. Both were "monotonous" lead car following tasks with a central discrimination and peripheral detection.

One possible explanation to this discrepancy is that we ACTUALLY drove whereas simulators were used in the Rogé and Miura studies. In a simulator one would not expect to have the mental taxation that would be expected while actually driving because one would know there really are no "risks" when "virtually" driving. In everyday driving however, there are potential hazards everywhere and the brain has to fully recognize them in addition to the task at hand. Actual driving might also prove to be less

monotonous than a simulator study due to the constantly changing environment, which also might have influenced the outcome. It should be noted that in a more recent study published by Rogé et al. (2004) they still support the tunnel vision explanation for *speed related* detection differences, but in overall detections they show no age-eccentricity interaction which again supports what we have concluded.

Gender does seem to play a roll but only when you consider detection rates interacting with direction observed. It was noticed that the trends observed were the same between age/gender groups so it may be accurate, or at least did not confound our results with one group being able to perform better do to some unseen variable.

It appears that there are other factors at work in determining age related detection losses as all vision covariates we assessed held no significance. This is not unexpected as peripheral vision should not rely on visual acuity and the foveal systems, but more on the indirect “sensing” systems of the brain which cannot be measured with visual acuity charts, etc. If it is not vision related, then it must be cognition related. Many possibilities have been speculated about in previous portions of this report, but mainly we believe it to be the *inability to efficiently process information presented* rather than just “not seeing it” like the tunnel vision theory suggests. The eye is able to “see” the peripheral stimuli equally well for all ages, but since more processing time is needed to actually recognize what was seen, it becomes easier to loose that recognition response in the other data streaming in through the visual channel.

Driving is a HEAVILY vision dominated activity with a constant stream of ever-changing stimuli being presented. It would be easy to overload the visual channel if one needed lots of time to process that incoming data. This is what may be happening when

an older individual is driving. It is known that brain functioning lessens with age resulting in slower reaction and processing times. It is possible that the influx of visual data is acting as a perceptual mask that is limiting the already taxed processing in the brain. The result would be an overall decrease in detections of peripheral stimuli. Since the visual systems themselves are not to blame, the statistical performance at each eccentricity would remain constant for all age groups with just the number of overall detections dropping as more processing time is needed. The time needed should directly correspond with a subject's age. This indeed seems to be what is seen in this experiment.

These conclusions lend support to the *General Interference* model of age related losses which predict that detections should only decrease as a function of the processing ability of the brain. This model would also be consistent with the lack of significance in the age/eccentricity interaction that should have been significant had age related “tunnel vision” been observed.

A possible follow up experiment might be to test the interior portion of this UFOV paradigm (i.e. ± 8 degrees) to see if the downward shift we observed in older drivers is seen throughout the visual range (figure 12) or if foveal vision ages differently than peripheral vision (figure 13). Will there continue to be a “DC Shift” all the way to the center of foveal vision, or will central vision demonstrate the age slope originally expected to be seen at the extended peripheries? Is it possible that the effect we expected to see might still be observed at eccentricities closer to center? Will age-related visual decrements seen in foveal vision compound with inefficient processing abilities?

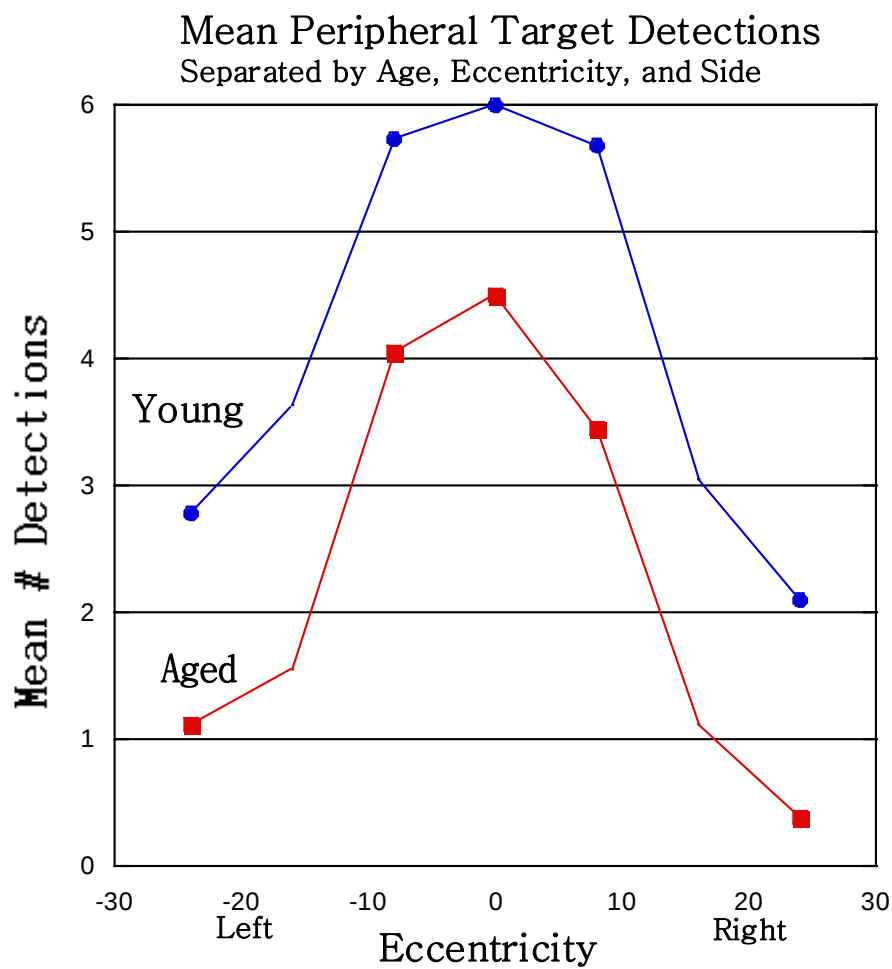


Figure 12. Possible outcome if DC shift remains constant throughout full visual field.

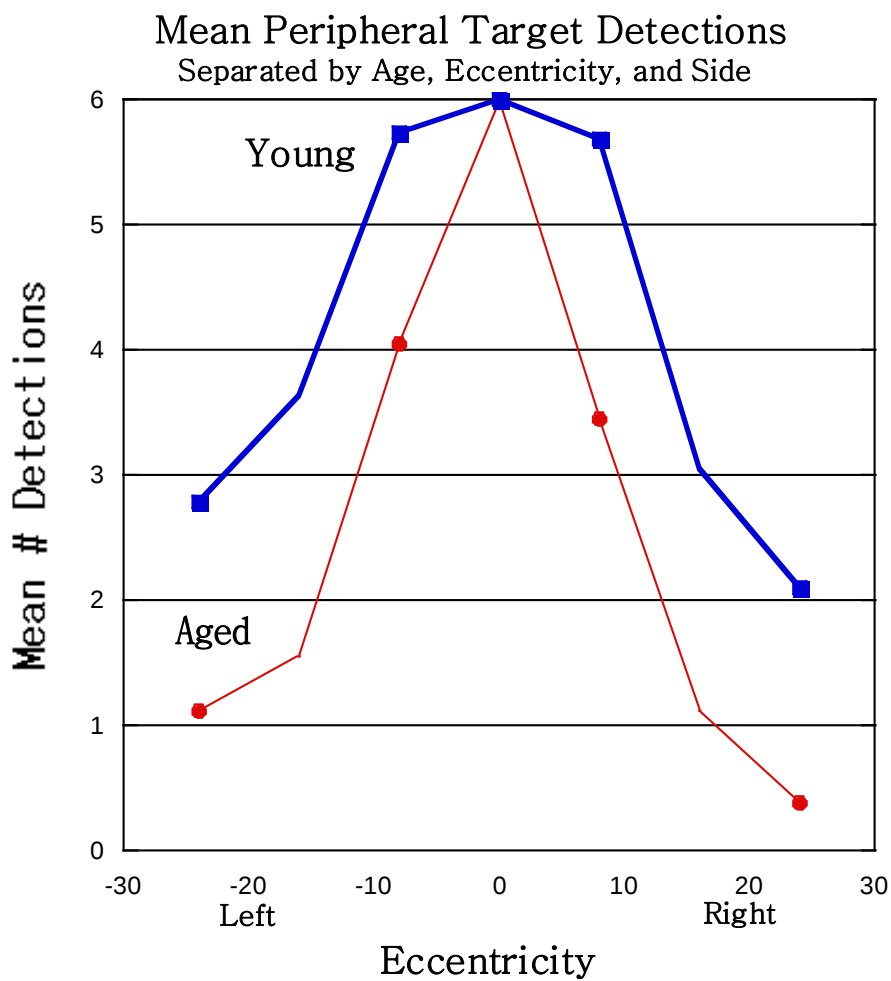


Figure 13. Possible outcome if DC shift does not remain constant throughout full visual field — and foveal vision begin helping with detections.

These differences in the *ambient peripheral* versus *focal* visual systems would be revealed by an interior visual field test. Will the aging visual systems affect detection rates as soon as you enter the regions where focal acuity begins to be used? An interior visual (from 8° to 0°) experiment would show if maybe there still is some validity to the “tunnel vision” phenomenon observed by others but it just gets phased-out and replaced by general interference the further out one goes into the periphery. Our experiment was specifically designed to assess detection rates *beyond* the outer limits of central vision and relies on peripheral vision only. Because of this we can only speculate about the results that would result in the center field of view

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Appendix A-1

Pictures of central stimulus possibilities presented at Rear of Lead Car. (Taken from driver's seat of Avalon)



“minus”



“plus”

Appendix A-2
Central Stimulus Board arrangement



Central Stimulus Mounting



Central Stimulus LED arrangement Close-up

Appendix A-3
Toyota Avalon (Subject driven car)



Toyota Avalon Test vehicle



View from Drivers Seat of Avalon.

Appendix B-1



Laser projection unit affixed to the dashboard of Avalon test car.



Picture of all possible stimuli positions on windshield.