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Effects of age -related changes in visual function on visual attention and simulated driving.

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EFFECTS OF AGE-RELATED CHANGES IN VISUAL FUNCTION ON VISUAL ATTENTION AND SIMULATED DRIVING

by

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A DISSERTATION

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ABSTRACT OF DISSERTATION
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The relationships between clinical and psychophysical measures of visual function, cognitive function, and driving performance were evaluated in young and older adults (18-30 years old and <65 years old, respectively). Performance was specifically examined between older adults with and without deficiencies on the Useful Field of View (UFOV®) test of visual processing speed and transient visual attention. Relationships between age-related changes in magnocellular visual function, transient visual attention, and sustained visual attention were the primary focus. Older adults with poor UFOV® consistently performed worse than other participants on several visual and cognitive tests. Visual memory and visual search were particularly affected in older adults with poor transient visual attention compared to other participants. Sustained visual attention performance was not specifically affected in participants with poor transient visual attention. Results suggest that measures of visual search and visual memory are highly dependent on intact transient attention mechanisms for rapid changes in fixation to capture large quantities of visual information in short time periods. This attentional capability is not necessary for sustained attention mechanisms whose primary function is to maintain fixation.

Additionally, analyses of visual function measures revealed that older adults with poor transient visual attention also performed significantly worse on magnocellular-sensitive measures compared to younger adults and older adults without transient attention deficiencies. To the contrary, older adults, regardless of visual attention, performed worse than younger adults on nonmagnocellular visual measures. This evidence supports existing literature showing that optimal transient visual attention performance is strongly dependent on information processed through the magnocellular visual pathway.

Driving simulation results also support these findings. A visual search task was given to participants while performing the driving task. Participants were to locate and identify various central and peripheral targets while driving along a predetermined route. Older adults with poor transient visual attention were less successful in locating central objects and took significantly longer to find them compared with other participants. These results further demonstrate that magnocellular visual function and intact transient visual attention mechanisms are necessary for optimal cognitive performance in both the laboratory and real world settings. Limitations of this study and future investigative directions are also discussed.

DEDICATION

This dissertation is dedicated to my loving wife Nikki. She provided me with unwavering support and confidence that allowed me to make it through the most difficult times. Thank you for always being there for me.

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LIST OF ABBREVIATIONS

BVRT	Benton Visual Retention Test
RCFT	Rey Complex Figure Test
RST	Road Sign Test
UFOV	Useful Field of View
M Pathway	Magnocellular Pathway
LGN	Lateral Geniculate Nucleus
V1	Visual Cortex Area 1
V2	Visual Cortex Area 2
MT	Medial Temporal Cortex
ERP	Event-related Potentials
MMSE	Mini Mental Screening Exam
ETDRS	Epidemiological Test
logMAR	Log Minimal Angle Resolved
PASAT	Paced Auditory Serial Addition Test
FDT	Frequency Doubling Technology
SWAP	Short Wavelength Automated Perimetry
LCD	Liquid Crystal Display
MCOMP	Magnocellular Composite
PCOMP	Parvocellular Composite

INTRODUCTION

Changes in cognitive abilities are prevalent in nonpathological aging, leading to declines in quality of life and increased likelihood of personal injury due to falls or other kinds of accidents (Rowe & Kahn, 1987). The issue of age-related cognitive decline is also a community concern. Age-related cognitive impairments are related to increased crash risk that can directly affect the health and safety of others in the community (Owsley, McGwin, & Ball, 1998). Understanding the origin and nature of age-related cognitive impairments and how they affect behavior could lead to new methods of treatment or cognitive training interventions to protect and extend the quality of life of older adults.

Salthouse (1996) suggested that much of the age-related deficits in cognitive function can be attributed to a general slowing in the processing speed of the aging nervous system. Reduced processing speeds could ultimately lead to impairments in cognitive functions such as memory (Luscz, Bryan, & Kent, 1997; Salthouse & Meinz, 1995), reasoning (Salthouse, 1985), and attention (Ball, Roenker, & Bruni, 1990). Ball and coworkers (1990) assessed speed of processing using a specific measure of the Useful Field of View, the UFOV® test. The UFOV® is defined as the spatial area within which visual information can be made available for cognitive processing in a single fixation. The UFOV® test assesses a person's ability to identify and localize supra-threshold targets simultaneously in both the center and periphery of the visual field. Adding secondary central tasks, embedding peripheral targets among visual distracters, and decreasing stimulus duration reduce the size of the UFOV® (Ball, Beard, Roenker, Miller, & Griggs, 1988). However, increasing the difficulty of the UFOV® tasks has a significantly more profound impact on the performance of older individuals. Ball et al. (1990) suggesteded age-related UFOV® impairments are primarily the result of reduced speed of visual processing, which also impair the ability to divide attention and the ability to selectively attend to a target in clutter.

In addition to decreasing cognitive functions, decreasing visual function is also a common occurrence among older adults (Owsley & Sloane, 1990; Tielsch, Sommer, Witt, Katz, & Royall, 1990; West et al., 1997). Even in the absence of ocular pathology, visual function is frequently compromised in older age. Much of age-related impairment in visual performance can be attributed to changes in the optics of the eye. However, a significant portion of visual deficits experienced by older adults may be neural in nature (Fozard, 1990; Owsley & Sloane, 1990; Spear, 1993). Neural deficits may underlie several age-related visual changes, including declines in visual acuity, contrast sensitivity, motion detection, and light sensitivity (Ball & Sekuler, 1986; Gittings & Fozard, 1986; Jackson, Owsley, Cordle, & Finley, 1998; Kim & Mayer, 1994; Owsley & Burton, 1991; Trick & Silverman, 1991). The neural mechanisms behind these age-related visual deficits are not fully understood. However, the physiological and behavioral evidence suggests that photoreceptor and ganglion cell impairment, transmission disruption, or loss may be responsible for some of the age-related vision deficits seen in humans (Curcio, Millican, Allen, & Kalina, 1993; Justino, Kergoat, & Kergoat, 2001; Schefrin, Shinomori, &Werner, 1995; Spear, 1993).

It has been suggested that the age-related declines in visual and cognitive functions previously described above are related (Baltes & Lindenberger, 1997; Lindenberger & Baltes, 1994; Salthouse, Hancock, Meinz, & Hambrick, 1996; S.B. Steinman, Steinman, Trick, & Lehmkuhle, 1994; Stevens, Cruz, Marks, & Lakatos, 1998). Salthouse et al. (1996) demonstrated that visual acuity was a significant factor along with perceptual speed in accounting for a large portion of age-related variance in measures of cognitive performance, including working memory, associative learning, and concept identification. Baltes and Lindenberger using the Berlin Aging Study database reported strong correlations between visual and auditory acuity and cognitive performance across all ages (25-103 years). Surprisingly, Lindenberger and Baltes reported that sensory measures were even better predictors of cognitive functioning in old age than years of education. The high degree of correlation between changes in age-related sensory and cognitive function has generated a great deal of discussion about the nature of the relationship between sensory and cognitive aging. One prominent hypothesis explaining these findings suggested that age-related changes in sensory and cognitive systems are the result of a single "common cause." Salthouse et al. (1996) has proposed that this common cause may be the slowing of neural processing speed mentioned earlier.

Others have suggested that declines in specific forms of cognitive function, such as visual attention, may be more directly affected by age-related changes in specific areas of the visual system. S.B. Steinman et al. (1994) presented evidence suggesting that age-related changes in the magnocellular visual pathway leads to poor cognitive performance in transient visual attention and motion detection tasks. S.B. Steinman et al. (1994) also stated that the UFOV® test is a measure of transient visual attention, therefore suggesting that it too may be influenced by age-related changes in the magnocellular pathway. The current study examined the relationship between age-related changes in visual and cognitive performance with a specific focus on examining the relationship between visual function tests sensitive to the magnocellular visual pathway and visual attention performance using the UFOV® test as the primary measure of visual attention (Ball, Owsley, Sloane, Roenker, & Bruni, 1993).

An additional aim of this study was to determine the effect of age-related changes in both vision and visual attention on real world behavioral tasks. Age-related changes to visual attention (UFOV®) have been linked to problems with activities of daily living, specifically driving (Ball et al., 1993; Owsley, Ball, Sloane, Roenker, & Bruni, 1991). Therefore, this study will determine whether visual measures sensitive to the magnocellular pathway are directly related to driving performance measured with the University of Alabama at Birmingham (UAB) Driving Simulator.

The specific aims of this study were to (a) evaluate the relationships between multiple measures of visual function, cognitive performance, and simulated driving performance in participants with and without known impairments in visual attention and processing speed, and (b) assess whether magnocellular-specific visual function contributes predominantly to performance on the UFOV® test of processing speed and visual attention.

Background and Significance

Visual Attention

In the real world, the visual system is continuously faced with numerous complex visual stimuli. To make purposeful interactions within our environment, it is necessary to prioritize the visual scene in order to devote sensory and cognitive resources to those stimuli of greatest relevance to behavior (Desimone & Duncan, 1995; Neisser, 1967). Neural attention mechanisms select which visual stimuli to expend sensory and cognitive processing resources and which visual stimuli to ignore. From a neural perspective, attention enhances the response properties of the neurons responsible for encoding and processing sensory information within the spatial or temporal range of the "attended" targets (Desimone, 1998). The process of enhancing the detection and processing of information in specified areas leads directly to reduced or ignored sensory information in nonattended areas (Sengpiel & Hubener, 1999).

There are two driving forces that control visual attention. Visual attention can be either cognitively driven (top-down control) or stimulus driven (bottom-up control) (Nakayama & Mackeben, 1989; S.B. Steinman & Steinman, 1998). Together these two visual attention mechanisms ensure that the visual system is always prepared to respond to changes in the visual environment both purposefully and efficiently. Consciously controlled visual attention (top-down control), also referred to as voluntary, sustained, or selective visual attention, in layman's terms is defined as "paying attention" to particular visual objects (S.B. Steinman & Steinman, 1998). Voluntary or sustained visual attention is cortically controlled from higher cognitive centers upon lower sensory-motor systems, hence the term top-down. Nakayama and Mackeben provided an effective example of a sustained visual attention in action. In a visual search task, participants were given a visual cue to direct their gaze toward the general area where the visual search target would appear. After repeated trials with the cue and the target presented at the same location, the cue was removed from further trials. In the absence of the cue, participants voluntarily directed their gaze to the area previously indicated by the visual cue. Visual attention in this case was voluntarily focused on the area previously associated with the visual cue and target. This shift in attention was initiated based on the past experience that the target always appears in the same location, not by the appearance of the visual cue. Past experiences induced learning mechanisms that directed the current attention behavior of the participants (top-down) rather than participants responding directly to the presence of a visual stimulus (bottom-up).

As opposed to sustained visual attention, transient visual attention is stimulus driven (bottom-up) and not voluntarily controlled (Mackeben & Nakayama, 1993; Nakayama & Mackeben, 1989; S.B. Steinman & Steinman, 1998; Yantis & Jonidas, 1984). This form of visual attention is quick to engage at the detection of a novel stimulus. Transient visual attention is independent of conscious, cognitive thought. As in Nakayama and Mackeben, the time to respond to a visual cue is essentially unchanged regardless of whether there is previous knowledge of the cue location. The independence of transient visual attention from conscious control suggests that the activation of transient visual attention is a lower order visual mechanism and more primitive and reflexive in nature than sustained visual attention. In this respect, transient visual attention is considered driven by bottom-up processing. It is believed that transient visual attention can be fully activated in as short as 50 ms, but is short lived and typically disengages after about 250 ms in favor of sustained visual attention mechanisms (B.A. Steinman, Steinman, & Lehmkuhle, 1995; S.B. Steinman & Steinman, 1998; Warner, Juola, & Koshino, 1990). Conversely, sustained visual attention is slow to activate, taking at least 500 ms to respond. Although, once activated, sustained visual attention can remain engaged indefinitely as long as concentration is maintained (Mackeben & Nakayama, 1993; S.B. Steinman & Steinman, 1998).

Magnocellular and Parvocellular Visual Pathways

Transient and sustained visual attention mechanisms compliment the anatomical and physiological evidence of the parallel structure of the neural visual pathways leading from retina to cortex. The retina consists of photoreceptors that capture light energy from the environment and convert that energy to neural signals. Neural signals are then transferred to retinal ganglion cells to be sent initially to the lateral geniculate nucleus of the thalamus and the superior colliculus and then on to higher brain centers for cortical processing and perception. At the earliest stages of the visual pathway, visual information is processed primarily through two anatomically distinct retinal ganglion cell pathways referred to as the magnocellular (M-pathway) and the parvocellular pathway (P-pathway). These pathways differ in their anatomical structure, neural geography, and response properties (Lehmkuhle, 1995; Lennie, 1980; Livingstone & Hubel, 1987, 1988).

The M and P pathways differ physically and functionally in several ways. The M-pathway retinal ganglion cells have larger cell bodies with more diffuse dendritic arborization and thickly myelinated axons. In contrast, the P pathway consists of retinal ganglion cells with smaller cell bodies with more restricted dendritic fields and thinly myelinated axons. The distribution of these two ganglion cell types across the retina also differs. M-pathway ganglion cells are evenly distributed throughout the retina, while P-pathway ganglion cells are densely packed in the fovea and parafoveal regions with few to none present in the peripheral retina. P-pathway ganglion cells far outnumber M-pathway ganglion cells, accounting for approximately 90% of all retinal ganglion cells. The ratio of ganglion cell types is proportional to the types of photoreceptors providing the visual information, which is evident in the function these two cell types serve (Lehmkuhle, 1995). Axons from magnocellular and parvocellular retinal ganglion cells terminate at the dorsal lateral geniculate nucleus (LGN) of the thalamus. The LGN is anatomically divided into 6 layers. Axons of magnocellular ganglion cells only synapse in the two ventral layers of the LGN, and parvocellular ganglion cells terminate in the remaining four dorsal LGN layers. Neurons in the LGN share the same cellular, anatomical, and physiological properties of the retinal ganglion cells that innervate them. Both magnocellular and parvocellular LGN neurons terminate in the visual cortex where they are further segregated into different cortical areas.

The M and P pathways largely project to different cortical areas for high level processing. In area one (V1) of the occipital lobe of the cortex, the M pathway remains unchanged, whereas the P pathway splits into two separate branches before proceeding to visual area two (V2). From V1, the M pathway projects to the medial temporal (MT) cortex for motion information processing (Newsome, Wurtz, Dursteler, & Mikami, 1985) and ultimately terminates in the posterior parietal lobe (Hubel & Wiesel, 1972). The P pathway ultimately projects to the inferior temporal cortex (DeYoe & Van Essen, 1988; Lennie, 1980; Livingstone & Hubel, 1988; Merigan & Maunsell, 1993; Van Essen, 1979). However, pathway convergence has also been noted throughout numerous levels of the visual cortex (Felleman, Burkhalter, &Van Essen, 1997; Ferrera, Nealey, & Maunsell, 1992; Sawatari & Callaway, 1996) suggesting that the M and P pathways are not exclusively segregated and that communication between the visual pathways occur.

Each of the two visual pathways can also be differentiated by their functional characteristics: color discrimination, spatial resolution, temporal sensitivity, motion sensitivity, and contrast sensitivity. Receptive fields of the photoreceptors that project to retinal ganglion cells in the M pathway are activated by all wavelengths of light. Being sensitive to all wavelengths of light, the M pathway is indiscriminant and insensitive to color information, making this visual pathway effectively "color blind." Conversely, the receptive fields of retinal ganglion cells in the P pathway receive input from wavelength sensitive cones, making the P pathway capable of color discrimination. The sizes of the respective receptive fields of these two types of ganglion cells determine the spatial resolution capable of each pathway. Magnocellular ganglion cells receive inputs from relatively large receptive field centers compared with parvocellular ganglion cells. The increased receptive field center size gives the M pathway a much lower spatial resolution, whereas smaller receptive fields give the P pathway much higher spatial resolution. The disparity in receptive field size is consistent throughout the visual field from the fovea to the periphery. The overall response properties of these two systems also vary. Because M pathway axons are thickly myelinated, conduction velocities are significantly faster than thinly myelinated P pathway neurons. This characteristic of the M pathway makes the pathway uniquely sensitive to high temporal frequency stimuli and motion. Last, the M pathway is most sensitive to lower luminance contrasts, whereas the P pathway is relatively insensitive at levels of low contrast but becomes progressively more sensitive as luminance contrast exceeds 10-15% (Livingstone & Hubel, 1988; S.B. Steinman & Steinman, 1998).

The characteristics of these two systems and the cortical locations to which they project define their role in the visual system. The M pathway is often referred to as the "transient" or the "where" visual pathway because it has the ability to detect form and motion across the entire visual field. Magnocellular cells respond transiently to the onset and offset of visual stimuli to allow the M pathway to detect small changes in form and motion, quickly providing a general location map of all objects in the visual field. The P pathway is considered the "sustained" or the "what" pathway because parvocellular neurons continuously provide fine spatial resolution and wavelength information to aid in identification of visual objects (S.B. Steinman & Steinman, 1998).

Visual Pathways and Transient Visual Attention

Based on the characteristics of the magnocellular and parvocellular visual pathways, it has been proposed that the information provided via the magnocellular visual pathway might be more heavily relied upon by the transient mechanism of visual attention and that parvocellular information is preferentially depended upon to drive the sustained mechanism of visual attention. A series of experiments by B.A. Steinman, Steinman, and Lehmkuhle (1996) suggested that information provided through the magnocellular visual pathway contributes predominantly to performance on transient visual attention tasks. In these experiments, B.A. Steinman et al. (1996) used the line-motion illusion (Hikosaka, Miyauchi, & Shimojo, 1993; B.A. Steinman, et al., 1995) as the measure of transient visual attention.

The line-motion illusion is simply the illusion of motion in a visual scene where none exists. This line-motion illusion can be induced by asking participants to fixate on a central target followed by the presentation of a visual cue at some other location in the visual field. Following the visual cue, a horizontal line is shown next to or adjacent to the visual cue. Although the line in reality is instantaneously displayed onto the screen, the perception by the observer is that the line appears as if it were being drawn onto the screen beginning at one end of the line and being drawn to completion (Figure 1). The line-motion illusion consistently starts nearest the visual cue and rapidly grows in the opposite direction.

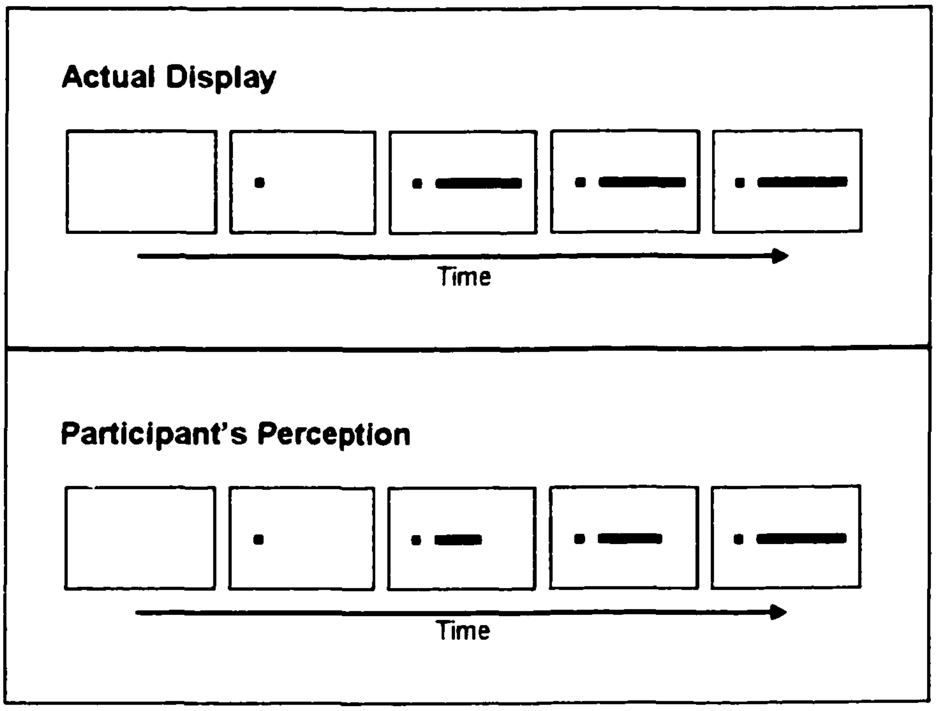

Figure 1. Line-motion illusion.

One hypothesized attentional mechanism suggested that neural information from the attended locations is processed more rapidly than stimuli in outlying, unattended areas (Hikosaka et al., 1993; Stelmach & Herdman, 1991). This would in effect hypothesize that perception of the line nearest to the attended location would occur before perception of the line further away from the attended location. The delay in the perception of the line would give the illusion that the line was being progressively drawn onto the scene. Hikosaka et al. tested this hypothesis by demonstrating that two simultaneously presented stimuli could appear asynchronous if one of the two targets were cued by a brief visual stimulus before the presentation of the two stimuli. In this experiment, the addition of the cue near one of the target stimuli enhanced the processing of visual information in the nearby region. To counter the illusion of asynchrony, the visual stimulus furthest away from the cue was presented earlier. In order to achieve perceived synchrony between the cued target and the noncued target, the visual stimulus furthest away from the cue had to be presented almost 100 ms earlier. Presenting two visual cues, one red and one green, and informing the participant to attend to one cue or the other altered the original transient visual attention task into a sustained attention task.

Prior to the trial, the participant was instructed to attend to the green cue. The rest of the experiment proceeded as in the previous experiment. In both the transient and the sustained visual attention conditions, participants observed the line-motion illusion. Therefore both sustained (top-down) and transient (bottom-up) attention mechanisms alter perception through accelerating early visual processing. However, when the transient and sustained attention systems were placed in competition with one another, transient visual attention consistently dominated in the perception of the line-motion illusion.

These experiments were conducted by giving the participant the instructions to attend to either the red or the green visual target. The second visual target on the opposite side of the screen was cued by a brief visual stimulus prior to the appearance of the red and green targets on the screen. Determination of whether the transient or sustained mechanisms of attention dominated in creating the illusion was based on which direction the participant perceived the line to be growing. If the illusion originated from the colored target, the participants were instructed to attend, and then sustained attention drove the perception. However, if the illusion originated from the briefly displayed cue, then transient attention mechanisms drove the perception. In all trials, transient attention mechanisms drove the line-motion illusion. The sustained visual attention condition never produced the line-motion illusion when the transient attention stimulus was present (Hikosaka et al., 1993).

S.B. Steinman et al. (1994) followed up the work of Hikosaka et al. (1993) and examined whether a participant's age influenced the magnitude of the attentional effects observed in the line-motion illusion. Younger adults (23-42 years old) were much more susceptible to the attentional impact of the line-motion illusion when compared with older adults (67-83 years old). Younger adults showed a peak attentional response when the visual cue was presented at time intervals between 17 and 50 ms before the bar. Older adults did not reach their peak attentional response until the cue lead-time interval was greater than 100 ms. The visual cues used by Hikosaka et al. were of high contrast and were not considered to preferentially activate either the magnocellular or the parvocellular visual pathways. S.B. Steinman et al. (1994) hypothesized that based on the temporal dynamics of the line-motion illusion perhaps the visual stimulus itself was being preferentially processed based on the visual pathways transmitting their information (magnocellular versus parvocellular). Therefore, S.B. Steinman et al. (1994) manipulated the properties of the visual cue to preferentially stimulate either the M or P pathway and examined the effect this had on the perception of the line-motion illusion. A low contrast visual attention cue was used to specifically activate the M pathway. An isoluminant visual attention cue was used to activate the P pathway.

S.B. Steinman et al (1994) was also interested in explaining the age differentials in the peak attentional response time intervals between younger and older participants reported in Hikosaka et al.'s study. Steinman (1994) hypothesized that perhaps age-related deterioration of the visual processing pathways was a contributing factor to the performance differences observed in Hikosaka et al.'s results. To determine if either the M pathway or the P pathway differed in the induction of the line-motion illusion by age, younger and older adults were tested using both visual attention cues.

No statistical differences were found in the peak attentional response time intervals for younger adults between the M-pathway sensitive cue and the high contrast cue used by Hikosaka et al. (1993). This evidence indicated the attention mechanism driving the generation of the line-motion illusion using both the M-pathway sensitive cue and nonpathway sensitive cue is virtually identical, suggesting that the attentional mechanisms may be utilizing the same neural substrate, hence using visual information processed primarily through the M pathway (S.B. Steinman et al. 1994).

However, differences in the peak attentional response time intervals were identified in older adults using the nonpathway specific attentional cue. The time interval data were slower than the M-pathway sensitive cues observed in younger adults, suggesting that older adults and younger adults may use different attentional mechanisms to generate the line-motion illusion or that their processing speed of the information is slower than younger adults. The peak attentional response performance of older adults closely resembled the peak attentional response performance of younger adults presented the P-pathway sensitive cue, suggesting that attention mechanisms driving the line-motion illusion in older adults may be utilizing visual information from the slower P pathway rather than information processed through the quicker M pathway as seen in the performance of younger adults (S.B. Steinman et al., 1994).

The results of this study suggest that, during the aging process, the mechanisms for driving transient visual attention, as observed in the line-motion illusion, shift from a mechanism relying predominantly on information from the M pathway into a mechanism more dependant on information from the P pathway. The authors suggested that this shift in how transient visual attention is processed may be the result of age-related changes to the magnocellular system. These changes may decrease the effectiveness of the transient visual attention mechanism by altering the integrity of the mechanism's primary informational resource, the magnocellular pathway (S.B. Steinman et al., 1994).

Eimer (1997) evaluated event-related potentials (ERP) in participants requested to attend to either the color or form of presented visual targets. Targets were presented in conditions favoring sustained attention and transient attention. Attention altered ERPs in both sustained and transient visual attention trials. Attention to color, however, produced noticeable ERP differences under sustained attention conditions but not under transient attention conditions. Eimer suggested that nonspatial attention mechanisms are most effective under sustained attention conditions. Furthermore, he suggested that sustained attention has a distinct and unique relationship with stimulus color. These findings support the evidence provided by S.B. Steinman et al. (1994) showing that magno-cellular-sensitive visual cues (form, motion, contrast) facilitate transient visual attention mechanisms, whereas nonmagnocellular-sensitive visual cues such as color negatively impact transient visual attention performance as determined with the line-motion illusion.

Transient Visual Attention and the UFOV®

The UFOV® has become a prominent measure of visual attention and cognitive processing speed in studies determining predictors of driving performance and crash risk in older adults (Ball et al., 1993; Owsley et al., 1991; Owsley, McGwin, & Ball, 1998). The UFOV® measures several cognitive aspects, including visual processing speed, selective attention, and divided attention. At a more fundamental level, however, the UFOV® test is also considered a measure of preattentive/ transient visual attention. UFOV® is defined as the spatial area within the visual field, viewed in a single brief fixation, that information can be processed for use in cognitive tasks (Ball et al., 1988).

The UFOV® measures the speed of preattentive visual-cognitive performance under three different levels of cognitive demand: stimulus identification, divided attention, selective attention (Ball et al., 1988; Ball et al., 1990; Sekuler & Ball, 1986). UFOV® subtest scores are calculated as the minimum stimulus durations required to successfully perform each subtest correctly 75% of the time. All subtests are presented on a touch-screen computer monitor at a distance of 23.5 cm. All visual targets are of high contrast (99%) and subtend 5.1 x 3.2 ° of visual angle.

In Subtest 1, participants must identify the silhouette of a car or a truck briefly flashed inside a white box in the center of the screen (Figure 2). The second UFOV®

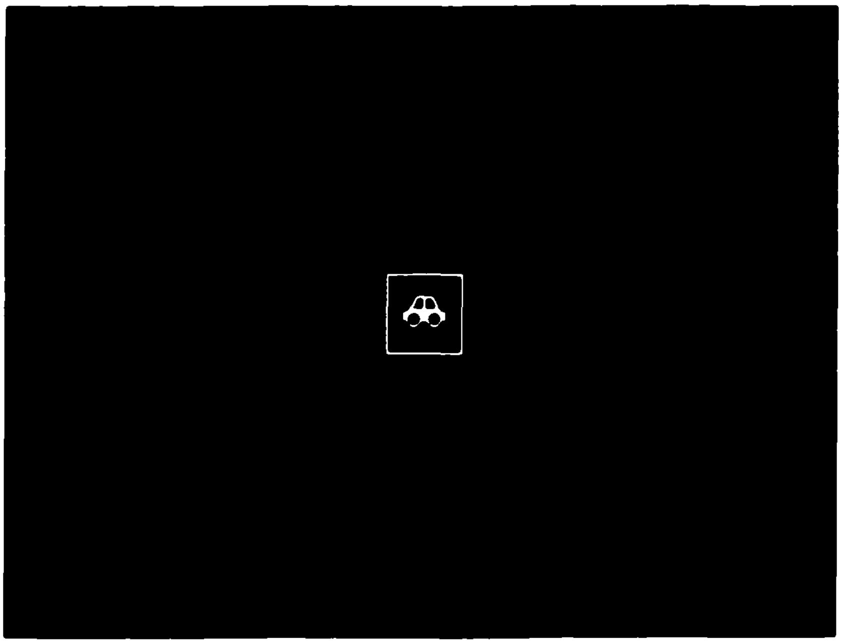

Figure 2. UFOV® Subtest 1: Processing speed.

subtest, divided attention, consists of identifying the central target from the previous task and simultaneously localizing an additional object (silhouette of a car) in the periphery (Figure 3). The third UFOV® subtest, selective attention, in addition to including objectives from the two previous subtests, adds visual distracters throughout the visual field to "hide" the peripheral target, increasing the demand of the peripheral task (Figure 4). The added difficulty requires the visual system to sift through visual noise to locate the peripheral target. If participants succeed in completing the previous three tasks, a fourth task is presented. The final task is an enhanced version of the selective attention subtest that increases the complexity of the central task by adding a second target inside the white box. In this test the participant must determine whether the two objects inside the white box are the same or different. The peripheral task remains unchanged; a target must be located from among visual noise (Figure 5).

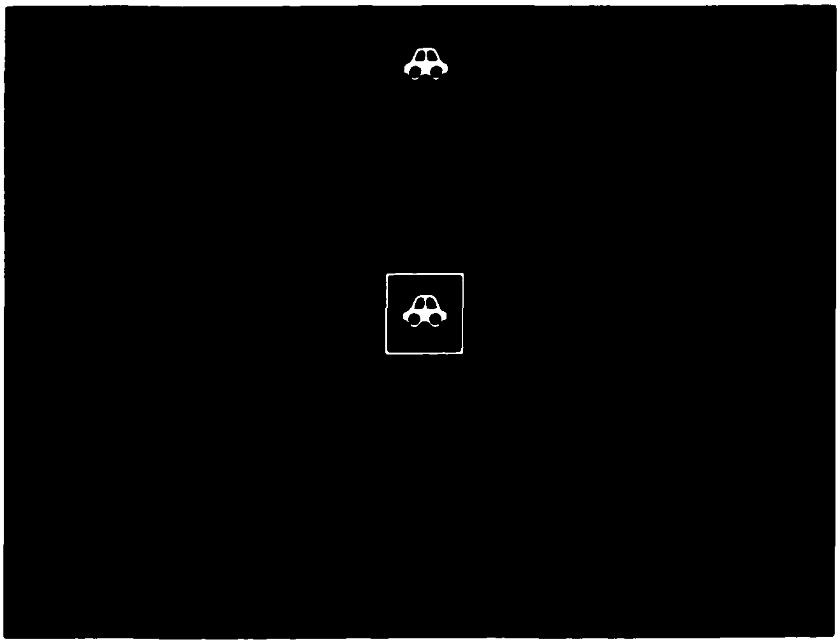

Figure 3. UFOV® subtest 2: divided attention.

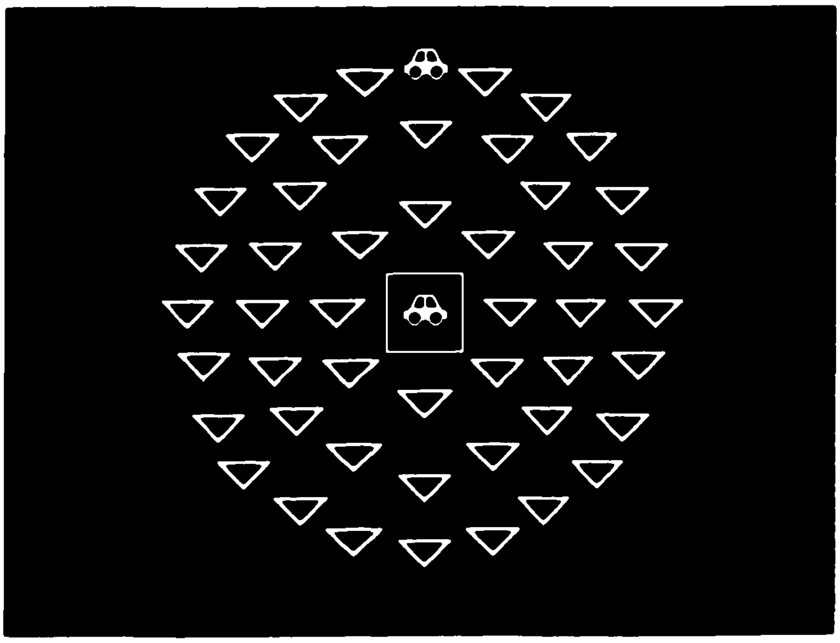

Figure 4. UFOV® Subtest 3: Selective attention.

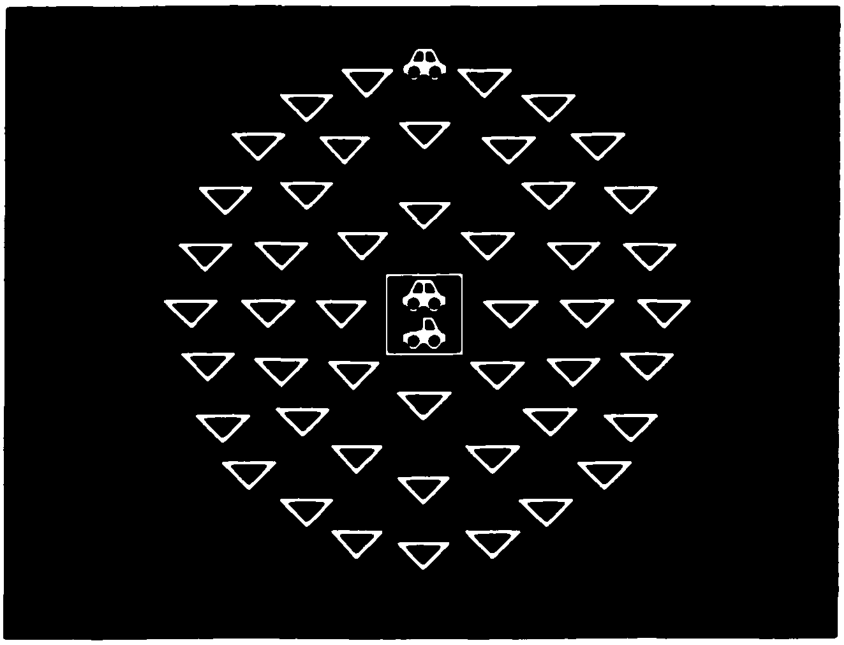

Figure 5. UFOV® Subtest 4: Enhanced selective attention (same or different).

The size of the UFOV®, or the spatial area of transient/preattentive discrimination, relates directly to stimulus duration (Bergen & Julesz, 1983). The peripheral targets in subtests 2, 3, and 4 are presented at a constant eccentricity of 35 ° from fixation. In all four tasks, only the stimulus duration is varied. Given a constant eccentricity, the time required to accurately detect the peripheral target is directly related to the size of the UFOV®. Within a given individual, larger spatial areas require longer stimulus duration, and a shorter duration results in more restricted fields of view. The dependent measure for all three subtests is the minimum target duration (in milliseconds) needed to achieve a 75% success rate of both the central and peripheral tasks. Scores from all three tasks are summed to form a composite score reflecting an overall index of speed of processing across tasks.

Impairments in visual processing speed and visual attention commonly occur during normal nonpathological aging and neurological diseases (Ball et al., 1988; Ball et al., 1993; D.W. Kline et al., 1992; Owsley et al., 1991; Parasuraman & Nestor, 1991). Visual attention impairments as measured with the UFOV® test strongly predict crash involvement. Older adults with substantial shrinkage of their useful field of view are more likely to be involved in car accidents than those without UFOV® deficits (Ball et al., 1993; Owsley et al., 1991; Owsley et al., 1998). Older adults with UFOV® impairments are particularly susceptible to accidents within intersections. An analysis of older drivers' accident profiles shows they tend to have the greatest number of vehicular accidents because of failure to yield the right of way or failure to turn correctly at an intersection (D.W. Kline, 1986). Intersections pose a significant demand on visual attention mechanisms. To safely navigate through intersections a person must be able to process visual information from a wide spatial area quickly to avoid any potential collisions. Older adults who failed the UFOV® test were 15.6 times more likely to have intersection accidents than those who passed the UFOV®. Of individuals passing the test, none were involved in intersection-related accidents (Owsley et al., 1991). The reduction of the useful field of view in older adults is also evident in self-report data. This data shows older adults with vision problems report a greater frequency of being "surprised" by objects entering from their periphery suddenly appearing from nowhere (D.W. Kline et al., 1992).

Driving Simulation and UFOV©

Research measures of driving behaviors consist of state accident records, self-report driving records, on-road and closed-course driving, and driving simulators. When examining performance on specific driving maneuvers, there is no substitute for on-road driving. However, when the population being examined is considered "at-risk" for driving-related accidents, there are ethical and experimental concerns that prevent the use of on-road tests in behavioral research. The rapid rise of technology avails researchers the use of computerized driving simulators. With driving simulators, the researcher has removed the potential hazards of on-road driving, while retaining the visual sensory and response demands of the real-world task. Driving simulators provide researchers with consistent, replicable driving conditions with which to evaluate driving performance. Each individual receives the same sensory experiences requiring the same driving maneuver to avoid simulated accidents. Such task consistency improves the reliability of statistical comparisons between individuals and groups. Ethically speaking, driving simulators allow for assessment of driving performance in complex and potentially hazardous situations without actually subjecting the individual or researcher to injury. In addition, driving simulators can vary the attentional or sensory demands of the driving task, giving the researcher more experimental flexibility to design the most appropriate behavioral tasks to address different research aims.

Simulation has been largely used in the evaluation of sensory and cognitive factors with driving performance. Walker, Sedney, and Mast (1992) assessed age-related driving performance and visual attention with a unique driving simulator. This driving simulator measured the useful field of view of participants using moving targets in a computer generated-driving scene. Older adults had significantly more difficulty compared with younger adults, suggesting a relationship between useful field of view, motion detection, and simulated driving. These results are consistent with previous findings of age-related changes in UFOV® (Ball et al., 1990, 1993) and motion detection (Tran, Silverman, Zimmerman, & Feldon 1998). Restricted UFOV® has been shown to predict poorer driving performance with the Iowa Driving Simulator (Rizzo & Robin, 1996; Rizzo, Reinach, McGhee, & Dawson, 1997); therefore, it is expected that the UFOV® is also related with performance on the UAB Driving Simulator. Given the transient nature of moving visual stimuli in real world and simulated driving environments, the observed impairments in UFOV® and driving performance may be traced back to deteriorate information form the magnocellular processing pathway discussed previously.

METHOD

Participants

Participants were recruited from several sources within and around the Birmingham, Alabama, area. Older participants (65 years +) were primarily recruited from members of the UAB Medwise organization, which is an organization that provides special benefits for area seniors. Other older adults were recruited from a database of former participants from the UAB's Center for Research on Applied Gerontology. Younger participants (18 to 30 years) were recruited from the UAB's Department of Psychology. Eighty-seven individuals participated in the current study. Participants were classified into three groups: older adults with poor UFOV® scores (n = 36, M = 76.92 years old), older adults with good UFOV® scores (n = 27, M = 73.96 years old), and younger adults (n = 24, M = 23.13 years old). The sample consisted of 34 males and 53 female, and included 70 Caucasians and 15 African Americans. Two participants reported their race as "other" (Table 1).

Participants were required to fill out a self-report health questionnaire to ensure no significant group differences were present. Presence of ophthalmological disease such as cataracts, diabetic retinopathy, macular degeneration, or glaucoma was of significant concern because disease status could influence participant performance. No differences in ophthalmological disease status were present between participants in the two older adult groups ($p > 0.250$).

Table 1

Participant Demographics

Group	Age			Gender		Race		
	n	Mean	SD	Male	Female	Caucasian	African American	Other
Younger adults	24	23.13	2.86	7	17	13	9	2
Older adults with good UFOV®	27	73.96	5.03	9	18	27	0	0
Older adults with poor UFOV®	36	76.92	5.70	18	18	30	6	0

Note. UFOV® = Useful Field of View Test

Design and Procedure

Informed consent was secured from all participants prior to testing. Testing was scheduled across two appointments for older adults and one visit for younger adults. The initial visit consisted of a visual screening exam (corrected distance visual acuity and contrast sensitivity). If participants met the minimum visual function requirements, testing continued with a battery of cognitive tests (UFOV®, Road Sign Test, Rey Complex Figure Test, Benton Visual Retention Test, Paced Auditory Serial Addition Test, and Trails B). Breaks were given periodically or as requested by the participant.

The second visit consisted of driving simulation, Starry Night, grating contrast sensitivity, and motion discrimination tests. Testing order was randomized to prevent order effects. If simulator sickness became a factor, the session was either delayed or terminated.

Additional vision testing was scheduled immediately following either the cognitive testing visit or the driving simulator visit. Frequency Doubling Technology

Perimetry and Short Wavelength Automated Perimetry were conducted at the UAB Eye Foundation Hospital in the Department of Ophthalmology. Total time to complete testing for both younger and older adults was approximately 3 to 4 hr across all visits. Older participants received monetary compensation for their participation ($10/hr), while younger participants received either classroom participation credit or monetary compensation ($10/hour).

Screening

Participants underwent screening tests to determine the presence of any cognitive or visual impairment that could interfere with study participation.

Participants were screened for general cognitive impairments using the Mini-Mental State Evaluation (MMSE); (Folstein, Folstein, & McHugh, 1975). The MMSE was selected because of its short delivery time and it achieves a general assessment of cognitive function through questions of general spatial awareness and memory. Participants with MMSE scores of 24 or less were excluded from study participation.

A basic level of visual function was necessary in order for participants to complete the UFOV® test. Minimal visual function accepted for performance on the UFOV® was taken from Owsley, Ball, and Keeton (1995). Distance visual acuity was measured using the Early Treatment Diabetic Retinopathy Study (ETDRS) distance acuity chart (Ferris, Kasoff, Bresnick, & Bailey, 1982). Wearing their normal correction, participants were required to have acuity of 0.50 log Minimal Angle Resolved (logMAR) or better to be included in the study. Contrast sensitivity was measured binocularly with the Pelli-Robson Contrast Sensitivity Chart (Pelli, Robson, & Wilkins, 1988) to assess the participants' ability to discriminate medium spatial frequency letters across a broad range of brightness contrasts. Participants were required to have a contrast sensitivity score of at least 1.35 log to be included in the study. General peripheral vision was assessed using the visual sensitivity test included with the UFOV® test (Visual Awareness Inc., Bowling Green, KY). The peripheral screening test is a preliminary test given before the standard Subtests 1-4 (Figure 6). This screening test asked the

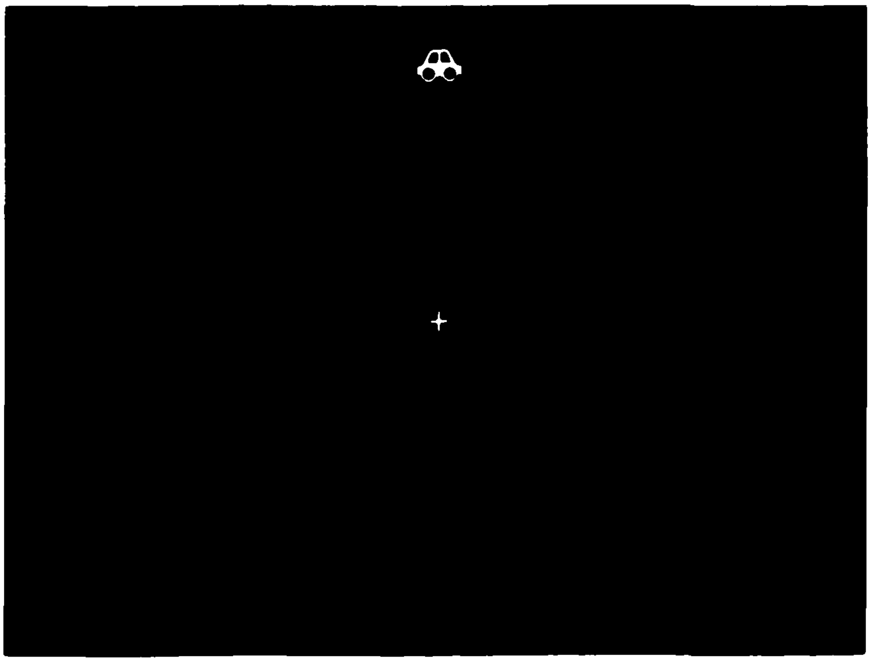

Figure 6. General peripheral sensitivity screener. Participants must locate the peripheral object.

participants to maintain focus on the central cross. The peripheral object was flashed onto the screen, and the participants respond by touching the location of the peripheral target. After successfully completing the screening protocol, study participants undergo the full battery of the following vision, cognitive, and behavioral tests.

Visual Memory

Two separate measures were used to assess participants' visual memory performance, the Rey-O Complex Figure Test (RCFT) and the Benton Visual Retention Test (BVRT). Both tests require immediate recall and reproduction of previously displayed shapes and designs.

Immediate visual recall was measured using the Rey Complex Figure Test following the standard procedure (Meyers & Meyers, 1995). All participants were required to complete the copy and immediate recall portion of the test. The RCFT consists of a complex design containing a variety of shapes (Figure 7).

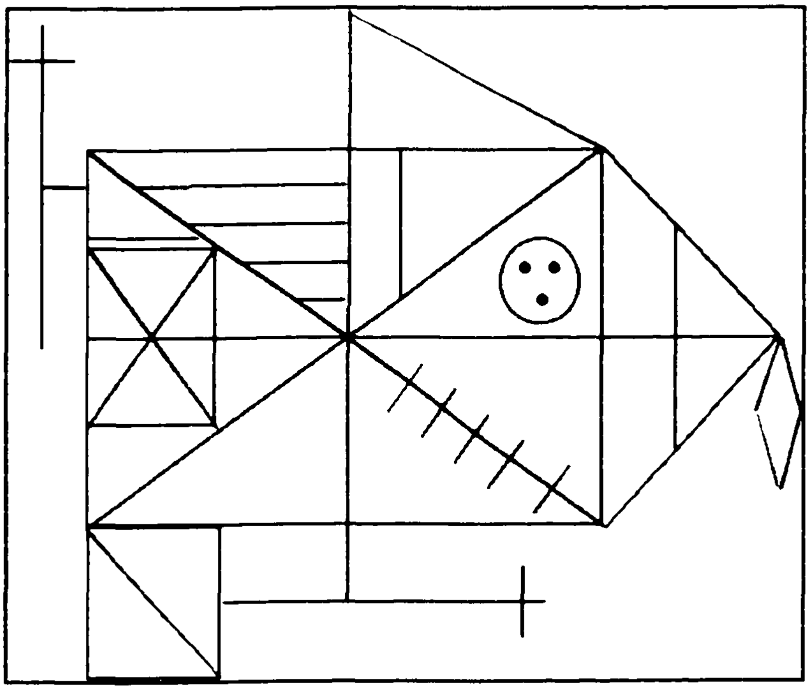

Figure 7. Rey Complex Figure Test. Participants are asked to copy the design exactly as it appears. An immediate recall trial follows.

For the copy portion of the RCFT, the participants looked at the image while copying the design to the best of his or her ability. There were no time constraints for the copy portion; participants continued to copy the image until they reported the copied design was complete. Participants were not corrected when mistakes were made but were encouraged to check their work with the reference image provided. After the copied image was completed, each participant received a clean sheet of paper, the reference image and the copied image were removed from sight, and the participant was asked to immediately reproduce the image just copied. The time to complete the immediate recall portion of the test was recorded. Scoring of the RCFT copy and immediate recall images followed the protocol set forth in the RCFT manual. Three scores were obtained from this test: copy score, immediate recall score, and the "forgetting" score (difference between the copy score and the immediate recall score).

The Benton Visual Retention Test is an additional measure of immediate recall visual memory (Sivan, 1992). This test differs from the RCFT in that participants are presented multiple visual images of increasing complexity (Figure 8). Early images consist of single shapes with each successive image becoming more complex consisting of up to three separate shapes of varying sizes. Participants were allowed 10 s to view each image before the page was masked and participants attempted to reproduce the image. For each correct drawing, the participant received 1 point, with a maximum score of 10.

Visual Search

The Road Sign Test examined participants' ability to scan an image, identify a predetermined visual target, and react. This computerized test is run on a standard Microsoft Disk Operating System personal computer using a 17 in. diagonal monitor. Participants were presented images of several different road signs with different symbols distinguishing them from one another (pedestrian, cyclist, left arrow, right arrow). Three to six signs were displayed on the screen at a given time. For each presentation, all signs but one

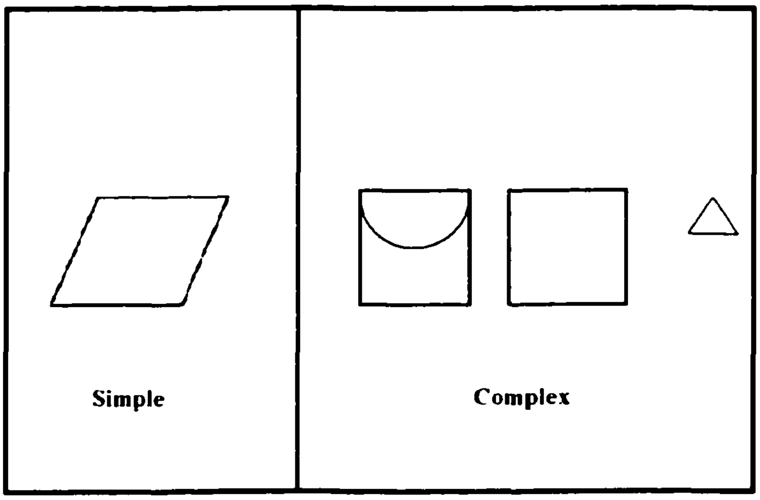

Figure 8. Sample images from the BVRT visual memory test. Participants view a single image for 10 s, the picture is removed, and they are asked to reproduce the image from memory.

were marked with a red slash through the center. The one sign without the red slash was the target of the search task. Once identified, the participant was required to respond accordingly depending on the target sign. Prior to testing the participants learned how to react for each type of sign. Pedestrian or cyclist signs were responded to with a button press on the computer mouse, arrow signs were responded to by sliding the mouse in the corresponding direction. Several practice sessions were given to ensure the participants understood the correct responses for each sign. Results were presented as average reaction times for each difficulty level (3 or 6 stimuli).

Transient Visual Attention

The UFOV® (Visual Awareness Inc., Bowling Green, KY) was used as a measure of transient visual attention. The UFOV® consists of four subtests designed to assess speed of processing under increasingly difficult cognitive demand. UFOV® subtest specifics can be found in the previous section. The UFOV® program ran on a Microsoft Disk Operating System personal computer. A 17- in. diagonal touch screen display was used to display the test material. Participants were required to sit at a distance of approximately 30 cm from the monitor. Participants made their choice selections through the monitor's touch screen interface.

Sustained Visual Attention

The Starry Night software program measured participants' sustained visual attention (Rizzo & Robin, 1990). Participants fixated on a central cross at a viewing distance of 50 cm in a darkened room. The screen consisted of 1,000 points of light (size, 0.68 mm; luminance, 5.00 c/m^2) evenly scattered across a 17-in. monitor. Participants were informed to monitor the entire screen for any changes in the star field. Changes in the star field consisted of disappearing and appearing stars. At random intervals (maximum interval of 3 s) a star was either removed from the screen (disappearance event) or drawn onto the screen (appearance event). Participants were instructed to press the spacebar on the keyboard for each event they detected. The reaction time and target coordinates were recorded for each of the 200 total events. Average reaction time and d-prime values were given for each quadrant of the display. To examine the ability of the participants to sustain their attention to the task, scores were broken into performance for the first 100 events and performance for the last 100 events. If performance declined during the second 100 events, it is an indication that participants were unable to sustain their attention to the task.

Sustained Attention / Sequencing

Trail-Making Test B (Reitan, 1958) was given as an additional attention measure. The standard protocol was followed; participants drew a line connecting 25 circles alternating between numbers and letters in ascending order as quickly as possible. Scores reflected the total time required to complete the task. If participants made an error during the testing session, they were prompted to try again starting at the last correct point. Errors were not noted other than indirectly as an increase in the total time for task completion.

Auditory Sustained Attention

An auditory attention/concentration task, Paced Auditory Serial Addition Test (PASAT), was included in the study to differentially examine auditory versus visual assessments of attention and its relationship with visual function and cognitive aging.

Participants were presented with an auditory recording of a stream of numbers (numbers 1-9) presented at an interval of 2.4 s between numbers. Participants were instructed to add each successive pair of numbers together and report the answer verbally. To successfully perform the PASAT, participants must store each number in working memory while maintaining attention to the recording to acquire the next number in order to complete the addition task. Scores consisted of the total number of correct responses out of 36 possible answers.

Magnocellular Sensitive Vision Tests

Magnocellular function was assessed using a variety of ophthalmic and psychophysical tests. These tests included frequency doubling technology perimetry (FDT; Humphrey Instruments, Dublin, CA), low spatial frequency contrast sensitivity (Nicolet CS 2000; Nicolet Biomedical Instruments, Madison, WI), and motion discrimination (Power DotMovie, Version 2.3; Steinman, 1992).

FDT presents a flickering (25 Hz) counterphased contrast grating of low spatial frequency (.25 cycles per degree) for a maximum duration of 720 ms. The contrast of the grating is adjusted in a staircase threshold procedure using 3-decibel reversals to determine participants' contrast threshold at 17 locations throughout the visual field using a modified binary search staircase procedure. Contrast thresholds were reported in decibels. Participants were asked to fixate at center and press a button each time they detected the flickering grating at any location.

FDT performance has been shown to be sensitive to the aging process and glaucoma, which is a disease believed to predominantly targets cells of the M pathway

(Adams, Bullimore, Wall, Fingeret, & Johnson, 1999; Johnson & Samuels, 1997; Quigley, 1998). The FDT was selected primarily because the task is behaviorally simple, has a relatively short administration time (approximately 10 min per eye), and has excellent test-retest reliability (Johnson & Samuels, 1997), making it an ideal test for older adults. To maximize participants' concentration and improve the validity of the results, the FDT was assessed in only the right eye. Participants wore their normal lens correction, because FDT performance is not significantly affected by optical blur (Johnson & Samuels, 1997).

As was discussed in previous sections, the M pathway is particularly sensitive to low spatial frequencies at low contrasts. Contrast sensitivity at low spatial frequencies less than or equal to one cycle per degree is primarily mediated through the M pathway (Merigan & Eskin, 1986). Low spatial resolution contrast sensitivity was assessed using the Nicolet CS2000 contrast sensitivity system (Nicolet Biomedical Instruments, Madison, WI). The CS2000 measures contrast sensitivity to sign wave gradients of several spatial frequencies (0.5, 1, 3, 6, 11.4, and 22.8 cycles per degree). Sensitivity thresholds were determined by averaging three threshold reversals. Contrast sensitivity thresholds for gratings of greater than 1° spatial resolution were not considered mediated by the M pathway.

Because the M pathway is also particularly sensitive to motion, a measure of participants' motion discrimination sensitivity was also included in the battery of magnocellular sensitive tests. Motion discrimination was assessed using a random dot cinematogram program (Power DotMovie, Version 2.3, Steinman, 1992). Power DotMovie, Version 2.3 runs on the Apple operating system. This test was run on an Apple Imac G3 with a 17-in. monitor. Power DotMovie, Version 2.3 was used to generate the random dot cinematograms. Each trial was created from several frames of animation. In each frame of animation, some dots moved in a random or uncorrelated direction ("noise" dots). The remaining dots ("correlated" dots) moved in a uniform direction at a constant speed generating the motion signal. From frame to frame, the correlated and noise dots were randomly dispersed across the screen. When the number of correlated dots reached a certain percentage of the total number of dots (correlated and uncorrelated), motion was perceived in the same direction as the correlated dots. Motion thresholds can be determined by varying the ratio of noise to correlated dots. The cinematogram consisted of 175 dots (dot size, 24.7213 min) across the visual field (19.22° horizontal, 13.84° vertical). The motion stimulus consisted of 20 total frames of animation with total stimulus duration of 0.896 s. Participants were tested under two different conditions: high dot velocity (12.25°/s), and low dot velocity (4.28°/s) using a four-alternative forced choice paradigm. Participants were forced to make a direction determination (up, down, left, right) for each motion trial. For each test session, the participant viewed displays of varying levels of correlated motion (15%, 20%, 25%, 30%, and 45% co-herence) for a total of 60 trials (12 trials per level of correlated motion). Outcome measures are the percent correct (low and high velocities) for each motion coherence level. For the low velocity condition, a motion discrimination threshold determination was available using a 3% coherence level staircase procedure.

Nonmagnocellular-sensitive Vision Tests

Nonmagnocellular-sensitive tests were included in the current study to determine whether any visual pathway-specific (M pathway) relationships existed between cognitive and behavioral tasks. Tests that particularly targeted nonmagnocellular visual pathways included high spatial resolution contrast sensitivity (Nicolet CS2000; Nicolet Biomedical Instruments, Madison, WI) and short wavelength automated perimetry (SWAP; Humphrey Instruments, Dublin, CA).

Originally the SWAP test was considered to measure visual function mediated through the P pathway (Sample, Bosworth, & Weinreb, 1997). Later studies reported that SWAP performance is mediated through small bistratified blue-yellow ganglion cells distinct from both parvocellular and magnocellular cell types (Sample, Bosworth, Blumenthal, Girkin, & Weinreb, 2000). SWAP is similar to standard automated perimetry as measured with Humphrey Automated Perimeter. The main difference between SWAP and standard perimetry is the color of the target and background. Participants were presented a blue target (440 nm, 1.8° visual angle, 200 ms) of varying brightness on a bright yellow background (100 cd/m). Participants were instructed to press a button whenever they detected the blue target flash on the yellow background regardless of the target location or brightness. Detection thresholds, measured in decibels, were calculated at each of 54 perimeter locations for the right eye of each individual with the contralateral eye patched.

High spatial resolution contrast sensitivity was measured on the Nicolet CS2000 following the same procedure as the low spatial resolution contrast sensitivity testing. High spatial resolution consisted of gratings of 11.4 and 22.8 cycles per degree. As with low spatial resolution, contrast sensitivity scores were determined by averaging three threshold reversals.

UAB Driving Simulation

The UAB driving simulator provides a realistic and safe measure of driving behavior. The visual environment is generated from three laser disk players that are then projected by three liquid crystal display (LCD) projectors displaying the visual scene onto three wall screens. Participants are placed inside an authentic vehicle cab (1990 Honda Civic) complete with the original Honda Civic instrument panel (speedometer, fuel gauge), accelerator, brake, and steering wheel. The car cab is centered in front of the three projector screens giving 120° simulated visual scenes. The accelerator and brake are interactive with the video scene. Pressing the accelerator will increase the playback speed of the videodisc players to simulate vehicle acceleration. The brake is similarly instrumented to decrease the playback speed slowing the visual scene. A variety of driving scenarios are included to determine driving performance at different light levels and degrees of visual clutter. Daytime and nighttime driving scenes are included to determine the effect of roadway lighting conditions on cognitive driving tasks. The density and nature of the roadside environments are varied by including suburban and urban scenes.

Participants are tested under eight conditions. Scenarios are selected based on several criteria. Because simulator sickness is a common experience in the elderly population (Watson, 1995), scenes with significant lateral movements of the visual scene (lanes changes, sharp turns) are excluded from the study. Scenes are also selected based on the difficulty of the driving environment and the driving maneuvers required to safely navigate through the scenario (braking events). Descriptions of the driving conditions and simulator measures are given below.

Suburban Daytime. The video footage in this scenario consisted of suburban, city streets with traffic lights, stop signs, pedestrians, traffic, and other obstacles found in typical suburban street driving. The participant was faced with several preset tasks with which to interact. At times in the video footage, cars suddenly slowed down or stopped in front of the participants' simulated car. Additional incidents involved people exiting parked cars, traffic swerving into the driver's lane, and pedestrians stepping out in front of the simulated car. While driving, participants simultaneously performed a visual search task. Drivers were instructed to watch for any vehicle that passed them in the adjacent lane and to respond to such an event by pressing a button located on their steering wheel according to the side that the vehicle passed.

Suburban Daytime with Added Demand. In addition to the driving tasks described above, an increased cognitive demand was placed on the driver for some driving conditions. Drivers were given a list of visual targets (businesses, restaurants, traffic signs, passing cars) to identify located along the roadway. The task required the driver to scan the scene for the specified targets. The participant was to press one of two buttons located on the steering wheel (left button, right button) in response to the side of the street where the target was located. The addition of this visual search task forced the driver to divide his or her attention between the driving task and the search task, thus increasing the overall attentional demand on the driver

Suburban Nighttime. Similar roadways were used in the nighttime scenarios as described for the daytime scenarios. These scenarios were similar in terms of the type of location and number of traffic lights, traffic density, and number of critical and minor braking events. The difference was that the scenarios took place at night where car headlights and streetlights could provide potential glare sources for the driver, making potential hazards more difficult to detect.

Suburban Nighttime with Added Demand. For these scenarios, the visual search task was added to the suburban nighttime driving task to increase the overall difficulty of the scenario.

Urban Daytime. Urban scenarios were similar to suburban driving tasks but in a different visual environment. The urban environment was more visually cluttered due to an increased density of apartments, office buildings, sidewalk vendors, parked vehicles, and increased roadway traffic. Critical braking events were included, as in previous scenarios, to test the driver's ability to react to hazardous situations.

Urban Daytime with Added Demand. Similar to the suburban scenarios with added demand, additional visual search tasks were given to the driver requiring they monitor the scene for preselected visual targets in addition to the regular driving task.

Urban Nighttime. The same urban setting was used as in the urban daytime scenario. As with the suburban nighttime scenes, glare sources from several streetlights, signs, lighted buildings, and oncoming headlights increased the difficulty of the driving task.

Urban Nighttime with Added Demand. The visual search task was added to the urban nighttime driving task to increase the overall difficulty of the scenario.

UAB Driving Simulator Dependent Measures

Critical events such as pedestrians stepping out in front of the car, traffic lights turning red, or other vehicles required the participant to brake accordingly to avoid an accident. Response time was calculated based on the time the event began relative to the time when the brake response was made. Similarly, response times to visual targets from the search task were also recorded. In addition, the total number of correct braking responses, missed braking response, correct target detections, and missed target detections were recorded.

Because participants' visual attention performance was of primary interest, the primary outcome measures were those that required the visual detection and subsequent response to events and objects in the driving scene. The additional visual search task given to the participants was the prime source of these data, as well as braking performance to critical events, which also demanded visual attention and vigilance for appropriate behavioral responses. The visual targets in the driving scenarios were categorized into central targets and peripheral targets. Central visual targets were targets that began in the center of the driver's visual field and moved toward the driver's periphery, such as road signs and restaurants. Peripheral targets were those objects that originated in the driver's periphery and moved toward the driver's central visual field, such as other vehicles passing from behind the participant. The third major category of outcome variables was participant response to critical events (red traffic lights, pedestrians entering the street, and other vehicles).

Each outcome variable category was broken down into two difficulty levels. The levels of difficulty were determined based on the amount of visual distraction/clutter in the driving scene. Urban city streets, with the dense business signage, pedestrians, cyclists, and heavy traffic, present numerous visual distracters creating a highly cluttered visual environment. Driving under these difficult conditions required a high level of persistent attention and vigilance of participants for successful performance on both the driving and behavioral tasks. Conversely, driving through simulation scenarios of wide-open suburban streets, containing less visual clutter and fewer distracters, was relatively less difficult than driving in the urban setting.

UAB Driving Simulator Data Collection Protocol

The UAB Driving Simulator computer system collects data at a high sampling rate, several times per second. Prior to data analysis, information pertinent to the human performance tasks was extracted from the data files for each individual participant (see Table 2 for sample simulation data). The data extraction procedure was accomplished both manually and with computer software developed within the UAB Center for Research on Applied Gerontology.

Because video-based driving simulation systems utilize filmed footage for visual imagery, the unit of measure within a given driving scenario is the frame number associated with the video footage. As discussed previously, participants were given a visual search task while simultaneously driving through each scenario. The addition of the visual search task gives the participant two primary driving tasks: finding the described visual search target and monitoring the environment for hazardous events (critical braking events). Visual search targets (restaurant signs, pedestrians on sidewalks, passing cars, etc.) and critical braking events (jaywalkers, stop signs, cyclists, other cars, etc.) are each identified in the simulation footage by a frame number. Frame numbers are associated with points in time during the video footage where visual search targets or critical braking events enter the screen. In the simulation data, frame number is continually monitored along with steering wheel position, throttle position, brake position, left button, right button, elapsed time, and driving rate. Participants were instructed to respond to visual targets by pressing either the left or the right button on the steering wheel relative to the side of the street the detected visual target resided. Knowing the frame number when the visual targets became visible, a search algorithm was written to locate each visual search target in the data stream and search for a subsequent correct button press response. Detection response times were determined by subtracting the elapsed time when visual target became visible from the elapsed time when the appropriate button press response was made. The calculation of braking response times to critical braking events was handled in the same manner as visual search targets. Braking response times were calculated by subtracting the elapsed time of the frame number when the hazardous entity entered the roadway from the elapsed time when a brake response was made. In the cases where participants failed to locate visual targets, a maximum score of 6.0 s was automatically scored. Six seconds was selected as the ceiling response time after identifying the maximum response time for all responding participants across all driving scenario categories was 5.876 s. This decision ensured that in all cases nonresponders performed worse than the slowest responder.

Table 2

Sample Data from the University of Alabama at Birmingham Driving Simulator

Steering	Throttle	Brake	L button	R button	Frame	Elap. time	Rate
1.9	11.8	0	Up	Up	2790	0	30899.87
-1.9	12.0	0.2	Up	Up	2790	0.0500122	30899.92
-1.9	12.0	0.2	Up	Up	2790	0.1113281	30899.98
1.9	12.0	0	Up	Up	2790	0.1601563	30900.03
1.9	12.0	0	Up	Up	2790	0.2207031	30900.09
0	12.0	0	Up	Up	2790	0.2714844	30900.14
-1.9	12.0	0.2	Up	Up	2790	0.3300781	30900.2
1.9	12.0	-0.1	Up	Up	2790	0.3808594	30900.25
0	12.0	-0.1	Up	Down	2790	0.4902344	30900.36
1.9	12.0	-0.1	Up	Down	2790	0.5507813	30900.42
1.9	12.0	-0.1	Up	Down	2790	0.6015625	30900.47
-1.9	12.0	0.2	Up	Down	2790	0.6015625	30900.47
3.7	12.0	-0.1	Up	Down	2790	0.6601563	30900.53
0	12.0	0	Up	Down	2790	0.7109375	30900.58
0	12.0	0.1	Up	Down	2790	0.7714844	30900.64
0	12.0	0.1	Up	Up	2790	0.8203125	30900.69
0	12.0	0	Up	Up	2790	0.8808594	30900.75
1.9	12.0	0	Up	Up	2790	0.9316406	30900.8
0	12.0	0	Up	Up	2790	0.9902344	30900.86

Note. L button = left button; R button = right button; Elap. time = elapsed time.

RESULTS

The objectives of the current study were to evaluate sensory, cognitive, and behavioral differences in older adults with and without UFOV® impairments. The inclusion of younger adults provided a baseline for age and UFOV® impairment status comparisons with the two older adult participant groups. Planned contrast comparisons were used in the present study in order to protect against inflated Type I errors and increase the power of the analyses. To analyze performance differences between all three participant groups, two planned contrast comparisons were conducted for all visual, cognitive, and behavioral measures. The primary comparison of interest was between older adults with UFOV® impairments and older adults without UFOV® impairments. For baseline purposes, younger adults were contrasted with older adults without UFOV® impairments. Because older adults without UFOV® impairments were included in both comparisons, the alpha level was reduced to 0.025 to retain confidence in the validity of the results. The outcome of these two planned comparisons could produce one of three patterns of significant results based on age, UFOV® status, or both.

Age-Based Performance

This pattern of results is reflected by equivalent performance for the two older groups, with significantly better performance for the younger group. For outcome measures with this result, good and poor UFOV® performance is unrelated to this ability.

The following vision measures fit this pattern of age-based performance differences: FDT mean, SWAP mean, distance acuity, grating contrast sensitivity (22.8 cpd); (Figures 9, 10, 11, and 12, respectively). Motion discrimination of slow moving targets was categorically age-based including all levels of coherent motion discrimination (15%, 20%, 25%, 30%, 45%) as well as the absolute detection threshold to slow moving targets (Figure 13). Of the cognitive measures, the less complex 3-sign version of the RST and Starry Night (d prime 1-100, 101-200, and d prime overall) matched this pattern of age-based performance differences (Figures 14 and 15, respectively).

UFOV® Impairment-Based Performance

This pattern of results is reflected by equivalent performance for the two unimpaired UFOV® groups (younger and older), with significantly poorer performance for the impaired UFOV® group (older). For outcome measures with this result, age is unrelated to this ability.

The only vision measure to fit this pattern was grating contrast sensitivity at the largest tested spatial frequency of 0.5 cpd (Figure 16). Motion discrimination of fast moving targets at coherence levels (20%, 25%, 30%) fit this pattern as well (Figure 17). The number of correct responses to central targets during high cognitive demand driving scenarios also showed this impairment-based pattern of results (Figure 18). However, eighteen participants experienced simulation sickness and could not complete the driving tasks. Therefore simulation results are based on an n of 69 rather than 87. No cognitive measures demonstrated purely UFOV® impairment-based performance differences.

Age and UFOV® Impairment-Based Performance

This final pattern of results describes the condition where all three groups perform differently, such that younger adults outperform all other participants, and older adults with unimpaired UFOV® outperform UFOV®-impaired older adults. Pelli-Robson chart contrast sensitivity was the only remaining vision measure to fit this pattern of results (Figure 19). All other vision measures were age-based. Cognitive measures almost exclusively fit this pattern of results, including Road Sign Test (RST) 6-sign version, BVRT, RCFT copy and RCFT recall, Trails, and PASAT (Figures 20, 21, 22, 23, and 24, respectively). Response time to center targets under high cognitive demand driving conditions also fit the age and UFOV® impairment-based pattern of results (Figure 25).

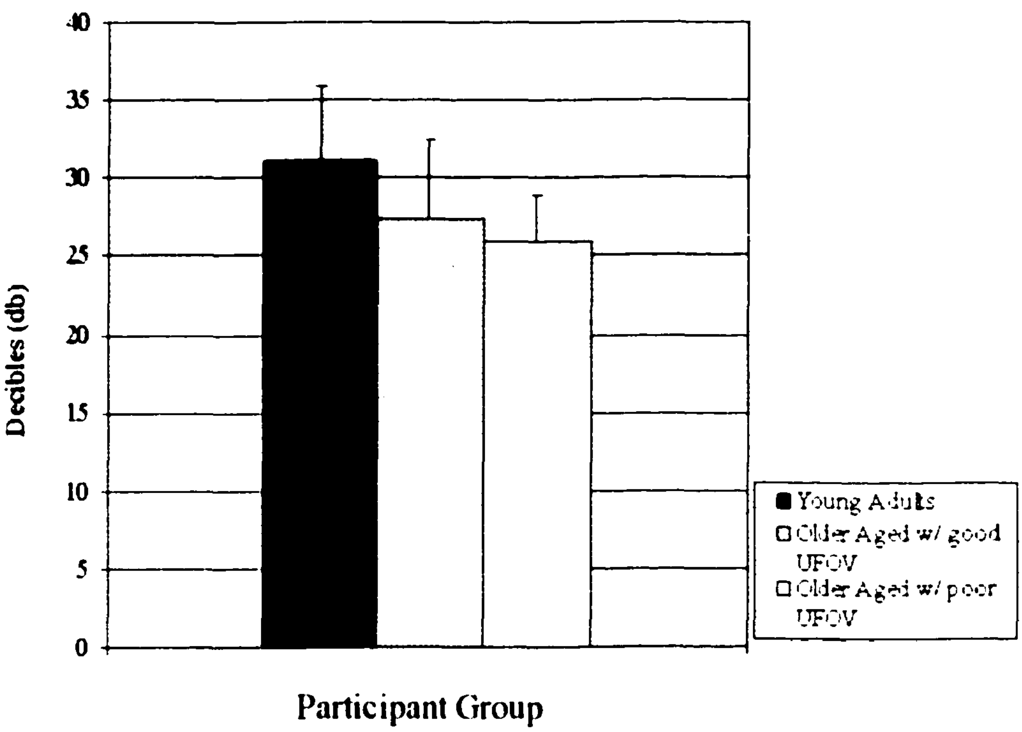

Figure 9. Mean FDT threshold by group (+SE). Age-based group differences were significant, with younger adults detecting more events than all older participants. Younger adults outperformed older adults with good UFOV[K] ($p = 0.001$), but no significant differences were found between older adult groups ($p = 0.181$). UFOV[K] = Useful Field of View Test.

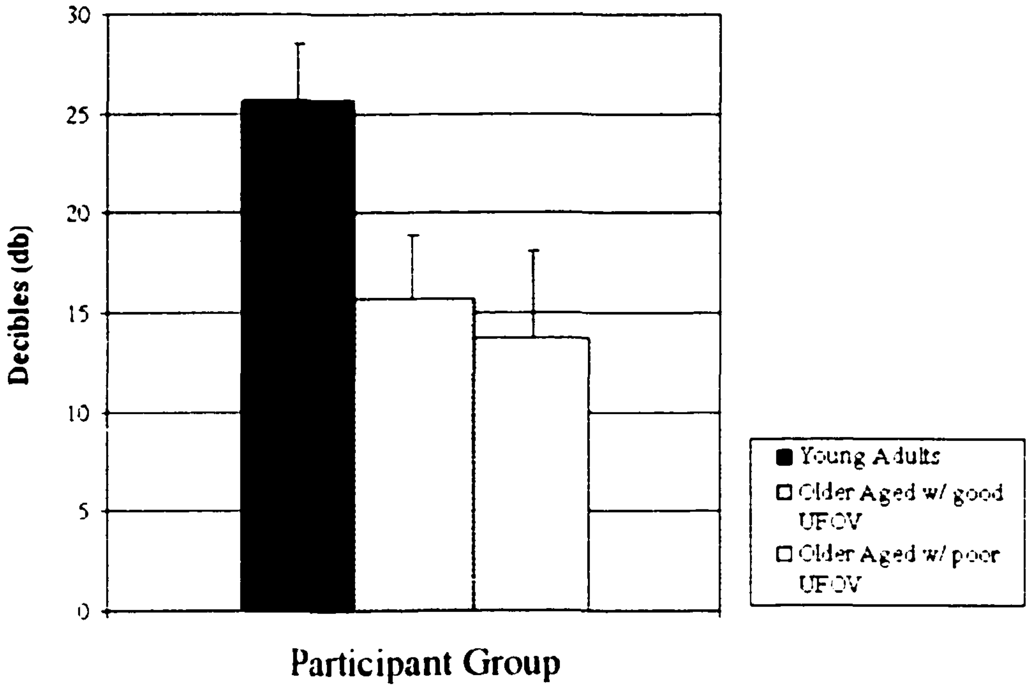

Figure 10. Mean SWAP threshold by group (+SE). Age-based group differences were significant, with younger adults detecting more events than all older participants. Younger adults outperformed older adults with good UFOV[κ] ($p < 0.001$), but no significant differences were found between older adult groups ($p = 0.047$). UFOV[κ] = Useful Field of View Test.

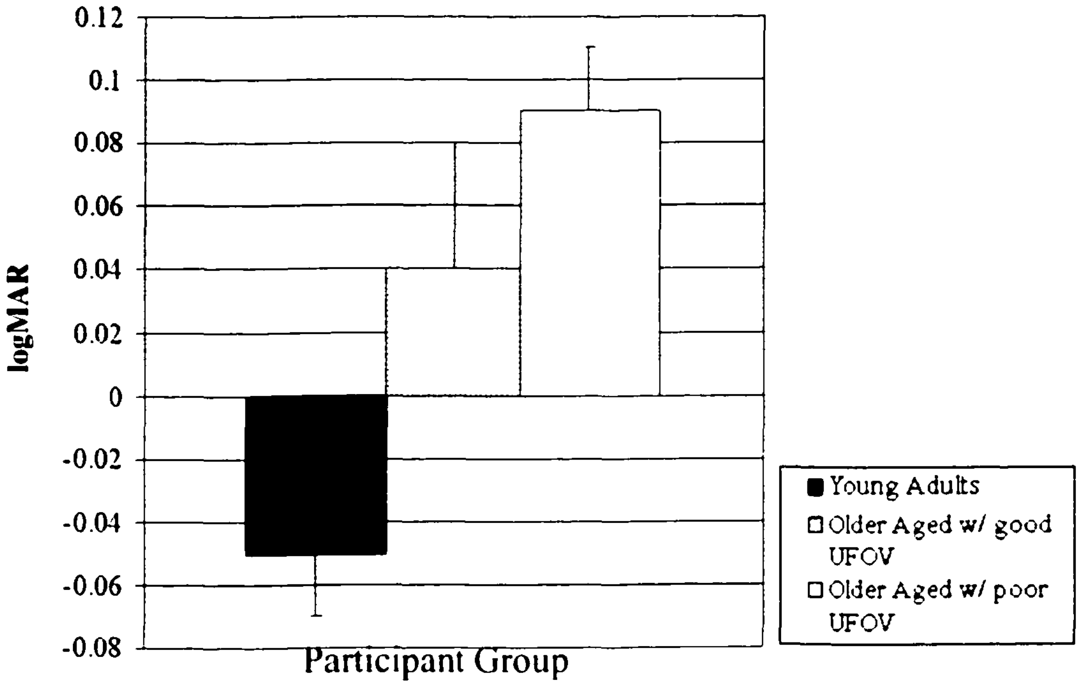

Figure 11. Distance acuity (ETDRS) by group (+/-SE). Age-based group differences were significant, with younger adults correctly identifying more letters than all older participants. Younger adults outperformed older adults with good UFOV[R] ($p = 0.021$), but no significant differences were found between older adult groups ($p = 0.285$). UFOV[R] = Useful Field of View Test; logMAR = log minimal angle resolved.

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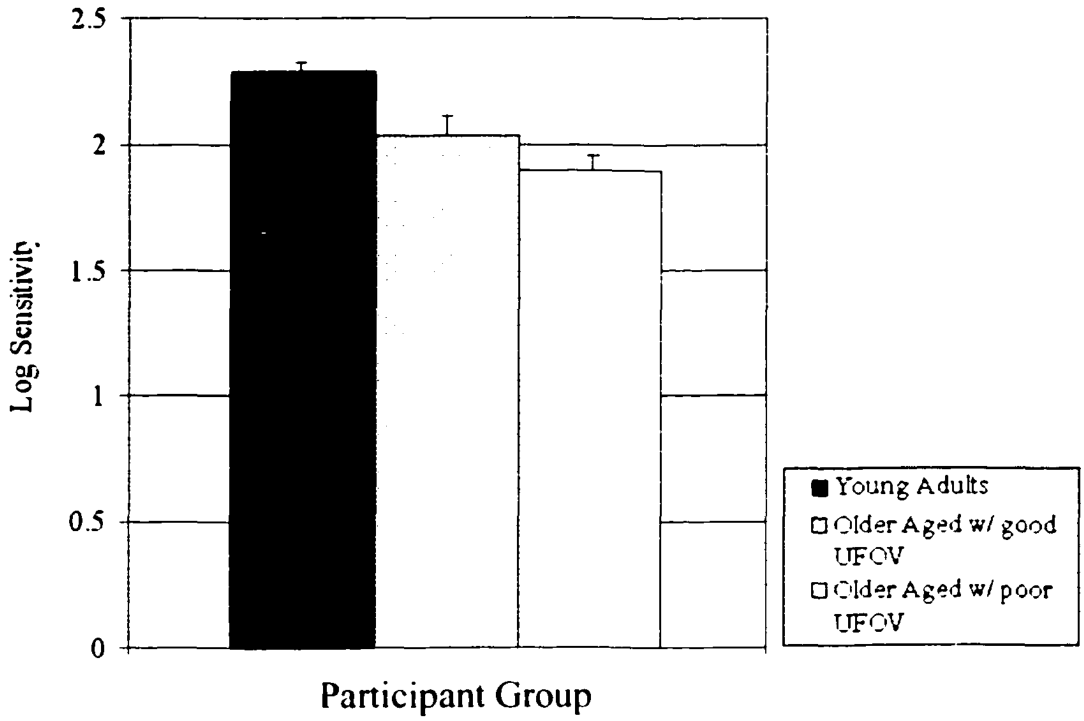


Figure 12. Grating contrast sensitivity (22.8 cpd) by group (+SE). Age-based group differences were significant, with younger adults outperforming all older participants. Younger adults outperformed older adults with good UFOV® (p = 0.016), but no significant differences were found between older adult groups (p = 0.039). UFOV® = Useful Field of View Test.

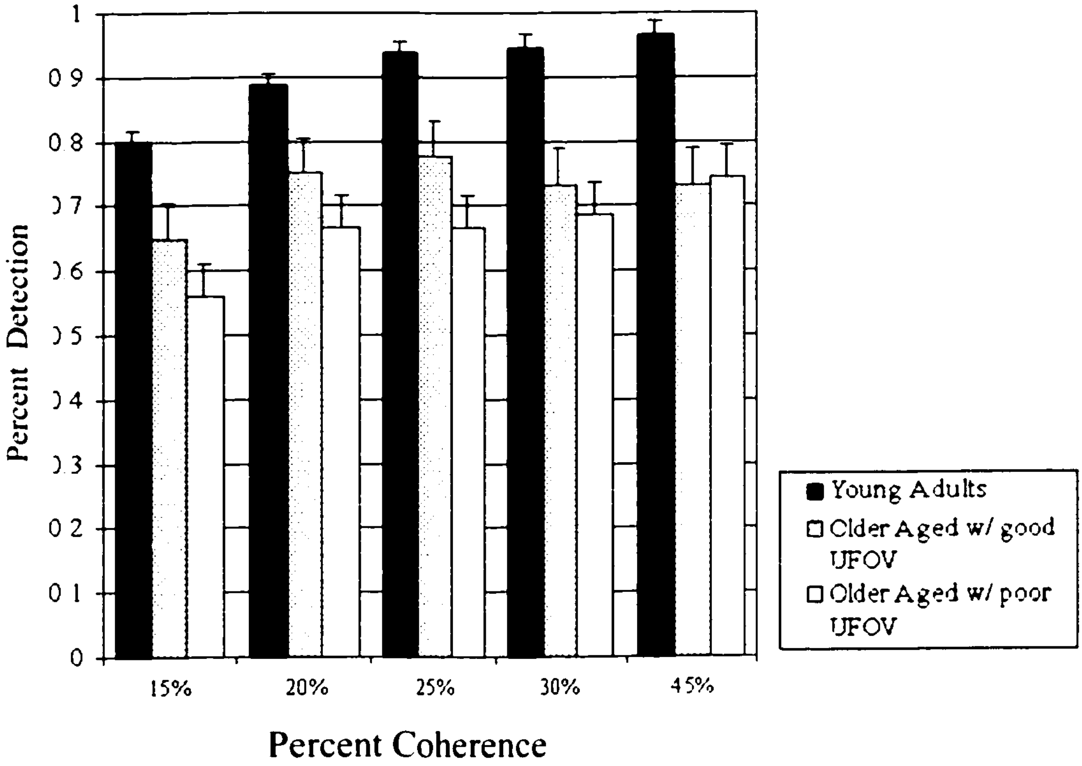
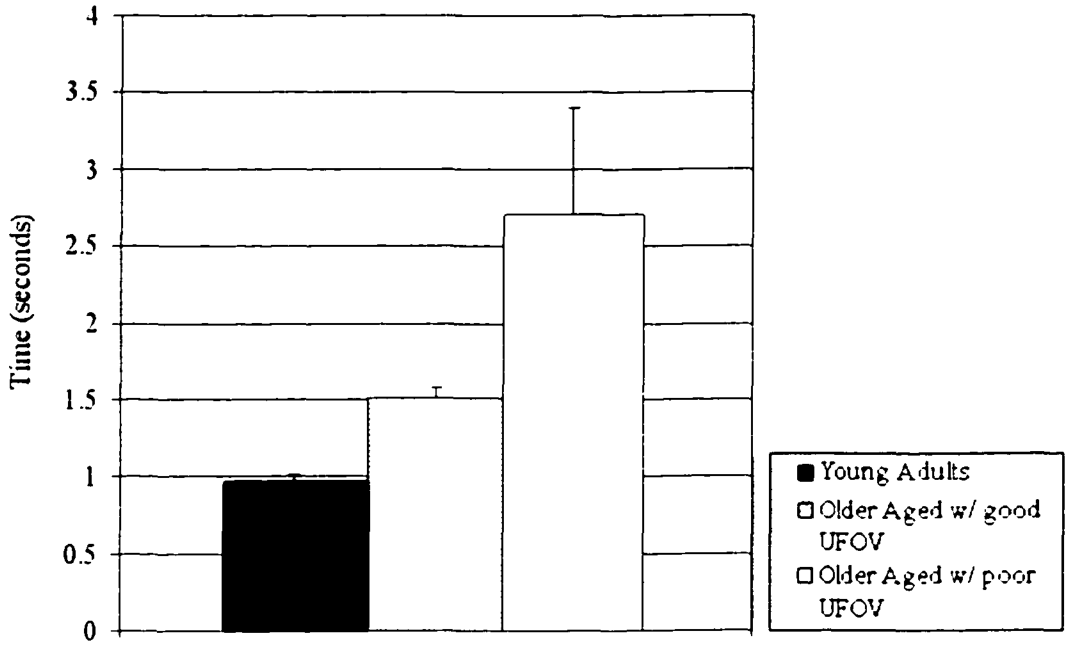


Figure 13. Low velocity motion discrimination by group (+SE). Age-based group differences were significant, with younger adults detecting more events than all older adults for all coherence levels. Younger adults outperformed older adults with good UFOV[R] ($p < 0.025$), but no significant differences were found between older adult groups ($p > 0.025$). UFOV[R] = Useful Field of View Test.



Participant Group

Figure 14. Road Sign Test 3-sign by group (+SE). Age-based group differences were significant, with younger adults responding faster than all older participants. Younger adults outperformed older adults with good UFOV[R] ($p < 0.001$), but no significant differences were found between older adult groups ($p = 0.096$). UFOV[R] = Useful Field of View Test.

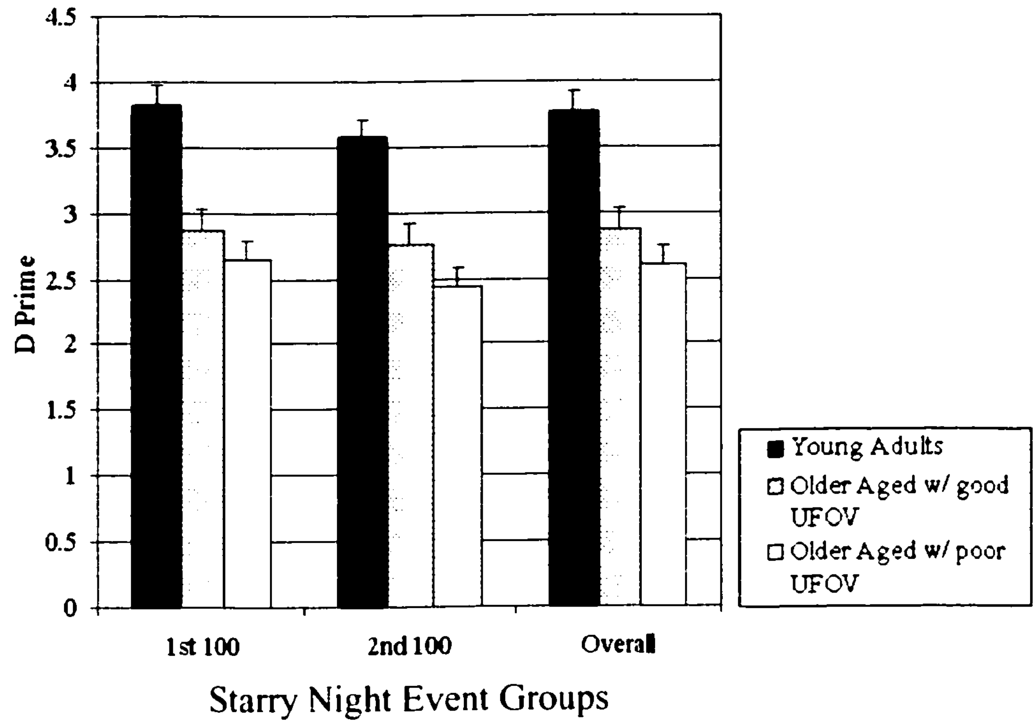


Figure 15. Starry Night Test of sustained visual attention by group (+SE). All groups experienced small performance decrements between the first and second 100 events, but only age-based differences were significant with younger adults detecting more events than all older participants. Younger adults outperformed older adults with good UFOV[K] ($p < 0.025$), but no significant differences were found between older adult groups ($p > 0.025$). UFOV[K] = Useful Field of View Test.

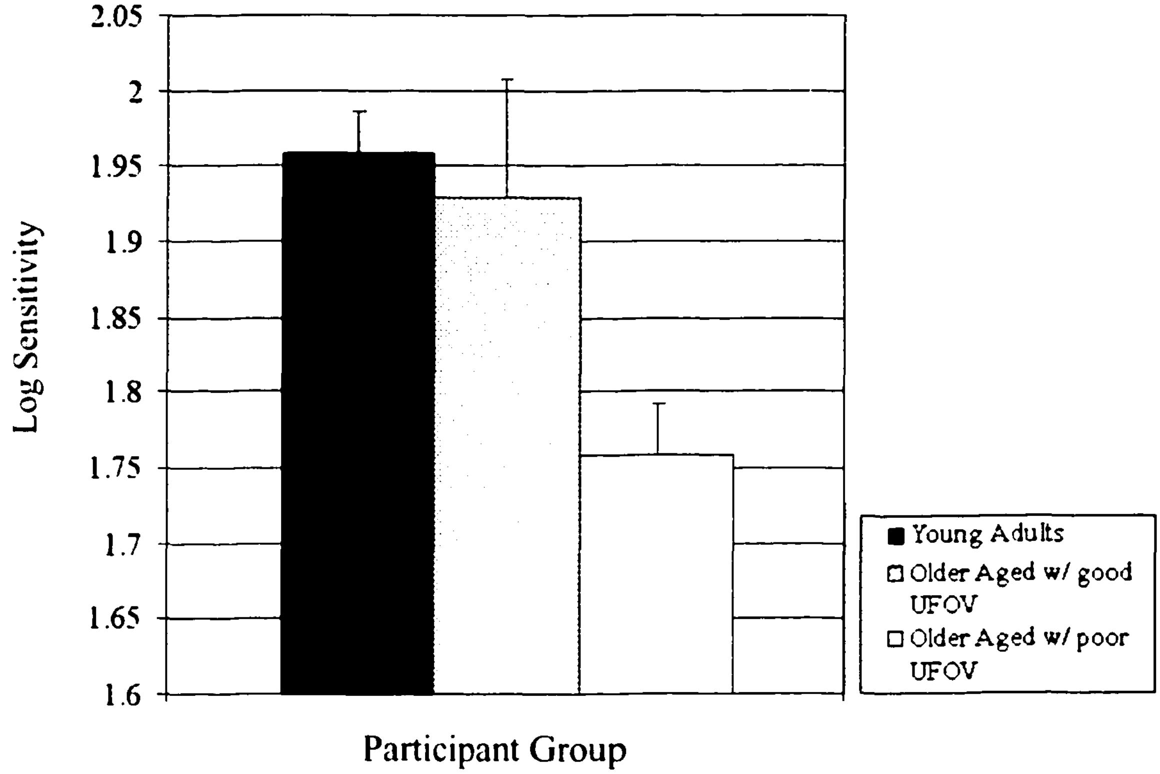


Figure 16. Grating contrast sensitivity (0.5 cpd) by group (+SE). UFOV[R] impairment-based group differences were significant, with younger adults and older adults with good UFOV[R] performing statistically equivalent to each other ($p = 0.492$). Older adults with good UFOV[R] outperformed older adults with impaired UFOV[R] ($p = 0.001$). UFOV[R] = Useful Field of View Test.

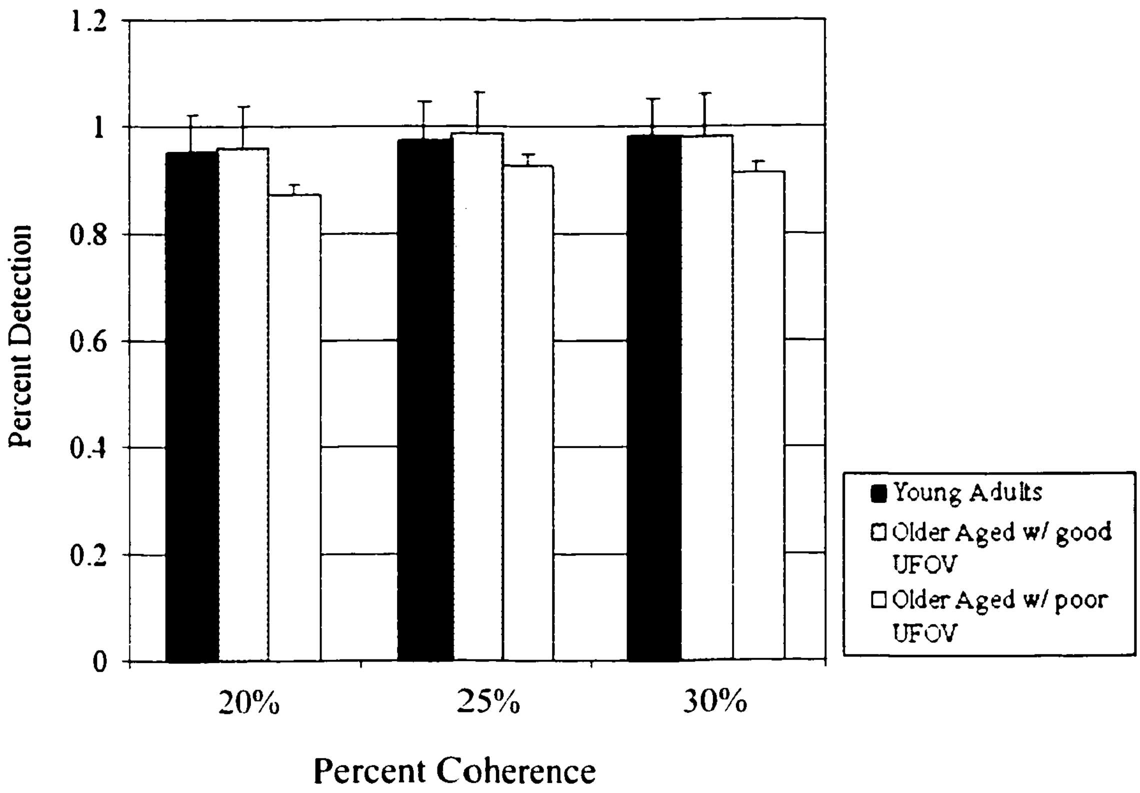


Figure 17. High velocity motion discrimination 20%, 25%, and 30% percent coherence by group (+SE). UFOV® impairment-based group differences were significant, with younger adults and older adults with good UFOV® performing statistically equivalent for coherence levels (20%, 25%, 30%; $p \leq 0.642$, 0.389, 0.867, respectively). Older adults with good UFOV® outperformed UFOV® impaired older adults for coherence levels (20%, 25%, 30%; $p = 0.002$, 0.08, 0.01, respectively). UFOV® = Useful Field of View Test.

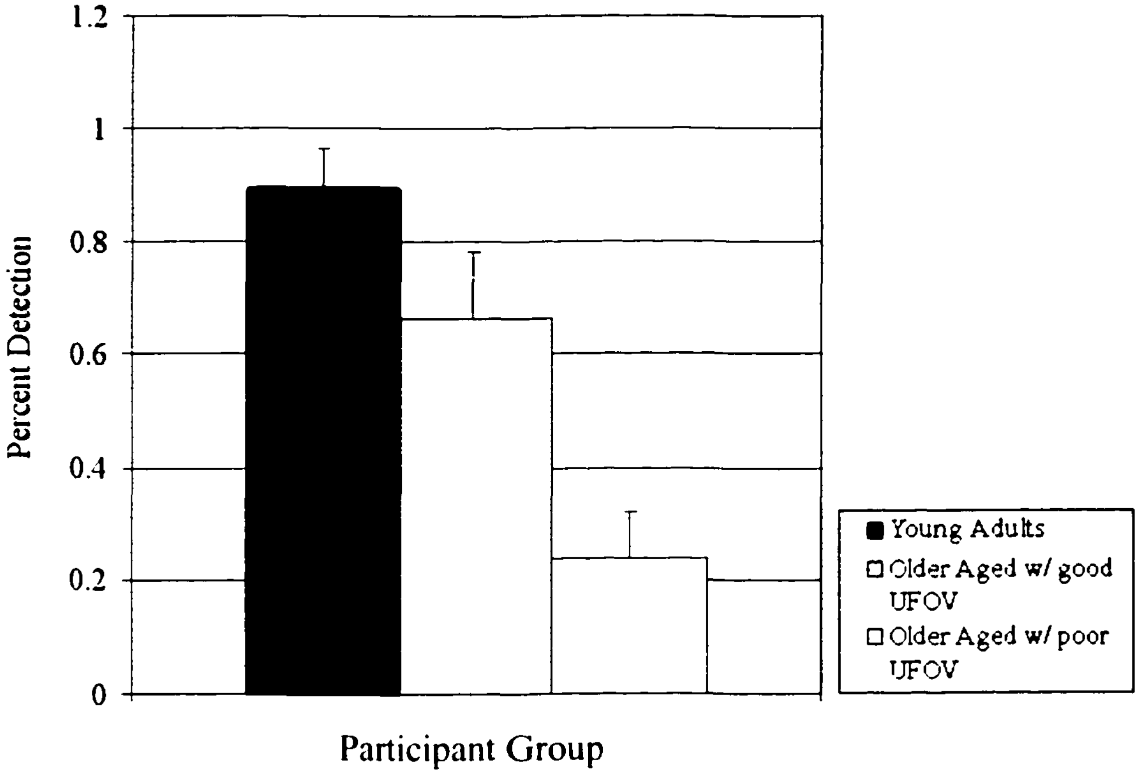


Figure 18. Percent detection for center targets under high cognitive demand driving conditions (+SE) by group. UFOV® impairment-based group differences were significant, with younger adults (n = 22) and older adults with good UFOV® (n = 18) performing statistically equivalent to each other (p = 0.827). Older adults with good UFOV® outperformed older adults with impaired UFOV® (n = 29); (p = 0.013). UFOV® = Useful Field of View Test.

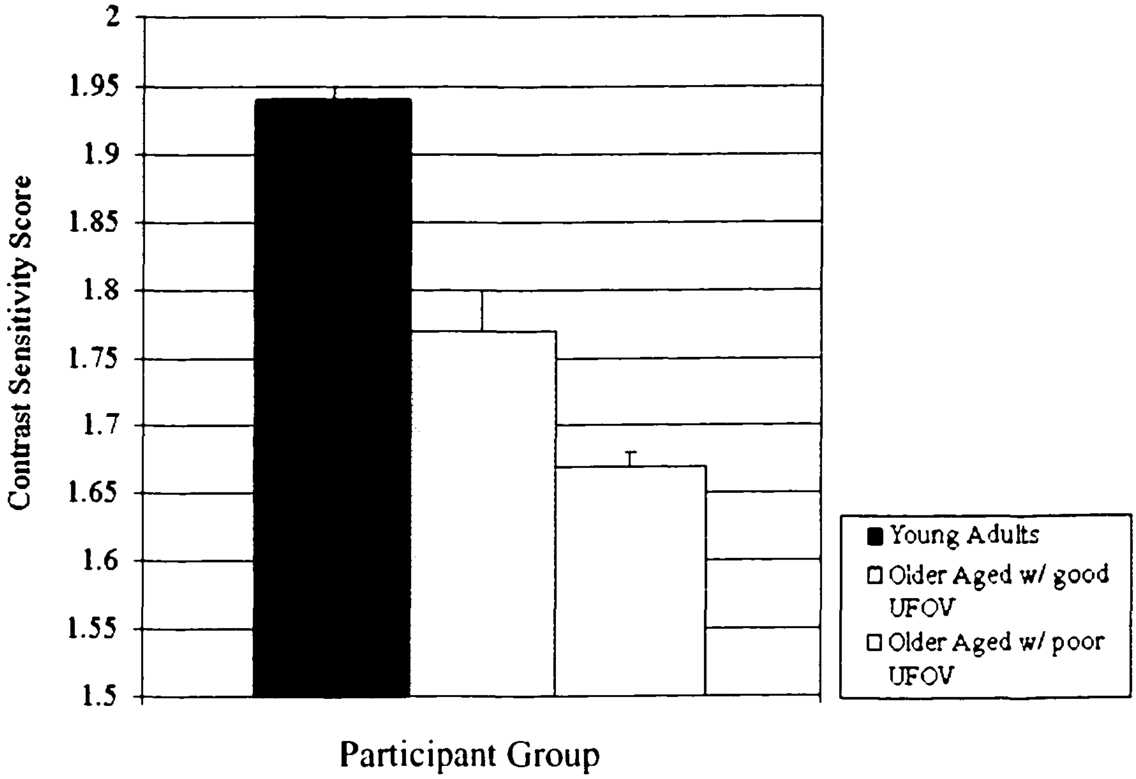


Figure 19. Pelli-Robson chart contrast sensitivity by group (+SE). Age-based and UFOV[R] impairment-based group differences were significant, with younger adults outperforming older adults with good UFOV[R] ($p < 0.001$) and older adults with good UFOV[R] outperforming older adults with impaired UFOV[R] ($p < 0.001$). UFOV[R] = Useful Field of View Test.

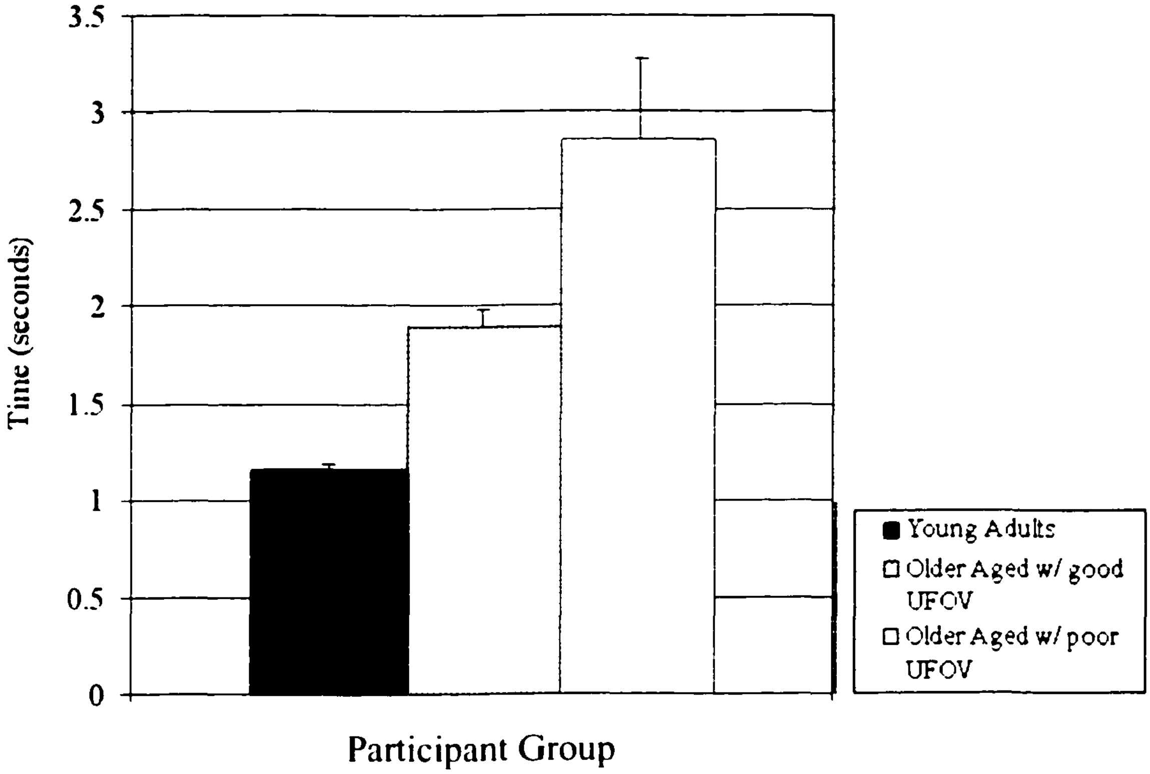


Figure 20. Road Sign Test 6-sign by group (+SE). Age-based and UFOV® impairment-based group differences were significant, with younger adults outperforming older adults with good UFOV® ($p < 0.001$) and older adults with good UFOV® outperforming older adults with impaired UFOV® ($p = 0.021$). UFOV® = Useful Field of View Test.

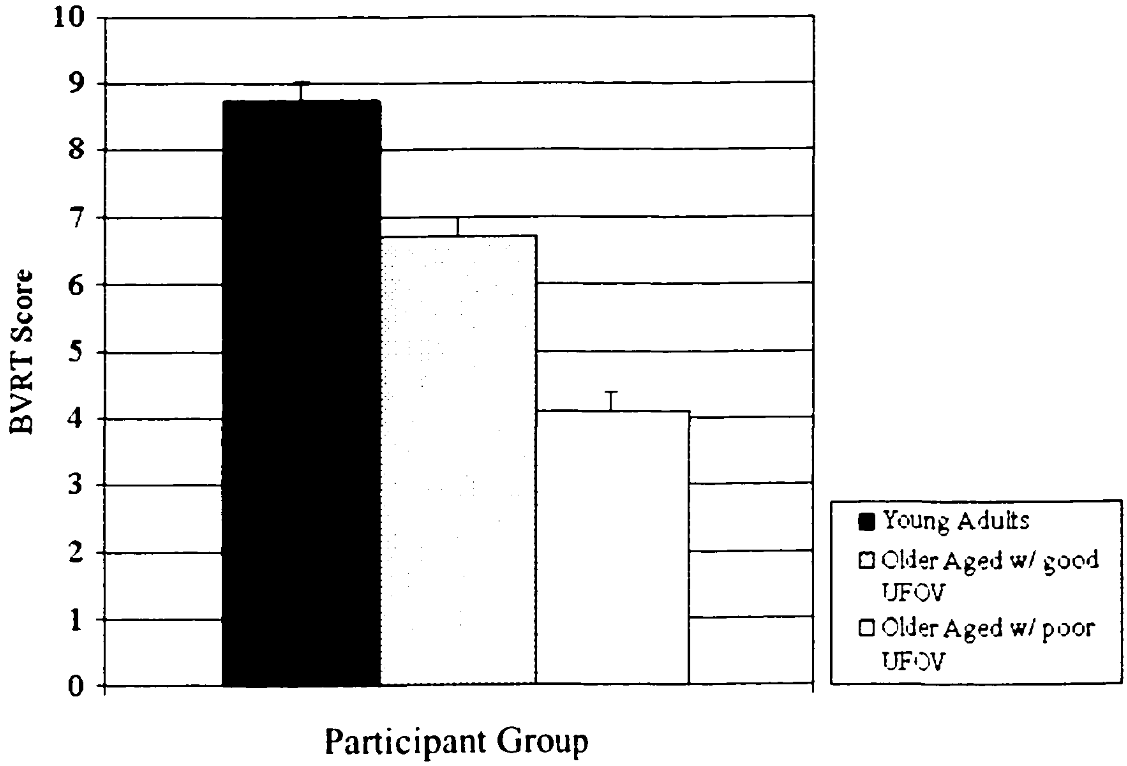


Figure 21. Benton Visual Retention Test (BVRT) by group (+SE). Age-based and UFOV® impairment-based group differences were significant, with younger adults outperforming older adults with good UFOV® ($p < 0.001$) and older adults with good UFOV® outperforming older adults with impaired UFOV® ($p < 0.001$). UFOV® = Useful Field of View Test.

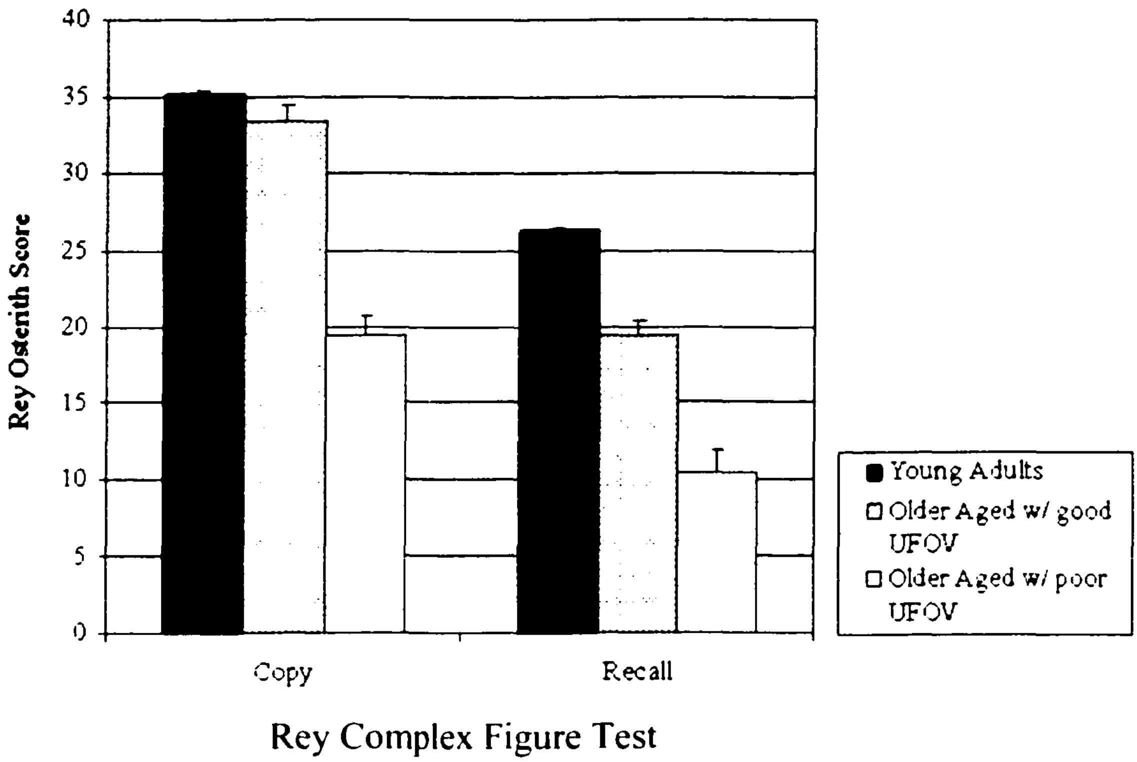


Figure 22. Rey Complex Figure Test (RCFT) by group (+SE). Age-based and UFOV® impairment-based group differences were significant, with younger adults copying the RCFT image more accurately than older adults with good UFOV® ($p = 0.006$) and older adults with good UFOV® copying the RCFT image more accurately than UFOV® impaired older adults ($p < 0.001$). In the more difficult immediate recall task, younger adults still more accurately reproduced the image compared with older adults with good UFOV® ($p < 0.001$) and older adults with good UFOV® outperformed UFOV® impaired older adults ($p < 0.001$). UFOV® = Useful Field of View Test.

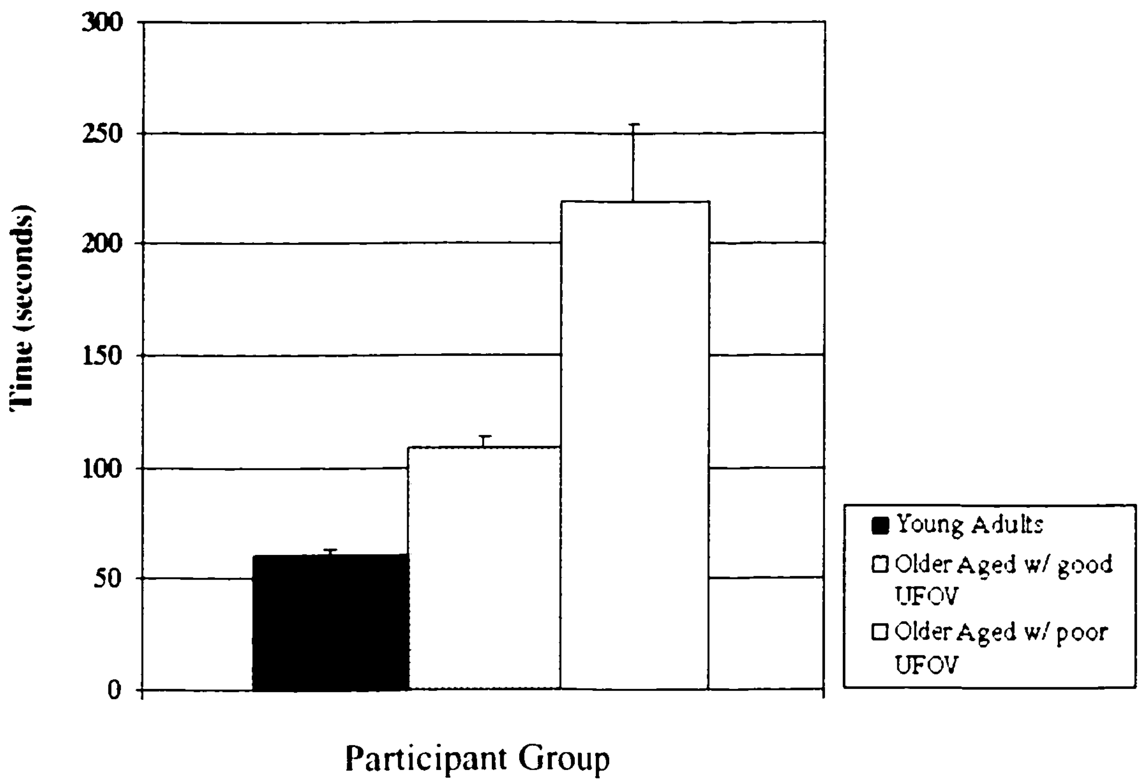


Figure 23. Trails Test by group (+SE). Age-based and UFOV[R] impairment-based group differences were significant, with younger adults more quickly completing the task than older adults with good UFOV[R] ($p < 0.001$) and older adults with good UFOV[R] completing the task more quickly than UFOV[R] impaired older adults ($p = 0.003$). UFOV[R] = Useful Field of View Test.

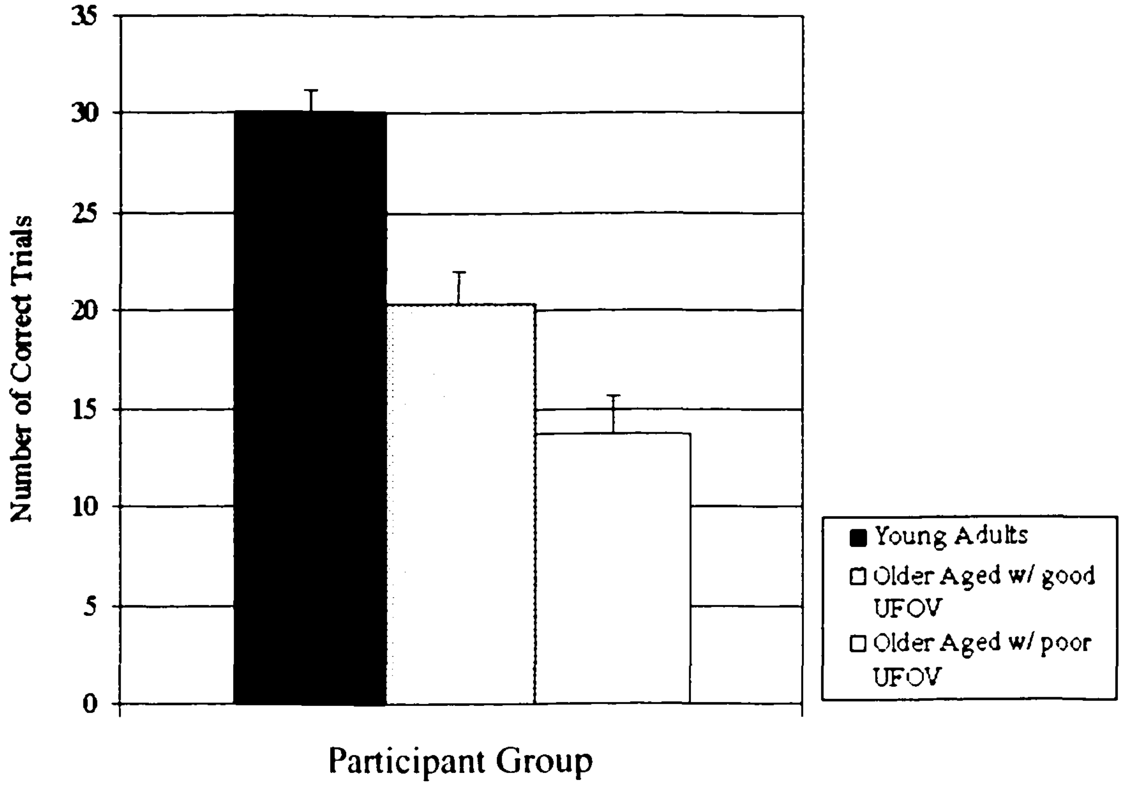


Figure 24. Paced Auditory Serial Addition Test (PASAT) by group (+SE). Age-based and UFOV® impairment-based group differences were significant, with younger adults outperforming older adults with good UFOV® ($p < 0.001$) and older adults with good UFOV® outperforming UFOV® impaired older adults ($p < 0.001$). UFOV® = Useful Field of View Test.

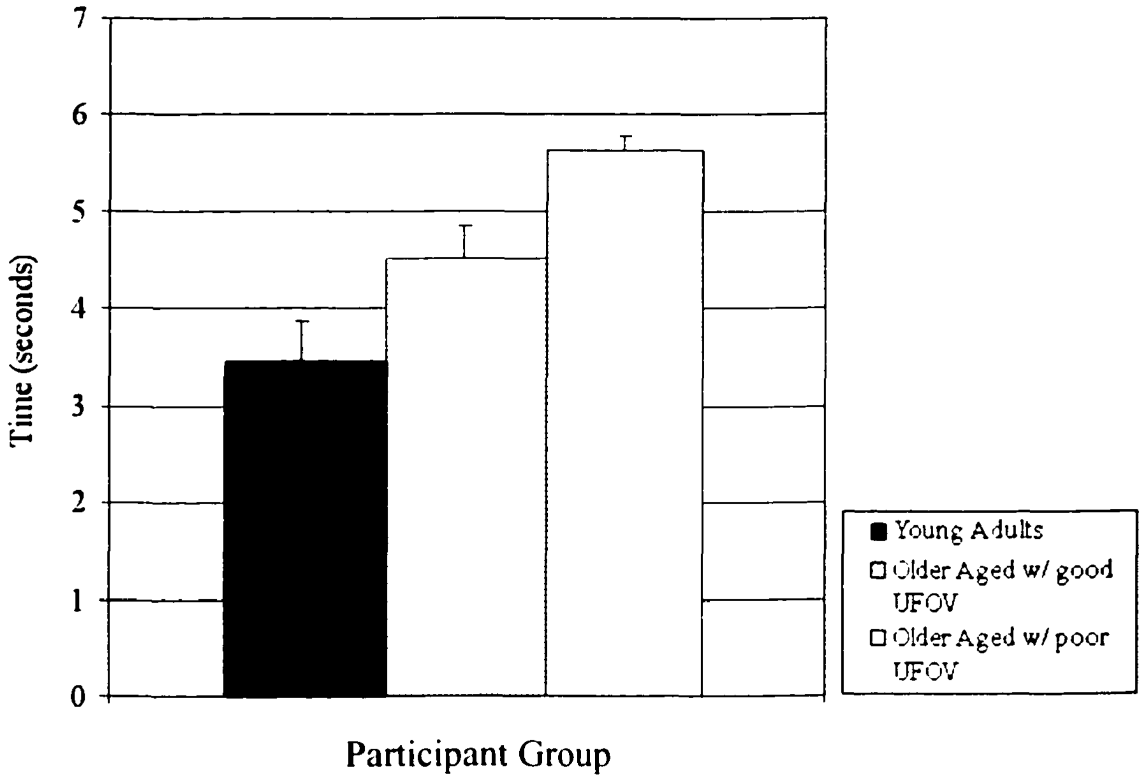


Figure 25. Response time to center targets under high cognitive demand driving conditions by group (+SE). Age-based and UFOV® impairment-based group differences were significant, with younger adults (n = 22) more quickly completing the task than older adults with good UFOV® (n = 18); ($p < 0.001$) and older adults with good UFOV® completing the task more quickly than UFOV® impaired older adults (n = 29); (p = 0.003). UFOV® = Useful Field of View Test.

Composite Analysis

To specifically address the relationship between magnocellular and nonmagnocellular sensitive visual function tests and UFOV® performance, data were structured to create a composite score. The composite score summarized performance across several similar measures of visual function. Two composite scores were calculated: one for performance on magnocellular sensitive tests and another for tests not sensitive to the M pathway. Composite scores were derived from calculating the mean z score for each participant across all pathway-sensitive tests. Certain variables were reverse scored such that a positive z score represented better performance. The magnocellular composite score consisted of the mean FDT threshold: 0.5 cpd grating contrast sensitivity and the low velocity motion discrimination threshold (reverse scored). Selecting vision measures that were not sensitive to the M pathway posed some challenge. Tests requiring high-resolution vision, such as grating contrast sensitivity for 22.8 cpd and distance visual acuity, were included. Because the SWAP measure is considered to be driven by a unique population of retinal ganglion cells, it was not clear whether or not to include it into the nonmagnocellular-sensitive composite score. To determine how SWAP might alter the composite score, the nonmagnocellular composite score was calculated with and without SWAP. The pattern of significance of the nonmagnocellular-sensitive composite score between groups with and without SWAP was unchanged. Therefore, SWAP was retained as part of the nonmagnocellular composite score as it behaved similarly to the other nonmagnocellular-sensitive vision tests.

Positive composite scores indicated that participants performed better than the overall mean of all participants. A negative composite score indicated performance below the overall mean of all participants. These composite scores were then analyzed for group differences, as were previous vision, cognitive, and behavioral measures. The average composite score for the younger adult participant group for both magnocellular and nonmagnocellular tests were 0.265 and 0.805, respectively. Older adults with good UFOV® had composite scores for magnocellular and nonmagnocellular tests of 0.202 and

-0.141, respectively. Older adults with poor UFOV® had composite scores for magno-cellular and nonmagnocellular tests of -0.358 and -0.470, respectively.

Contrast comparisons show that the magnocellular composite score fits a UFOV® impairment-based pattern of significance (Figure 26), with younger adults and older adults with unimpaired UFOV® performing significantly better than the UFOV® impaired older group to each other ($p = 0.601$) and older adults with impaired UFOV® performing worse than all other participants on magnocellular sensitive vision tests ($p < 0.001$).

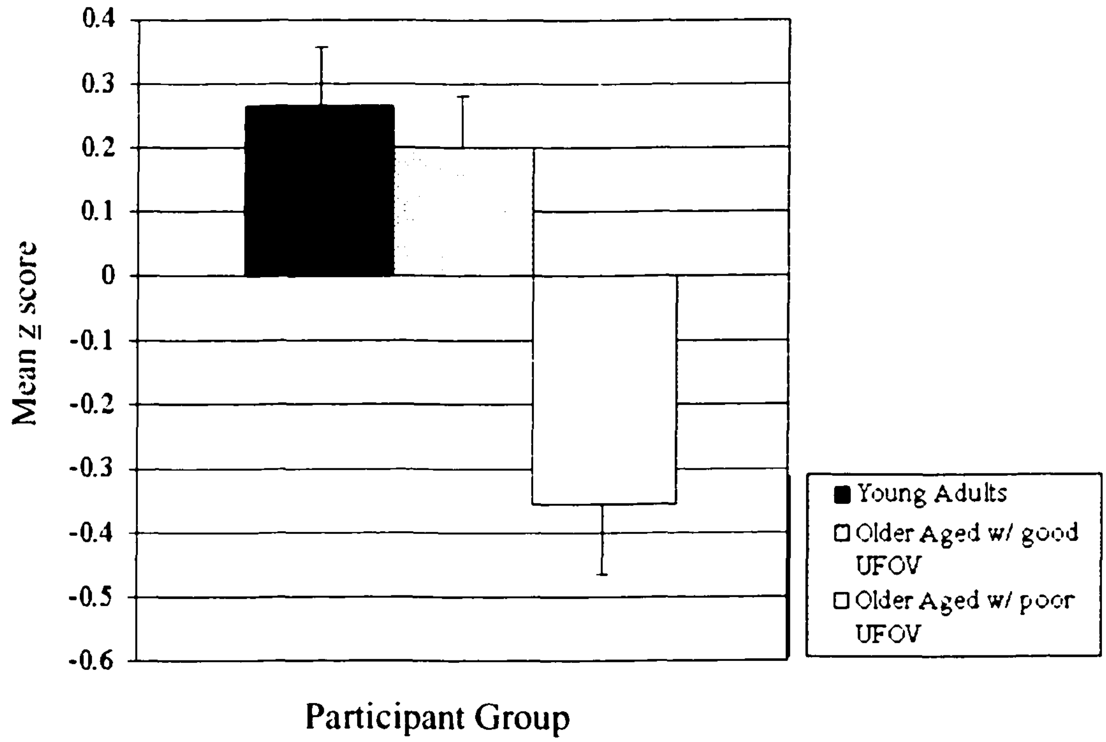


Figure 26. Magnocellular-sensitive composite scores by group (+/-SE). This composite score fits into the UFOV® impaired-based pattern of performance. Younger adults and older adults with good UFOV® were statistically equivalent ($p = 0.601$), and older adults with good UFOV® outperformed older adults with impaired UFOV® on magnocellular sensitive vision tests ($p < 0.001$). UFOV® = Useful Field of View Test.

Contrast comparison of the nonmagnocellular-sensitive composite score, however, shows the age-based pattern of results between participant groups (Figure 27). Younger adults outperformed both older groups on measures not sensitive to the magnocellular pathway ($p < 0.001$). Although there was a trend toward poorer performance for older adults with impaired UFOV®, no statistical difference was found between the older adults with good UFOV® ability and those with poor UFOV® ability ($p = 0.045$).

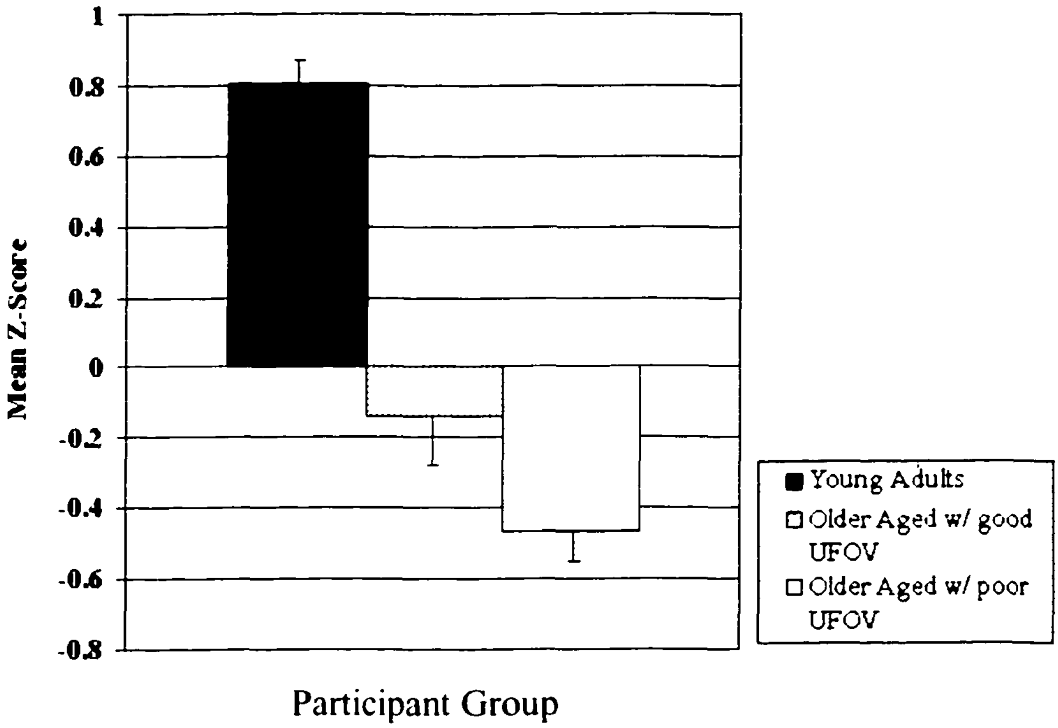


Figure 27. Nonmagnocellular-sensitive composite scores by group (+/-SE). Younger adults performed better than all older adults on vision measures not sensitive to the magnocellular pathway ($p < 0.001$). Older adult performance did not differ between groups ($p = 0.045$). These results fit the age-based pattern of significance. UFOV® = Useful Field of View Test.

Path Analysis

A comprehensive path diagram was developed to describe and evaluate the direct and indirect relationships among the visual, cognitive, and driving measures. The model diagramed below takes into account all the primary measured variables in this study and includes latent variables representing major factors or constructs of the measured variables. Measured variables are identified as rectangles, and circles represent latent variables. Relationships between both measured and latent variables are diagramed with lines. Lines with a single arrowhead indicate a direct relationship between two variables. The variable being pointed at by the arrow is considered the dependent variable in the relationship. Lines with double arrowheads indicate a covariance between two variables with no causal relationship.

The specific aims of this study were to examine the relationship between visual function tests, cognitive measures of visual attention, and measures of driving simulator performance. Two latent variables represented the primary pathways of visual information: magnocellular and parvocellular vision (nonmagnocellular). Observed variables were those variables included in the calculation of the magnocellular-sensitive composite score and nonmagnocellular composite score. UFOV® Total, RST (6-signs), Starry Night (d-prime overall), and Trails B Time were the observed variables for Transient and Sustained Visual Attention latent variables. The Driving Performance latent variable was derived from reaction time and percent correct for the Center high demand, Center low demand, and Peripheral high demand driving simulation tasks.

In accordance with the hypotheses of this study, the model demonstrated magnocellular vision is the primary resource of visual information for transient visual attention, whereas nonmagnocellular vision is the primary resource of sustained visual attention. Both mechanisms of visual attention, however, were required for safe driving performance, which is indicated by the present model. Minor relationships between magnocellular and sustained visual attention and nonmagnocellular and transient visual attention were also included in the model, because these relationships did exist but were not the primary source of visual information utilized by the attentional mechanisms as hypothesized by this study. Dotted lines have been used to demonstrate the presence of these minor effects (Figure 28).

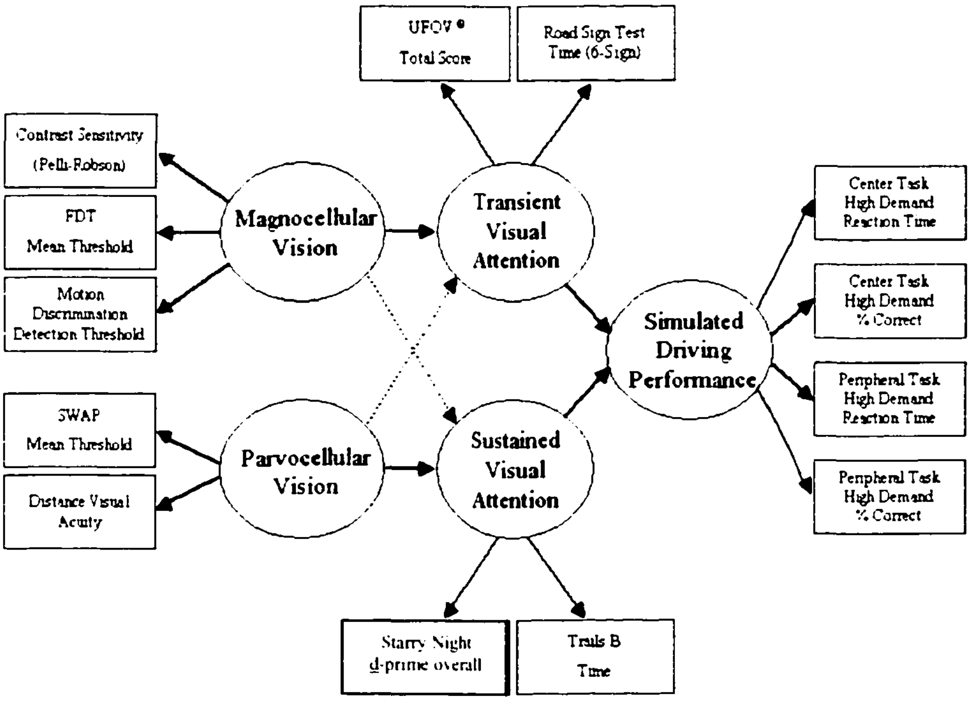


Figure 28. Comprehensive path diagram. UFOV® = Useful Field of View Test; FDT = Frequency Doubling Technology; SWAP = Short Wavelength Automated Perimetry.

One of the drawbacks of using path analysis to test theoretical models is it requires a relatively large sample to test models of any complexity (such as the comprehensive model displayed here). Samples of greater than 200 participants would be required to test this model with any assurance of validity. To test these relationships with the present sample, however, redundant latent variables and minor observed variables were removed from the model. Path relationships between the most representative of the observed variables were retained to evaluate the primary relationships hypothesized in the comprehensive model. For the purposes of reducing the comprehensive model, observed variables that best represented the construct variables were selected. In the case of magnocellular vision, contrast sensitivity measured using the Pelli-Robson chart was used, because it demonstrated the greatest correlation with UFOV® total, which is the observed variable to be used in place of the transient visual attention construct. SWAP mean threshold remained as the observed variable for nonmagnocellular vision, and Starry Night remained as the measure of sustained visual attention. Driving performance was the only latent variable not replaced by a single observed variable. To retain the distinctness between central visual task performance and peripheral visual task performance in the driving simulator, the reaction time scores for the high demand target detection tasks were retained as individual variables in the reduced model.

The reduced model was analyzed with LISREL using the maximum likelihood method. Participants with missing data in any of the included observed variables were removed from the analysis, leaving the final analysis with 68 out of the total of 87 participants. A preliminary full model was analyzed allowing the two vision measures to covary. The full model produced a significant chi-square value, χ^2 (6, $\underline{N}$ = 68) = 14.05, $\underline{p}$ < 0.029. The model fit well to the data, with a goodness of fit index (GFI) of 0.935. $\underline{T}$ values for each interaction are shown in Figure 29.

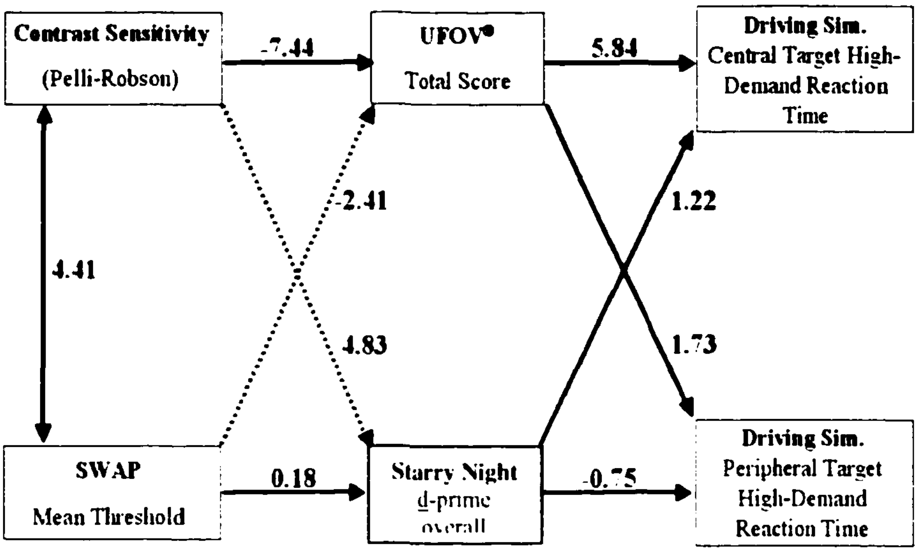


Figure 29. Reduced model with t values. UFOV® = Useful Field of View Test; SWAP = Short Wavelength Automated Perimetry.

Path analysis of the reduced model showed that the measure of transient visual attention, UFOV® total, was related to observed measures of magnocellular and non-magnocellular vision, $t = -7.44$ and -2.41, respectively. The negative t values reflected that increased scores on the Pelli-Robson Contrast Sensitivity Chart and SWAP (better performance) correlate with faster visual processing speed. The representative of sustained visual attention (Starry Night d prime overall) was significantly related to contrast sensitivity performance ($t = 4.83$) but not with SWAP performance ($t = 0.18$). With respect to driving simulator performance, response times to peripheral targets under high demand conditions were not related to either measure of visual attention. Only the transient visual attention, UFOV® total score, was significantly correlated with response times to central targets under high demand conditions ($t = 5.84$). The positive t value reflected that faster speed of processing on the UFOV® correlates with quicker target detection for central targets in the high demand driving simulation tasks.

Examining the standard solutions for the full model indicated the relative strength of associations between variables in the model. Standardized scores for the reduced model are shown in Figure 30. Much like correlation coefficients, the closer to 1.0 or -1.0 the stronger the association between variables. The two strongest pathways in the reduced model are those between contrast sensitivity and UFOV® total score and UFOV® total score and central high demand reaction time. The nonmagnocellular vision measure, SWAP, was not related to performance on the sustained visual attention task and only marginally related to the transient visual attention task. The magnocellular vision measure, contrast sensitivity, had three times greater associative strength with the transient visual attention measure than did the nonmagnocellular representative, SWAP mean. The transient visual attention representative measure, UFOV® total score, was similarly related to target detection in the simulated driving task, whereas the sustained visual attention representative, Starry Night, was not significantly related to either simulated driving measure.

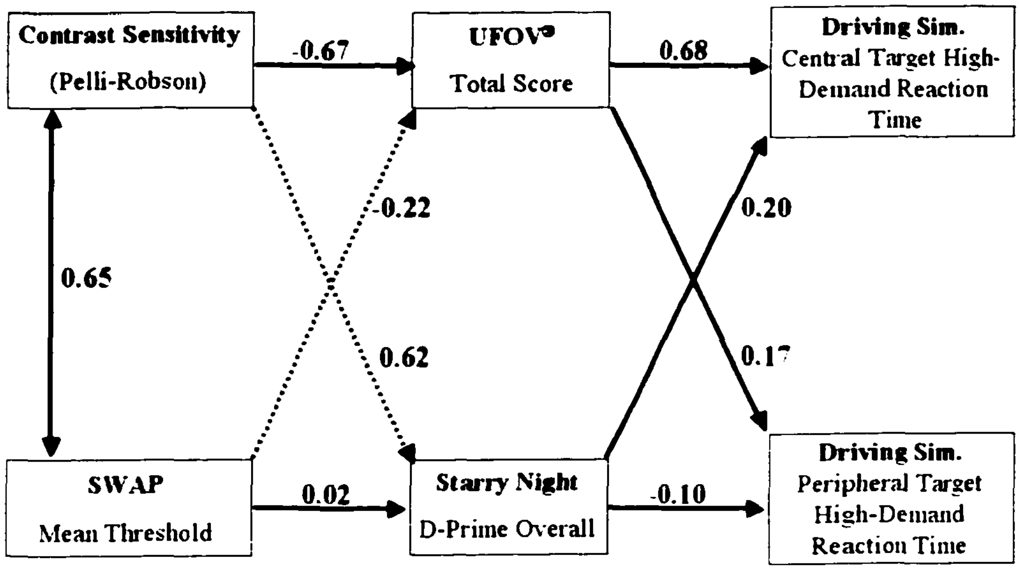


Figure 30. Reduced model with standardized scores. UFOV® = Useful Field of View Test; SWAP = Short Wavelength Automated Perimetry.

CONCLUSIONS

The specific aims of this study were to examine the relationships between measures of visual function, cognitive ability, and driving performance with specific emphasis on the effects of age and UFOV® performance. While not unexpected, the results of this study provide continued support that younger adults perform better overall on visual function, cognitive function, and simulated driving tests. But the evidence does not indicate that age is the only determining factor in participants' overall performance. Categorizing older adults based on their UFOV® performance provided the opportunity to evaluate sensory, cognitive, and driving performance in the absence of age effects. The results suggest that older adults with deteriorated UFOV® abilities are likely experiencing deficiencies in cognitive areas other than simply visual attention. Conversely, older adults with good UFOV® could at times perform as well as adults as much as 40 years younger in age on some visual and cognitive function measures. Although not always statistically significant, visually inspecting performance differences between older adults with good UFOV® and younger adults does show a general trend of decreased performance for older adults across all measures. This observation suggests that older adults with good UFOV® are visually and cognitively younger than their peers with poor UFOV®. The evidence indicates that the effects of age on visual and cognitive processes have not progressed at the same rate or to the same extent as with other older adults of similar age.

Similar findings of this general decline in cognitive and sensory abilities have been shown in other studies of older adults. Described earlier, using data from the Berlin

Aging Study, Baltes and Lindenberger likewise found that the detrimental effects of age on sensory and cognitive function were strongly related. In their words, sensory and cognitive function appeared to age together (Baltes & Lindenberger, 1997, Lindenberger & Baltes, 1994). These results are not limited to the population evaluated in the Berlin Aging Study. Salthouse demonstrated similar findings (1992, 1994, 1996) suggesting that age-related performance deficits on cognitive tasks may not necessarily be task specific but could be related to more general neurological factors that influence sensory and cognitive behaviors. The common cause hypothesis referenced earlier suggests a common factor or root cause driving the overt manifestations of sensory and cognitive deficiencies observed in these studies. Salthouse (1996) hypothesized the common cause to be the general slowing of the speed of neural processing, leading to a reduction in the overall effectiveness of neural systems. Salthouse's hypothesis compliments the findings observed in the present study. Processing speed as assessed in all four UFOV® subtests may capture elements of Salthouse's common cause, explaining the ubiquitous correlations between UFOV® performance and other cognitive and visual function measures.

In addition to examining the relationship between age and UFOV® performance, the present study also took a closer look at the relationship between certain types of visual function tests and performance on the UFOV®. This study investigated the theory that magnocellular vision was necessary for optimal performance on tests of transient visual attention, such as the UFOV® (S.B. Steinman et al., 1994). The results of the current study provide partial support for this theory. Using the line-motion illusion, S.B. Steinman (1994) demonstrated that older adults consistently experienced weaker illusory motion than did younger adults and in many cases did not observe the illusion at all. As has been discussed, it was ultimately learned that perception of the illusion was strongest when the visual components of the illusion were modified to favor the magnocellular visual processing pathway. A much weaker illusory affect (similar in magnitude with older adults) was observed in younger adults when the visual components of the illusion were modified to favor parvocellular visual processing.

In the present study there was no consistent significant relationship between tests of magnocellular-specific visual function and UFOV® impairment in older adults. Contrast sensitivity to low spatial resolution targets and motion discrimination of high velocity targets were related to UFOV® impairment in older adults, while performance on the FDT was primarily age-based. However, when a composite score was examined evaluating magnocellular-sensitive and nonmagnocellular-sensitive visual function tests, UFOV® was related to an overall performance on magnocellular-sensitive vision tests but not with the overall performance on nonmagnocellular-sensitive vision tests. Based on the composite score evaluations, some support for the magnocellular theory of transient visual attention is given. In the present study, overall performance on magnocellular-sensitive tasks (motion discrimination, low spatial resolution contrast sensitivity, FDT) by individuals with poor transient visual attention was significantly worse than all other participants regardless of age. Older adults with low magnocellular-sensitive composite scores had poorer overall performance on the measures of transient visual attention (UFOV® and RST), lending further support to the hypothesis that magnocellular visual information is predominantly required for optimal performance of the transient visual attention mechanism. In contrast, there was a trend toward poorer performance on the nonmagnocellular tasks based only on participants' ages, not on UFOV® impairments.

Path analysis techniques used to further explore these relationships demonstrate that magnocellular visual function has a three times greater impact on UFOV® performance than does nonmagnocellular visual function. This difference indicates that both visual processing systems are influential to UFOV® performance and to transient attention mechanisms as a whole; however, there is a unique and predominantly stronger relationship between the ability for older adults to acquire and process magnocellular visual information and the utilization of that visual information to analyze, interpret, and orient visual attention through transient visual attention mechanisms. Much of this may be related to the fact that successful performance on the UFOV® requires foremost the ability to perceive and locate a peripheral target presented at high rates of speed on the visual display. Detection of rapidly displayed images is a task that the magnocellular system does particularly well when compared with the parvocellular system. The UFOV® determines the size of participants' useful field of view by altering the presentation rates of the visual stimuli. The shorter the display time the greater a participants' useful field of view must be in order to detect and perceive both the central and the peripheral targets. When participants have a constricted UFOV®, it is typically at the expense of the peripheral area leaving central vision relatively in tact (Figure 31). Therefore, when UFOV® scores are poor, it is almost always due to the inability of participants to complete the localization component of the peripheral task as opposed to the identification component of the central task. To achieve better UFOV® scores, a faster processing speed is required to capture and interpret visual information from the larger spatial area. If performance within the visual processing pathway specific to brief, transient visual information is compromised, performance on cognitive tasks that specifically depend on rapidly perceived visual information would likewise be compromised.

Examining the specific cognitive areas where older adults with poor UFOV® had difficulty provides further clarification for these findings. Visual search and sequencing tasks (RST and Trails Test) and visual memory (BVRT and RCFT) tasks were significantly deficient in older adults with poor UFOV®. A primary component for successful task completion in these tests is the ability to rapidly scan the visual scene to acquire relevant task-related information. In the RST, this comes in the form of detecting the one sign without the diagonal red slash. This is essentially a stimulus feature detection task with the absent diagonal line being the relevant feature. In the Trails Test, success is dependent on rapidly scanning the test area in search of the next letter or number in the sequence. In this case, top-down processing is clearly required for storing the information about target sequence. At a more fundamental level, however, transient visual attention mechanisms are also at play.

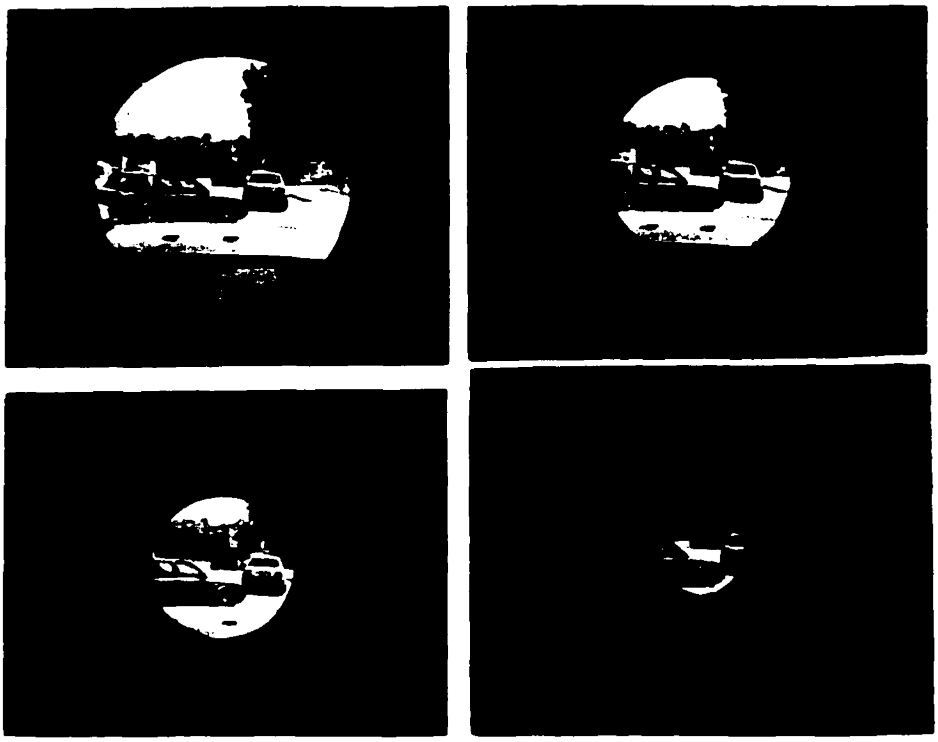


Figure 31. Reduction in UFOV®. Reduction in the UFOV® begins in the periphery and progresses inward with increased severity.

Vidyasagar (1999) stated that, even in dyslexic patients where the cognitive disability seems to be related to parvocellular processes, there is strong evidence that these children experience magnocellular defects. In reading disabilities that are largely attributable to problems in the sequential allocation of attention, magnocellular visual function appears to be a common element among sufferers. In the case of Trails performance, transient attention mechanisms may still be a potential source of performance deficits. The ability to rapidly engage and disengage fixation is crucial to quick completion of both Trails and RST tasks. If transient visual attention systems are not functioning at optimal levels due to poor sensory input via M pathways, the ability to serially search the stimuli in Trails or RST could be inefficient and inaccurate leading to slower performance times. Evidence from the present study and from S.B. Steinman et al. (1994) shows that magnocellular or nonmagnocellular vision is capable of driving transient attention mechanisms. However, under normal physiological circumstances magnocellular input provides the stronger driving force behind the transient attention function as is shown in path analysis data. But if circumstances change visually due to age-related effects or otherwise, altering the balance of visual information provided to the attentional mechanisms, then performance decreases in the form of slower response times or weaker illusory perceptions as shown in the case of S.B. Steinman et al. (1994). Following this evidence, if older adults experience age-related changes to the M pathway and nonmagnocellular information is being utilized to drive the attention shifts observed in Trails and RST, then slower less accurate performance might be expected. Similar results were found in Iles, Walsh, and Richardson (2000). Dyslexic participants who displayed poor magnocellular visual function using similar visual measures (coherent motion discrimination) also displayed increased visual search times on serial search tasks, whereas dyslexic participants who performed well on coherent motion tests showed no decrease in serial visual search rates compared to nondyslexic controls.

Visual memory performance in this study was also affected in older adults with poor UFOV®. As in the previous discussion, memory tasks are clearly cortical in nature. However, if images are not adequately scanned and the visual information is not encoded, then memory becomes irrelevant. If older adults with poor UFOV® have difficulty scanning or searching a visual scene, as was evident in the Trails and RST data, then they may also fail to scan the image to be recalled in the memory tasks, ultimately producing poorer memory scores. Evidence of improper scanning is shown in both RCFT copy and

RCFT recall. Scores are significantly lower in individuals with poor UFOV®. In this situation there may be no deficiencies in participants' memory function, rather the visual information is not being encoded accurately.

An aspect of transient visual attention often ignored is its involuntary nature. Transient attention mechanisms are largely involuntary, forcing visual fixation to locations regardless of top-down conscious control. Araujo, Kowler, and Pavel (2001) evaluated eye movements during a visual search task. Participants were instructed to search for and identify an alphabetical character embedded in one of two clusters of distracters situated on either side of the central fixation point. One cluster was positioned near fixation, and the other was positioned a significant distance away. The participants were trained on the task such that 80% of the time the target appeared in the distant cluster. Knowing this information, top-down influences were expected to bias visual search patterns, such that the distant cluster of greatest target probability would be investigated first, followed by the less probable target area. However, in most participants visual search was conducted in just the opposite order. Top-down influences were unable to alter the involuntary search strategies. In the normal scanning of an image, involuntary search patterns are predominating. In most visual search tasks, individuals with normal UFOV® are somewhat passive observers, and involuntary attention mechanisms provide a full scan of the images presented largely without input from higher consciously controlled centers. Individuals with poor UFOV® may not have as efficient transient/involuntary attentional mechanisms, therefore requiring more conscious effort to fully scan and search the image during the copying task of the RCFT.

Much of the negative effects on cognitive performance in individuals with poor UFOV® can be potentially traced back to lower level visual processing via M or P pathways. The visual search literature provides evidence that early processing of magnocellular visual information is valuable for rapidly and involuntarily orienting visual attention based on the physical characteristics of stimuli in the visual environment. It is this aspect of visual attention that the UFOV® captures. The evidence that magnocellular performance is decreased in this sample of individuals with poor UFOV® and the evidence that UFOV® is highly correlated with numerous cognitive measures and that visual search and visual memory measures are significantly correlated with one another suggest the possibility that altered early visual processing and transient attention mechanisms may have widespread indirect influences on cognitive performance.

This study was also the first to examine the relationship between UFOV® ability and behavioral performance in the UAB Driving Simulator. The UFOV® has historically been a strong predictor of vehicular crash risk (Ball et al., 1993). The inclusion of the UAB Driving Simulator allowed for the assessment of the indirect and direct effects of visual function on driving performance. But more specifically, this test was to replicate the observed relationship between UFOV® and driving performance, as assessed by crash records, with simulated driving behavior in the UAB Driving Simulator. The findings in this study are consistent with crash analysis studies, showing that UFOV® performance is predictive of certain aspects of driving performance. Poor UFOV® performance in older adults was related to the detection of fewer targets and overall slower detection times for central and peripheral visual targets in a variety of driving conditions and environments. The slower target detection times for objects in the simulated driving scene again suggest potential inefficiencies in visual search behavior in older adults with poor UFOV®, causing them to require more time to detect potentially hazardous objects in real world driving environments and placing them at higher crash risk.

Results from this study, however, demonstrated distinct differences in the types of visual targets that older adults with poor UFOV® had difficulty detecting. Compared with critical targets and targets originating in the periphery, targets originating in the central visual field posed the greatest challenge for older adults with poor UFOV®.

One explanation for this apparent discrepancy could be the level of saliency of the critical and peripheral targets. The higher the degree of saliency of the visual target, the easier it was for the participant to detect. Less salient targets posed a greater cognitive challenge requiring more efficient visual attention and visual search capabilities. Critical targets took the form of pedestrians stepping out into the roadway or car doors opening on the side of the street. Peripheral targets included vehicles passing around the participants' simulated vehicles. These targets all share a high degree of saliency in the form of a quick, sudden entry into the participants' fields of view. In the case of the peripheral targets, the passing vehicles were much larger in size compared with central targets. Central targets may have been more difficult to detect as they were often times static targets such as street signs, parked cars, or pedestrians walking down the street, requiring the participant to detect more subtle differences in the visual field. A similar outcome was observed in the motion discrimination data. On less challenging cognitive tasks such as high-percentage correlated motion tasks, few group differences were observed between older adults. However, as tasks became more challenging and visual targets became less salient, older adults with poor UFOV® were unable to maintain the same level of performance as the older adults with normal UFOV®.

Another possible explanation for the lack of group differences in critical braking performance and target detection relates to the divided attention component of the tasks. Participants with poor UFOV® demonstrated no difficulty, compared to others, in their performance on primary driving tasks, avoiding potentially hazardous situations such as pedestrians crossing the street or cars inadvertently pulling out into their lanes of traffic. For these tasks older adults with poor UFOV® performed as well as other older adults and only mildly worse than younger participants. However, when asked to divide their attention to perform a secondary visual search task, this participant group took significantly longer to identify targets and on average found fewer targets than other groups. The addition of secondary tasks, however, did not significantly impair their performances on the primary driving task, suggesting that older adults with poor UFOV® maintained awareness of their immediate surroundings (as in Figure 31) but failed to actively search the environment for additional central and peripheral targets. To maintain equal performance to that of older adults with normal UFOV® would require the impaired participants to perform more fixations. The increase in target response times in older adults with impaired UFOV® may be due to the increased number of fixations necessary for these older adults to adequately survey the visual scene and locate the additional visual targets.

Other common causes such as neural processing speed may contribute even further to the overall age-related changes in sensory and cognitive performances observed in this study and other studies. But the quality of the early visual processing of information through M and P pathways is crucial to downstream performance of lower order cognitive processes such as transient visual attention and higher order cognitive processes, including sustained visual attention and visual memory.

Limitations

The strength of the current study could be improved through the improvement of driving simulation data extraction procedures, inclusion of more path specific functional vision tests, streamlining participant testing sessions, and altering the participant screening process.

A primary drawback in the current study was the limitations in extracting driving simulation data. The UAB Driving Simulator outputs data at an extremely high frequency, thus producing large quantities of data. Due to the volume of data produced, more refined automated data extraction procedures were needed to take full advantage of the information available. When more comprehensive automated data extraction become available, more specific driving behaviors will be able to be extracted from the data.

Many of the vision tests used in this study were not designed to isolate one particular visual processing pathway or another. Other than the FDT, other tests such as contrast sensitivity and motion discrimination could only be defined as predominantly sensitive to one visual pathway or another, but not pathway specific. Additionally, a clinical or psychophysical vision test specifically targeting the P pathway was not found prior to testing. Therefore the choice was made to create composite scores based on tests that were sensitive to the M pathway, and, in the absence of purely parvocellular measures, a second composite score was created based on tests largely considered nonmagnocellular in nature.

Differentiation between the composite scores might have been more evident were there more purely pathway specific variables included. In the current study, the true magnocellular contributions to transient visual attention performance might have been diluted by the inclusion of tests in the magnocellular composite score that were not purely pathway specific.

Logistically, the data collection sessions were longer than expected. Even given appropriate rest periods, some participants became fatigued during the testing sessions. Unfortunately, due to the number of cognitive and sensory tests in the battery, little could be done to decrease the workload on the participants. Due to the fact that some participants were involved in additional studies at the Center for Research on Applied Gerontology, scheduling for these individuals often resulted in their being at the research facility for an entire day. Reducing the session lengths could have improved the consistency and accuracy of participant performance.

This study also screened out participants with poor contrast sensitivity or distance visual acuity; therefore, effect sizes between groups may have been constrained. Although this was a necessity to ensure that participants had the visual capacity to adequately accomplish the test protocol, it may have reduced the effect sizes between participant groups. Had there been a larger spectrum of visual function ability among the participants, greater group differences might have been observed providing stronger evidence to either support or reject the hypotheses of this study.

Future Directions

To directly evaluate the sensory requirements used by transient visual attention tasks such as the UFOV®, it would be valuable to alter the stimuli of the UFOV® test. If the white on black, high contrast stimuli present in the UFOV® were altered to be more visual pathway specific, changes in processing speed, selective attention, and divided attention performance would indicate under which stimulus conditions visual attention performance was optimal. In much the same way that S.B. Steinman et al (1994) created isoluminant visual cues in the line-motion illusion test to isolate the P pathway, the stimuli in the UFOV® test could be made isoluminant to evaluate parvocellular contributions to UFOV® performance. If S.B. Steinman et al.'s (1994) and B.A. Steinman et al.'s (1996) conclusions were correct and magnocellular vision primarily drives transient visual attention, then UFOV® performance would suffer under isoluminant conditions. Conversely, were UFOV® stimuli made a lower contrast compared to the white on black, high contrast stimuli of present, it might further elucidate attention differences by forcing the visual attention mechanisms to function with completely segregated visual information.

Group size was limited in the present study. With increased numbers of participants, group differences might become more divergent. Since the completion of this study, an additional 69 older adults with poor UFOV® have completed the experimental protocol. In these additional cases, performance on peripheral target detection in the driving simulator became significantly worse compared with the present performance of the other participant groups. If the performance of the other two participant groups maintained at their current level, significant group performance differences would be found for both central and peripheral target detections in the driving tasks. This makes a strong case for the expansion of the current study with more younger adults and older adults with good UFOV®. Increasing the sample size would also allow for a complete path analysis of the relationships between sensory, cognitive, and driving performance variables as opposed to the simplified model evaluated in the present study.

In addition to increasing the sample size, recruiting different target populations other than older adults would also be beneficial. To more effectively describe the relationship between magnocellular vision and transient visual attention, recruiting participants with known magnocellular visual deficits would be valuable. Beyond age-related deficits in magnocellular visual function, magnocellular visual impairments have been found in individuals with dyslexia (Pammer & Lovegrove, 2001; Pammer & Wheatley, 2001; Vidyasagar, 2001; Vidyasagar & Pammer, 1999), schizophrenia (Butler et al., 2001; Schwartz, Maron, Evans, & Winstead, 2001; Schwartz, Tomlin, Evans, & Ross, 2001), retinitis pigmentosa (Alexander, Pokorny, Smith, Fishman, & Barnes, 2001), and migraine headaches (McKendrick, Vingrys, Badcock, & Heywood, 2001). The inclusion of individuals with distinctly different potential sources of magnocellular deficiencies would be valuable in determining trends or differences in performance on the UFOV® test of transient visual attention.

Summary

Both age and UFOV® ability influenced participants' performances on visual function, cognitive performance, and simulated driving performance. Older participants with poor UFOV® had much more difficulty on a variety of cognitive measures compared with other older adults with normal UFOV® and younger adults. Performances on measures of visual memory, visual search, visual attention, sequencing, and auditory attention were all decreased in older adults with poor UFOV®. Behavioral tasks evaluated in the driving simulator were also poorer in older adults with poor UFOV®. Participants with poor UFOV® took longer to locate central visual targets and saw fewer targets overall than did other participants.

Older adults with UFOV® deficits had particular difficulty with visual function measures dependent on the magnocellular visual processing pathway. Although results from individual visual function tests varied, analysis of a composite measure of magnocellular and nonmagnocellular vision demonstrated that only magnocellular visual function was significantly affected in individuals with poor UFOV®. The current findings provide support for the relationship between measures of transient visual attention, such as the UFOV® and magnocellular vision. In addition to supporting the work of S.B. Steinman et al. (1994, 1996) and B.A. Steinman et al. (1998), these findings are also consistent with evidence from ERP studies (Eimer, 1997).

With the growing percentage of the older adults in the population, there will be a greater probability of individuals with decreased cognitive abilities functioning in the world. The percentage of older adults behind the wheels of automobiles will also increase, potentially increasing their likelihood to be involved in crashes. Based on current evidence from this population, the incidence of personal injury or injury to others from vehicular accidents would likely increase. If deficiencies in transient visual attention (UFOV®) play a role in increased crash risk in older adults, then there is value in trying to understand the source or cause of that attention deficiency. If sensory impairments are contributing to decreases in cognitive functioning in older adults, then there is hope that sensory assistance devices or new treatments for ophthalmological disease might lead to improvements in visual attention or to individuals' cognitive abilities as a whole.

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APPENDIX A

MEANS TABLES FOR VISUAL, COGNITIVE, AND DRIVING PERFORMANCE MEASURES

Table 1A

Means Table Contrast Sensitivity by Group

Group	0.5 cpd	1.0 cpd	3.0 cpd	6.0 cpd	11.4 cpd	22.8 cpd	Pelli-Robson Chart Contrast Sensitivity
Younger adults	1.958	2.47	2.808	2.815	2.597	2.283	1.94
Older adults with good UFOV®	1.929	2.567	2.753	2.707	2.493	2.073	1.77
Older adults with poor UFOV®	1.758	2.488	2.67	2.574	2.34	1.892	1.67

Note. UFOV® = Useful Field of View Test

Table 2A

Means Table Starry Night d prime Values by Group

Group	d prime events 1-100	d prime events 101-200	d prime overall
Younger adults	3.76	3.82	3.567
Older adults with good UFOV®	2.875	2.877	2.776
Older adults with poor UFOV®	2.599	2.645	2.432

Note. UFOV® = Useful Field of View Test

Table 3A

Means Table High-velocity Motion Discrimination Percent Correct by Group

Group	15% coherence	20% coherence	25% coherence	30% coherence	45% coherence
Younger Adults	0.836	0.953	0.975	0.984	0.979
Older Adults with good UFOV®	0.932	0.961	0.987	0.982	1.00
Older Adults with poor UFOV®	0.787	0.875	0.928	0.914	0.94

Note. UFOV® = Useful Field of View Test

Table 4A

Means Table Low-velocity Motion Discrimination Percent Correct by Group

Group	15% coherence	20% coherence	25% coherence	30% coherence	45% coherence	Discrimination threshold
Younger adults	0.799	0.887	0.937	0.948	0.966	0.127
Older adults with good UFOV®	0.648	0.751	0.778	0.733	0.734	0.377
Older adults with poor UFOV®	0.56	0.666	0.661	0.686	0.745	0.428

Note. UFOV® = Useful Field of View Test

Table 5A

Means Table of Visual Function Measures by Group

Group	Visual acuity (LogMAR)	Magnocellular composite	Non-magnocellular composite	FDT mean threshold	FDT mean deviation	SWAP mean threshold	SWAP mean deviation
Younger adults	-0.05	0.105	0.183	31.07	2.696	25.675	4.997
Older adults with good UFOV®	0.04	0.314	-0.022	27.536	3.643	15.724	5.452
Older adults with poor UFOV®	0.09	-0.334	-0.115	25.921	4.36	13.721	5.867

Note. UFOV® = Useful Field of View Test

Table 6A

Means Table of Cognitive Measures by Group

Group	RST (3-Sign)	RST (6-Sign)	BVRT	PASAT	Trails B time (seconds)	Rey-Osterrieth copy score	Rey-Osterrieth recall score
Younger adults	0.97	1.16	8.75	30.00	60.12	35.13	26.21
Older adults with good UFOV®	1.51	1.89	6.70	20.30	109.07	33.40	19.39
Older adults with poor UFOV®	2.70	2.86	4.11	13.81	219.51	8.08	0.29

Note. UFOV® = Useful Field of View Test

Table 7A

Means Table of Individual UFOV® Subtest Scores by Group

Group	Subtest 1 processing speed	Subtest 2 divided attention	Subtest 3 selective attention	Subtest 4 same different	Total score
Younger adults	16.0	18.1	60.3	163.3	257.7
Older adults with good UFOV®	17.3	54.9	215.8	430.4	718.4
Older adults with poor UFOV®	29.3	162.0	447.3	497.6	1136.3

Note. UFOV® = Useful Field of View Test

Table 8A

Means Table Simulated Driving Performance Critical Braking Events

	High demand	High demand	High demand	Low demand	Low demand	Low demand
Group	Response time	Correct	Missed	Response time	Correct	Missed
Younger adults	2.275	2.00	591	1.889	2.273	591
Older adults with good UFOV®	2.204	1.94	667	1.408	1.944	667
Older adults with poor UFOV®	2.337	1.815	778	1.468	2.296	667

Note. UFOV® = Useful Field of View Test

Table 9A

Means Table Simulated Driving Performance Central Visual Targets

Group	High demand	High demand	High demand	Low demand	Low demand	Low demand
	Response time	Correct	Missed	Response time	Correct	Missed
Younger adults	3.455	864	.136	1.612	2.227	727
Older adults with good UFOV®	4.525	.667	222	1.547	1.778	1.167
Older adults with poor UFOV®	5.608	.296	741	1.848	1.519	1.519

Note. UFOV® = Useful Field of View Test

Table 10A

Means Table Simulated Driving Performance Peripheral Visual Targets

Group	High demand Response time	High demand Correct	High demand Missed	Low demand Response time	Low demand Correct	Low demand Missed
Younger adults	1.163	5.227	.727	.835	4.818	.045
Older adults with good UFOV®	1.962	4.778	.556	1.319	4.667	.167
Older adults with poor UFOV®	1.569	4.926	.630	1.384	4.704	.222

Note. UFOV® = Useful Field of View Test

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I certify that I have read this document and examined the student regarding its content. In my opinion, this dissertation conforms to acceptable standards of scholarly presentation and is adequate in scope and quality, and the attainments of this student are such that he may be recommended for the degree of Doctor of Philosophy.

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